INVESTIGATING THE LEVEL OF APPLICATION/EDUCATION OF PASSIVE/NATURAL SYSTEMS IN THE DESIGN OF SUSTAINABLE BUILDINGS IN THE US

A Dissertation

by

MEHDI AZIZKHANI

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Chair of Committee,	Jeff Haberl
Committee Members,	Liliana Beltran
	Zofia Rybkowski
	Wei Yan
Head of Department,	Robert Warden

May 2019

Major Subject: Architecture

ABSTRACT

The purpose of this research is to examine the degree of adoption and education of the concepts of natural systems for heating, cooling, and lighting (i.e., passive systems) versus artificial/mechanical systems (i.e., active systems) in the design of sustainable buildings by practitioners and educators. In addition, this research investigates the variables that may increase/reduce the application of these systems in architectural designs. Natural systems use renewable energies or ambient conditions, while mechanical systems often use non-renewable energies to heat, cool, ventilate, and illuminate buildings. Although an extensive list of publications about natural systems exist, there are very few studies about the approaches/tools used by professionals for the design of natural systems in sustainable buildings. This research seeks to fill this gap through three methodologies, including: a content analysis, a case study, and a survey questionnaire to practitioners/educators.

The findings show that there is a low percentage of the application of passive/natural systems in architecture design in the US. To promote the application of passive systems, the clients' desire/collaboration, building code/rating systems, and simulation tools for passive design are the most influential factors according to a survey of the practitioners in the US. The findings also indicate that the education of passive/natural systems in the US architecture schools are mainly focused on discussions at the conceptual level, which needs to be further developed to include the teaching of the simulation of these systems as well.

Overall, the findings suggest that investment in several areas can facilitate the application of passive systems in the US, which include: better educational focus on the simulation/calculation of passive systems; stronger connection between academia and the building industry focused on passive design; providing user-friendly tools for the design of passive systems; better collaboration between architects, clients, and engineers; reducing the work experience gap between retiring faulty and new faculty; better focus on passive design in integrated design studios; and strong inclusion of passive systems in building codes/rating systems. The long term goal of this study is to pave the way for reducing a building's energy consumption by shifting society's dependency from non-renewable energies to renewable energies.

DEDICATION

Dedicated to All Who Care About the Built Environment and Global Warming

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a dissertation committee consisting of Dr. Jeff Haberl [advisor], Dr. Liliana Beltran, and Dr. Wei Yan of the Department of Architecture and Dr. Zofia Rybkowski of the Department of Construction Science.

Part of the survey distribution was conducted through the author's communication with AIA and ASHRAE Chapters in the US, who kindly distributed the survey questionnaire to their members on behalf of the author. All of the work conducted for the dissertation was completed by the student independently.

Funding Sources

This work was partly supported by the dissertation fellowship award from the Office of Graduate and Professional Studies (OGAPS) at Texas A&M University.

TABLE OF CONTENTS

Page

ABSTRACT ii

DEDICATION iv

CONTRIBUTORS AND FUNDING SOURCES v

TABLE OF CONTENTS vi

LIST OF FIGURES x

LIST OF TABLES xiv

1. INTRODUCTION 1

  1.1. Background and Problem Statement 1
  1.2. Research Goals and Task Objectives 7
  1.3. Significance and Limitations of the Study 8
  1.4. Overview of the Dissertation 10
  1.5. Definition 12

2. LITERATURE REVIEW 17

  2.1. Sustainable Architectural Design 17
    2.1.1. Trends in Sustainable Architectural Design 17
    2.1.2. Conceptual Trends in Sustainable Design: Nature/Passive Versus Active Systems 22
    2.1.3. Natural/Passive Systems and Human Well-being 35
  2.2. Brief History of Passive Building Design in the US 49
    2.2.1. From Early Attempts until the 1940s 49
    2.2.2. From the 1940s until 2010 53
    2.2.3. Passive House Institute US (PHIUS) 59
  2.3. Models and Approaches of Passive Building Design 66
    2.3.1. Natural/Passive Heating of Buildings 67
    2.3.2. Natural/Passive Cooling and Natural Ventilation 91
    2.3.3. Building Envelope 108
    2.3.4. Daylighting 112
  2.4. Factors Influential in Passive Systems Applications 117
    2.4.1. Building Standards and Rating Systems: The Status Que 117

2.4.2. Climate 132
2.4.3. Simulation and Modeling Tools 139
2.4.4 Construction Cost and Construction Complexity.........................156
2.4.5. Design Team and Client Collaboration 158
2.4.6 Knowledge and Experience for Simulating and Integrating Passive Systems..163
2.4.7. Architectural Curriculum and Natural/Passive systems...............172
2.5. Case Studies: Practitioners' Application of Passive Systems 176
2.5.1. Practitioners' Approach Toward the Use of Passive Systems..176
2.5.2. Three Case Studies on The Approach of Using Passive Systems..180
2.5.3. Best Practices: AIA COTE Top 10 Awards................................187

3. RESEARCH METHODS...190

3.1. Introduction 190
3.2. Qualitative Methods Applied 191
3.2.1. Case Study..191
3.2.2. Content Analysis 199
3.3. Quantitative Methods Applied 201
3.3.1. Survey Questionnaire Design Principles.....................................202
3.3.2. Reducing Survey Measurement Errors 203
3.3.3. Reducing Nonresponse Error 204
3.3.4. Reducing Survey Sampling and Survey Coverage Errors............205
3.4. Research with Human Subject 216
3.5. Summary of the Applied Research Methodologies and Strategies 216

4. PRACTITIONERS SURVEY: RESULTS AND DATA ANALYSIS.....................218

4.1. Introduction 218
4.2. Procedure..219
4.3. Survey Tools and Analysis Procedure 223
4.4. Demographic Information (Practitioners) 227
4.4.1. Primary Professional Role (Practitioners)...................................227
4.4.2. Affiliations (Practitioners)...228
4.4.3. Professional Work Experience (Practitioners) 233
4.4.4. Age Group (Practitioners) 234
4.4.5. Location (Practitioners)...236
4.4.6. Professional Registration (Practitioners).....................................236
4.4.7. Location of Education (Practitioners) 241
4.5. Professionals Projects..242
4.5.1. Projects Typologies (Practitioners) 242
4.5.2. Climates of the Practitioners' Passive Projects 245

4.6. Passive/Natural Systems (Practitioners) ... 249
  4.6.1. Renewable Energy (Practitioners) ... 249
  4.6.2. Passive/Natural Cooling Systems (Practitioners) ... 251
  4.6.3. Passive/Natural Heating Systems (Practitioners) ... 257
  4.6.4. Daylighting Systems (Practitioners) ... 261
  4.6.5. Passive Building Envelope Strategies (Practitioners) ... 264
4.7. Phase of Analyzing the Use of Passive Systems by Practitioners ... 266
4.8. Practitioners’ Tools ... 268
4.9. Phase of the Calculation of Passive Strategy Savings (Practitioners) ... 274
4.10. Influential Factors in Increasing/Reducing the Use of Passive/Natural Systems (Practitioners) ... 276
4.11. The Open-Ended Question for Practitioners ... 282
4.12. Major Findings of the Practitioners’ Survey ... 293

5. EDUCATORS SURVEY: RESULTS AND DATA ANALYSIS ... 298

5.1. Introduction ... 298
5.2. Demographic Information (Educators) ... 298
  5.2.1. Professional Role (Educators) ... 298
  5.2.2. Affiliations (Educators) ... 302
  5.2.3. Teaching Experience ... 304
  5.2.4. Age Groups (Educators) ... 305
  5.2.5. Location (Educators) ... 307
  5.2.6. Professional Registration (Educators) ... 308
  5.2.7. Location of Education (Educators) ... 311
  5.2.8. Teaching Specialty ... 313
5.3. Educators’ Projects ... 319
5.3.1. Project Typologies (Educators) ... 320
5.3.2. Climates of the Educators’ Passive Projects ... 321
5.4. Passive/Natural Systems ... 325
  5.4.1. Renewable Energy Systems (Educators) ... 326
  5.4.2. Passive/Natural Cooling Systems (Educators) ... 331
  5.4.3. Passive/Natural Heating Systems (Educators) ... 336
  5.4.4. Daylighting Systems (Educators) ... 338
  5.4.5. Passive Building Envelope Strategies (Educators) ... 341
5.5. Phase of Analyzing the Use of Passive Systems (Educators) ... 343
5.6. Educators Tools ... 345
5.7. Phase of the Calculation of Passive Strategies’ Savings (Educators) ... 351
5.8. Factors Influencing the Use of Passive/Natural Systems (Educators) ... 353
5.9. Open-ended Question (Educators) ... 359
5.10. Major Findings (Educators) ... 363

6. SUMMARY AND CONCLUSION 369

6.1. Scope of the Section 369
6.2. Summary 369
6.3. Recommendations 380
6.4. Discussion of the Research Limitations 386
6.5. Path for the Future Research 389
6.6. Conclusion 391

REFERENCES 393

APPENDIX A IRB REVIEW LETTER 424

APPENDIX B SURVEY INVITATION LETTER 425

APPENDIX C SURVEY QUESTIONNAIRE FOR EDUCATORS AND PRACTITIONERS 427

APPENDIX D PARTICIPANTS’ RESPONSES TO THE OPEN-ENDED TEXT QUESTION 446

APPENDIX E RADAR CHARTS FOR 2017 AIA COTE TOP TEN CASE STUDIES 455

APPENDIX F TABULAR ANALYSIS OF AIA COTE TOP TEN 2017 AND 2010 AWARDS 461

LIST OF FIGURES

Page

Figure 1.1 Estimated US energy consumption in 2016: 97.3 Quads (LLNL, 2016; Department of Energy) 1

Figure 2.1 Level of worldwide green building activity based on (Dodge Data and Analytics, 2016) 19

Figure 2.2 Operation of an in-vent passive intelligent system, adapted from (Ventive, 2018) 48

Figure 2.3 Passive cooling strategies on a building bioclimatic chart (adapted from Milne and Givoni, 1979; Kwok and Grondzik, 2015) 91

Figure 2.4 Passive cooling and heating design strategies for Las Vegas, Nevada using Climate Consultant 94

Figure 4.1 Survey duration for practitioners (amount of time respondents spent completing the survey) 222

Figure 4.2 Percentage of the respondents' primary profession among practitioners 227

Figure 4.3 Respondents' affiliations among practitioners 229

Figure 4.4 Respondents' affiliations among practitioners with the expansion of the "other" category 232

Figure 4.5 Respondents' years of professional experience 233

Figure 4.6 Practitioners' age group 235

Figure 4.7 Locations of the survey respondents on the US map 237

Figure 4.8 Distribution of professional registration among the participants 238

Figure 4.9 Number of states where a respondent is professionally registered as an architect or engineer 239

Figure 4.10 Respondents' Architectural Licensure or PE with their distribution in each state 240

Figure 4.11 Percentage of respondents with Architectural Licensure or PE in each state 240

Figure 4.12 Location of education that the respondents earned their degree(s) most related to their current profession 241

Figure 4.13 Areas for which respondents were asked about their earned degree(s) most related to their current profession 242

Figure 4.14 Mean percentage of professionals projects in different categories for the last 10 years 243

Figure 4.15 Mean percentage of the projects in only the “other” project category for the last 10 years 244

Figure 4.16 Areas defined on ASHRAE climate map to be selected by practitioners as the location of their projects in the last ten years 247

Figure 4.17 Total number of times each area on the map in Figure 4.16 was selected by practitioners 247

Figure 4.18 Areas selected by practitioners on the US climate map as the locations of their projects with passive design strategies in the last ten years (top, selection of a group of 120 practitioners, and bottom, selection of a group of 15 practitioners) 248

Figure 4.19 Practitioners’ use of renewable energy in the last 10 years’ projects 249

Figure 4.20 Renewable energy usage in the last 10 years categorized by professional registration 251

Figure 4.21 Practitioners use of passive cooling strategies in the US in the last 10 years 252

Figure 4.22 Passive cooling strategies categorized by professional registration 256

Figure 4.23 Frequency of the use of passive heating strategies by practitioners in the last 10 years 257

Figure 4.24 Frequency of the application of passive heating strategies categorized by practitioner’ professional registration 260

Figure 4.25 Application of daylighting strategies by practitioners 263

Figure 4.26 Application of daylighting strategies categorized by professional registration 263

Figure 4.27 Application of passive building envelope strategies broken out by professional licensure 265

Figure 4.28 Practitioners passive systems' analysis phase categorized by professional registration.....267

Figure 4.29 Professionals tools for analyzing the feasibility of passive systems on their projects.....271

Figure 4.30 Tools used for analyzing the feasibility of passive systems categorized by professionals registrations.....272

Figure 4.31 Phase of calculating passive systems savings broken out by professional registration.....274

Figure 4.32 Factors influential in the use of passive/natural systems broken out by professional registrations of the respondents.....280

Figure 4.33 Factors influential in increasing the use of passive/natural systems in buildings categorized by respondents' years of work experience.....281

Figure 5.1 Educators additional current professional role.....299

Figure 5.2 Educators previous professional role.....301

Figure 5.3 Educators' affiliations.....303

Figure 5.4 Educators teaching experience.....305

Figure 5.5 Educators' age group.....306

Figure 5.6 Educators locations.....307

Figure 5.7 Professional registration of the educators.....309

Figure 5.8 Professional registration of the educators broken by their states of professional registration.....310

Figure 5.9 Location that the educators earned their degree(s) most related to their current profession.....312

Figure 5.10 Educators degrees most related to their current profession.....313

Figure 5.11 Teaching specialty of the respondents.....317

Figure 5.12 Teaching specialty of the educators based on their professional registrations.....318

Figure 5.13 Educators contribution to projects design/construction broken by professional registrations 319

Figure 5.14 Mean percentage of educators projects in different categories for the last 10 years...320

Figure 5.15 Location of the educators’ passive projects for the last 10 years reflected on ASHRAE Climate Map. 322

Figure 5.16 Location of educators’ passive projects for the last 10 years 323

Figure 5.17 Location of the educators’ passive projects for the last 10 years categorized by their professional registration..324

Figure 5.18 The most taught renewable energy systems in the US by educators..........329

Figure 5.19 The teaching level of passive/natural cooling systems by educators and their frequency 335

Figure 5.20 The frequency for teaching levels of passive heating systems 338

Figure 5.21 The frequency for teaching levels of daylighting systems..........................340

Figure 5.22 The frequency of teaching levels for building envelope systems...............342

Figure 5.23 The frequency/frequency percentage of the phase of teaching passive design in a class project 345

Figure 5.24 Tools that educators use for analyzing the feasibility of passive systems on their projects..350

Figure 5.25 Phase of calculating passive systems’ savings categorized by professional registration of the educators 352

Figure 5.26 Factors influential in the use of passive/natural systems categorized by professional registration of the educators 357

Figure 5.27 Factors influential in increasing the use of passive/natural systems in buildings categorized by educators’ years of teaching experience.........358

LIST OF TABLES

Page

Table 1.1 Comparison of passive and active solar systems for cooling and heating based on (Chan et al., 2010)....15

Table 2.1 Simple active and passive home energy saving strategies (Casey, 2016; Ref. DOE, 2016)....21

Table 2.2 Examples of groups that apply biomimetic design strategies, adapted from (Badarnah and Kadri, 2015)....27

Table 2.3 Problem based steps for biomimetic design (Badarnah and Kadri, 2015)....28

Table 2.4 Solution-based steps (Badarnah and Kadri, 2015)....28

Table 2.5 System Ventilation Efficiency and primary outdoor air fraction....45

Table 2.6 Performance requirements for PHIUS Certification adapted from (PHIUS, 2015)....63

Table 2.7 DOE High-Performance Home Staircase, adapted from (PHIUS, 2015)....64

Table 2.8 Overall heat loss criteria for passive solar design by Balcomb et al. (1980); SI conversion by Grondzik and Kwok (2015)....71

Table 2.9 Rules for estimating optimum areas of south-facing glazing area for Trombe’ wall and direct gains (Lechner, 2015)....72

Table 2.10 Design guidelines for passive solar thermal mass from Balcomb et al. (1980) and Grondzik and Kwok (2015)....74

Table 2.11 Rules for Estimating Required Thermal Mass in Direct-Gain Systems (Lechner, 2015)....74

Table 2.12 Comparison of glass and plastic as the exterior surface in a Trombe’ wall....81

Table 2.13 Several examples of indirect solar gain systems and their features, particularly Trombe’ walls....82

Table 2.14 Indoor Δt swing based on 45 Btu/ft2F thermal storage mass capacity (Balcomb et al., 1980; Grondzik and Kwok, 2015)....90

Table 2.15 Different types of roof ponds in the literature 98

Table 2.16 Table for vertical fins slanted to the north and installed on east/west façade (Lechner, 2009) 102

Table 2.17 Examples of the types of DSFs used in different locations and their findings (Ghaffarianhoseini et al., 2016). 110

Table 2.18 Possibilities for the design of adaptive façades 112

Table 2.19 Strengths and weaknesses of light guiding systems by previous researchers (Wong, 2017) 116

Table 2.20 Examples of Green Building Rating Systems and their features 119

Table 2.21 Pros and cons of simulations validation techniques (NREL, 2008) 143

Table 2.22 Stages of the design process in which first energy model is created (Athienitis et al., 2010) 143

Table 2.23 Features of the NZESB design tools that are lacking 144

Table 2.24 Building performance simulation tool criteria (Attia et al., 2012) 148

Table 2.25 Participants' professional background (Attia et al., 2012) 149

Table 2.26 The important parameters of a simulation tool (Attia et al., 2012) 149

Table 2.27 Usability and graphical visualization importance of simulation tools (Attia et al., 2012) 149

Table 2.28 Importance of the items for intelligence of knowledge base and adaptability to design process in simulation tools (Attia et al, 2012) 150

Table 2.29 Architects versus engineers in BPS priorities and tool ranking 150

Table 2.30 Architects versus engineers ranking of ten simulation tools (Attia et al, 2012). 150

Table 2.31 Building envelope, daylighting, and solar analysis capabilities of twenty simulation tools by Crawley et al. (2008) 154

Table 2.32 Classification of analysis methods for building energy use: steady state methods 166

Table 2.33 Classification of analysis methods for building energy use: dynamic methods 167

Table 2.34 Academic credit grouped into six subject areas required to become a NAAB accredited program in the US (NCARB, 2018) 175

Table 2.35 The three-tier design approach with the highlighted tier of passive design for achieving a high performance sustainable building..................179

Table 3.1 List and region of the AIA Chapters who were contacted to participate in the survey...209

Table 3.2 List and region of the ASHRAE Chapters who were contacted to participate in the survey..211

Table 3.3 List of the top ten sustainable design firms in the US ranked by..................213

Table 3.4 List of top ten design firms in the US ranked by Architectural Record (2017) 214

Table 3.5 List of top 50 Architecture Schools in the US ranked by Niche (2019) 214

Table 4.1 Percentage of the respondents' primary profession among practitioners 228

Table 4.2 Respondents' affiliations among practitioners...230

Table 4.3 Respondents' years of professional experience 234

Table 4.4 Practitioners' age group 235

Table 4.5 Distribution of professional registration among the participants..................238

Table 4.6 Mean percentage of the projects in only the "other" project category for the last 10 years...244

Table 4.7 Areas selected by practitioners as the location of their projects in the last ten years 246

Table 4.8 Use of renewable energy in the last 10 years by practitioners......................250

Table 4.9 Practitioners use of passive cooling strategies in the US in the last 10 years...253

Table 4.10 The total number of cooling strategies in the questionnaire selected by each practitioner 254

Table 4.11 Selection of the passive cooling strategies in four states with higher participation and four different humid climates (4A, 5A, and 2-3A) 255

Table 4.12 Frequency of the application of passive heating strategies by practitioners 258

Table 4.13 Application of daylighting strategies by practitioners 262

Table 4.14 Application of passive building envelope strategies by professional licensure 265

Table 4.15 Practitioners' phase of analysis of passive systems 267

Table 4.16 Passive systems' analysis tools, their application frequency, and percentage..........273

Table 4.17 passive systems' saving calculation frequency in each phase..........275

Table 4.18 Items ranked based on the practitioners' top three choices to increase the use of passive systems in the US..........277

Table 4.19 Major findings of the survey from practitioners 294

Table 5.1 Educators additional current professional role..........299

Table 5.2 Educators' previous professional role..........301

Table 5.3 Educators' affiliations 303

Table 5.4 Educators teaching experience..........304

Table 5.5 Educators' age group..........306

Table 5.6 professional registration of the educators 309

Table 5.7 Number of states for the professional registration of the educator 309

Table 5.8 Location of the respondents' degree(s) most related to their current profession..........312

Table 5.9 Teaching specialty of the respondents 316

Table 5.10 Location of educators' passive project for the last 10 years 322

Table 5.11 The most taught renewable energy systems in the US by educators 326

Table 5.12 The level of most taught renewable energy systems in the US by educators 328

Table 5.13 The teaching level of renewable energy systems categorized by educators’ professional registration 330

Table 5.14 The teaching level of passive/natural cooling systems and their frequency percentage 333

Table 5.15 The frequency for teaching level of passive cooling systems categorized by professional registration 334

Table 5.16 The frequency and frequency percentage for teaching levels of passive heating systems 336

Table 5.17 The frequency and frequency percentage for teaching levels of daylighting systems 339

Table 5.18 The frequency and frequency percentage for teaching levels of building envelope systems 341

Table 5.19 The frequency and frequency percentage of the phase of teaching passive design in a class project 344

Table 5.20 Tools that educators use for analyzing the feasibility of passive systems on their projects 349

Table 5.21 Phase of calculating passive systems savings broken out by professional registration of educators...351

Table 5.22 Items ranked based on the educators’ top three choices to increase the use of passive systems in the US 354

Table 5.23 Major findings from educators’ survey results 363

1. INTRODUCTION

1.1. Background and Problem Statement

Buildings consume a large portion of the total United States energy use. A recent report by Lawrence Livermore National Laboratory (LLNL, 2016) shows that the total United States (U.S.) energy use in 2016 was approximately 97.3 Quads Btu (1 Quad = 1015 Btu). In this study by Lawrence Livermore National Laboratory (LLNL), the three main energy end-use sectors included: buildings (i.e., residential and commercial), industrial, and transportation, which consumed 20.02 QBtu (27.7%), 24.5 QBtu (33.8%) and 27.9 QBtu (38.5%), respectively.

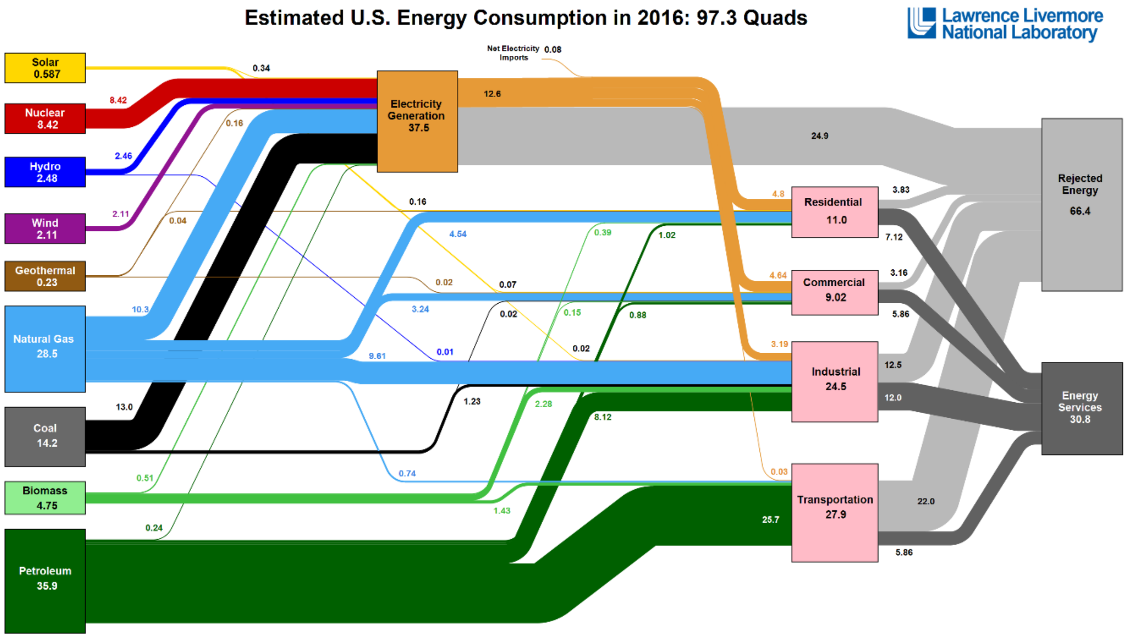


Figure 1.1 Estimated US energy consumption in 2016: 97.3 Quads (LLNL, 2016; Department of Energy)

In the LLNL 2016 study (Figure 1.1), the buildings sector (i.e., residential and commercial) accounted for 20.02 QBtu energy consumption or about one-third of the end-use energy consumption in the US in 2016. However, a large portion of the energy provided to the residential and commercial end-use sectors is electricity. Therefore, if the energy waste from converting source energy into electricity is considered and proportioned for the building sector according to the end-use, then the buildings sector is responsible for 38.6 QBtu of the total U.S. source energy. On this basis, the building sector represents almost 40% of the total U.S. source energy consumption. [1]

Therefore, designing energy efficient buildings that utilize passive/natural systems is an important goal for designers. Sustainable design strategies in buildings include energy saving and energy efficiency measures that can contribute to this goal. A case in point is the set of sustainable design strategies defined through the three categories or tiers described by Norbert Lechner (2015). Lechner's approach toward sustainable heating, cooling, ventilation and lighting (HCVL) of buildings proposes a brief, though comprehensive, illustration of design strategies from simple to more advanced. The first/bottom tier includes "basic building design strategies" for heat rejection, retention,

---

[1] The following calculations demonstrate the breakdown of reaching this number for the reported 24.9 QBtu waste of source electricity:
Residential and Commercial sections portion of waste=
(Received input portions of electricity for Residential and Commercial) / (Received input portions of electricity for all sectors)
(4.8 + 4.64) QBtu / (4.8+ 4.64+3.19 + 0.03) QBtu = 74.9%
74.9% × 24.9 QBtu = 18.65 QBtu
Total source energy= 20.2 Q Btu + 18.65 Q Btu = 38.6 Q Btu
38.6 Q Btu / 97.3 Q Btu = 39.7%

or avoidance depending on the climate or season. This tier includes large-scale strategies such as site design or building location as well as design strategies at the scale of a building such as air tightness, orientation, color, insulation, construction materials and glazing features (Lechner, 2015, p. 9).

The second tier includes “passive systems” for the application of natural energies in the design process. The third/top tier of the three-tier design approach includes active system strategies, renewable energies, and mechanical systems such as photovoltaics, wind turbines, low-energy artificial lighting, and heating/cooling equipment. The focus of this study is on the second tier, which is the “passive system” tier utilizing the ambient conditions or natural energy for HCVL in buildings and has been referred to in the study as passive/natural systems. Design strategies such as light shelves, earth contact, direct/indirect solar gain systems, and natural ventilation are a few examples included in the second tier.

A brief review of the history of passive design strategies show that each period of interest in their application was usually followed by an era of indifference (Grondzik and Kwok, 2015). In the US, active and passive solar heating has received more attention than other passive design strategies, though historical interest in solar energy has also occurred in cyclical trends. Unfortunately, the low energy prices of the1960s in the US dampened enthusiasm for solar energy.

In response to the oil embargo of the early 1970s, interest exploded again and lasted until the mid-1980s when political changes claimed that the energy crisis had been solved, which reduced public interest in energy saving (Balcomb, 1992). The year 1976 was the beginning of the promotion of the application of passive solar energy when the first passive solar conference was held in Albuquerque, New Mexico (Balcomb, 1987). At the conference, the major focus was on passive solar heating in single-family houses. Although projects were reported in multifamily housing, commercial buildings, natural cooling, and daylighting, the majority of the reported projects included single-family residential buildings.

At the beginning of the 1990s, a new wave of interest in renewable energy and passive design emerged and gained momentum following the worldwide spread of the concept of sustainability. However, during the early years of the 21st century, interest in passive design strategies gradually faded again. Issues such as the heavy material weight of passive systems, complexity of their implementation, and unfamiliarity of the occupants in combining these systems with their lifestyles were some of the reported issues (Strong & Burrows, 2017, p.33).

Beginning about 2010, interests in the application of passive design strategies started to make a come-back to the forefront of sustainable design approaches as in the case of net zero/net positive energy buildings and high performance building components. During this new resurgence, the main goal was to reduce the carbon footprint of buildings by reducing their usage of non-renewable energies resulting in the reduction of carbon emissions from the power plants that would have provided the electricity that the passive natural systems could save. In the US, the legislative initiative called Architecture Challenge 2030 became a catalyst in 2010 for further rekindling the interests in the application of passive systems by setting specific targets for fossil fuel reductions in buildings to 60% in 2010, 70% in 2015, 80% in 2020, 90% in 2025, and finally carbon neutral (100%) in 2030 (Architecture Challenge 2030, 2015).

However, many of these designs used legacy analysis methods and concepts of passive design strategies that were developed in the 1970s and the 1980s. Some of these concepts now have reappeared under the guise of new terms and concepts such as biomimetic designs, double-skin buildings, and kinetic facades. In most cases, the emergence of new materials/technologies in the building industry as well as the inclination toward interdisciplinary design collaborations, such as biology and architecture/engineering in biomimetics, were key factors contributing to this change of terminology.

Therefore, to save on time and cost, there is no need to start research studies about passive/natural systems from scratch; rather the examining of previous research/work on passive design, their developments through time, and their current applications on a practical scale may yield valuable information. Consequently, there is a need to examine the architects' and engineers' use of natural/passive versus artificial/mechanical energy systems in buildings to find opportunities and challenges to reduce our dependency on non-renewable energies by increasing the contribution of nature to our building designs. Therefore, the purpose of this research is twofold: first, to examine the degree of adoption of the concepts of natural HCVL systems (i.e., passive, biomimetic) versus artificial/mechanical systems (i.e., active) in the design of sustainable buildings by practitioners; and second, to investigate the variables that may increase/reduce the application of these systems in future designs.

In a building's annual operating budget, energy is often the single largest cost representing about 30% of the total expenses. Data and reports regarding annual building costs are prepared by several entities including the Building Owners & Managers Association (BOMA, 2017), Commercial Buildings Energy Consumption Survey (CBECS, 2012), the Northwest Energy Efficiency Alliance (NEEA, 2014), and the US Energy Information Administration (EIA, 2018). Most noticeable of these reports is the lack of attention to the inclusion of data related to natural/passive systems' contributions to reducing energy and operating costs in commercial buildings.

Sporadic data that is available usually addresses daylighting, which tends to indicate a low priority within the building industry for the contribution of natural/passive systems toward building performance. For example, according to CBECS data (2012), only 9% of large buildings draw significantly on daylight harvesting. While a lack of data related to the use of natural HCVL systems in buildings makes it difficult to evaluate the contribution of passive systems for energy savings, it reinforces the problem statement by showing how designers and the construction industries have ignored the importance of natural/passive systems in buildings/designs in more recent years.

1.2. Research Goals and Task Objectives

The goal of this research is twofold: First, to promote sustainability by reducing the use of non-renewable energy through a better understanding of how/why building professionals choose or do not choose to incorporate natural systems into their designs. Second, to increase educational awareness toward professionals' application of natural systems in the design of sustainable buildings to better inform the content of architectural course curriculums in the future. Toward this end, the tasks related to the research include:

1) Review the existing strategies and tools for designing natural heating, cooling, and lighting systems in buildings to identify/demonstrate the relevant passive/natural design strategies as well as tools and methods for calculating the annual contribution of natural systems in buildings.

2) Review best sustainable design practices in the application of passive/natural systems in the US:

    2.1) Review cases studies of the approaches and tools used by professionals for making decisions on choosing or not choosing the application of passive/natural systems in their projects.

2.2) Review case studies of the AIA COTE (American Institute of Architects Committee on the Environment) TOP 10 Awards for the design firms within the last 10 years, which are representative of best practices.

2.3) Decompose and analyze the buildings of Task 2.2 based on their natural systems/sub-systems contribution to HCVL versus active systems' contributions to the performance of the buildings.

3) Conduct survey questionnaires, analyze the results, and develop recommendations:

3.1) Review the results of the previous surveys, such as the AIA survey on the habits of high-performance firms (AIA, 2017).

3.2) Provide a sample group for the survey questionnaires to practitioners[2]

3.3) Provide a sample group for the survey questionnaires to educators

3.4) Design and conduct IRB-approved survey questionnaires to collect data from practitioners and educators to analyze their approaches/challenges in the application or education of passive/natural systems.

3.5) Summarize the results of the previous tasks and develop recommendations.

1.3. Significance and Limitations of the Study

Although the list of publications on the use of passive systems is extensive, there are very few studies that have analyzed the approaches and the passive system analysis tools

---

[2] For example, see TOP Contractors list in http://www.enr.com/Top_Lists/Top_Contractors1 or TOP Design Firms list in http://www.enr.com/toplists/2016_Top_500_Design_Firms1 and http://www.architecturalrecord.com/top300/2014-Top-300-Architecture-Firms-6.

utilized by professionals to determine the annual contribution natural systems provide in sustainable buildings. As described in the background and problem statement, such studies could pave the way for reducing the total US energy consumption by reducing building energy consumption, particularly through the reduction of the use of non-renewable fossil fuels. This reduction will be compensated by the contribution of natural HCVL to improve the efficiency of buildings in using non-renewable energies. Improving the efficiency of buildings is important because buildings in the US utilize 65% of the electricity produced and cause 30% of carbon emissions (Syed, 2012; WBDG, 2017).

Reduction of the use of fossil fuels will also reduce air pollution and improve the ambient air quality. Therefore, this study is significant because it intends to fill a gap in the literature resulting from the unknown extent that natural systems are actually being incorporated into the design of sustainable buildings. On this basis, the original contribution of this research is to determine the current degree and approaches to the use of natural systems in professional architectural design, and to determine what reasons, if any, exist for their deficiencies.

This study can also provide recommendations for the improvement of the use of natural systems in the future. Particularly, the results will be significant for educators and students in architecture who seek to include in their course curriculum the incorporation of natural systems in buildings. Lastly, this study will draw a parallel comparison between old and new terms/concepts with respect to the use of natural systems to provide an enriched repertoire for today's designers; thereby, future design ideas would not need to be created from scratch. Additionally, this comparison may help better understand why many of the new design terms and concepts that are being used are rephrasing the passive design concepts used in the past through the application of new materials and technological concepts.

Because the research scope excludes design and engineering firms outside the US, the generalizability of the findings should be limited to the US. This study is also limited to the extent that full access to architectural drawings and specifications was limited.

1.4. Overview of the Dissertation

This dissertation has been organized through the following sections:

Section 1. Introduction: this section provides information on the background of this study and outlines its goals and task objectives. The introduction section also addresses the significance of the study and its limitations. To help readers better perceive the content of the following sections, the first section also contains definitions of technical terminology.

Section 2. Literature Review: this section includes a review of the literature about sustainable design trends and methods with respect to the inclusion of active and passive/natural systems in design. It also reviews green building rating systems and codes/standards in relation to the use of natural systems in buildings. Other aspects of the literature review include: review of the advanced and legacy passive/natural system strategies; the impact of natural/passive systems on health and wellbeing; a brief history of the evolution of passive design in the US; professionals' tools and methods for the application of natural systems; the issues that have not been addressed properly in the literature for the application of passive systems such as architectural education, client-designer's collaboration, and simulation tools; and most importantly a review of the AIA TOP Ten Award case studies.

Section 3. Methods: this section offers a detailed description of the methods used to conduct this research and develop the survey questionnaire as well as the theoretical framework supporting the application of these methods.

Section 4. Results and Data Analysis of Practitioners' Survey: this section explains the data collection/analysis procedures focused on practitioners' survey along with the findings.

Section 5. Results and Data Analysis of Educators' Survey: similar to the previous section, this section explains the data collection/analysis procedures focused on the educators' survey along with the findings.

Section 6. Summary and Conclusion: this section includes a discussion summary of the main findings of this research and provides recommendations for the incorporation of passive/natural systems in buildings.

In addition, in the Appendix the readers will find supporting materials such as requests approved by the Institutional Review Board for the research field survey and the analysis charts and tables of the AIA TOP Ten Award case studies.

1.5. Definition

Active systems are systems that use non-renewable energy such as electricity to heat, cool, ventilate, or illuminate buildings (Strong & Burrows, 2017; Ewing, 2006).

Active solar systems use electrical or mechanical equipment, such as pumps and fans, to increase the usable heat in a system. These systems are active solar power setups that rely on external energy sources—or backup systems, such as radiators and heat pumps — to capture, store, and then convert solar energy into electricity. Depending on the complexity of their design, active solar systems can heat, cool, or ventilate buildings or provide power to an entire neighborhood (CEF, 2018).

Biomimicry has been defined as the abstraction of good design from nature (Vincent, 2010) and the conscious emulation of nature's genius (Benyus, 2002).

High performance building uses a "whole-building design approach to achieve energy, economic, and environmental performance that is substantially better than standard practice" (NREL, 2005). Whole-building design creates energy efficient buildings that save actual operating costs and produces healthy places for work and life. (NREL, 2005). Federal Research and Development Agenda for Net Zero and High Performance Buildings considers a building high performance if it "integrates and optimizes on a life cycle basis all major high-performance attributes, including energy conservation, environment, security, safety, durability, cost-benefit, productivity, sustainability, functionality, and operational considerations" (FRDAZ, 2008; EPA, 2005). The Agenda considers differences between high performance buildings and green high performance buildings as defined below.

High performance green building is a building that during its life cycle, compared with data of similar buildings collected by Commercial or Residential Buildings Energy Consumption Surveys data from the EIA (Energy Information Administration) fulfills several objectives including: reduction of energy use, water use, and material resource consumption; improvement of Indoor Environmental Qualities (IEQ) by reducing indoor pollution, improving thermal comfort, and improving lighting quality and acoustics that affect occupants' health and productivity; reduction of negative impacts on the environment such as air/water pollution and waste generation; increase of application of environmentally friendly materials such as bio-based recycled content and non-toxic products with lower life cycle impacts; promotion of reuse and recycling; integration of systems; reduction of environmental and energy impacts of transportation choices for occupants; consideration of its indoor/outdoor effects on human health and environment including workers productivity, life cycle impacts of materials and operations, and other factors that the Federal Director/Commercial Director consider to be appropriate.

Life cycle: in a high performance green building, includes all stages of a building's useful life, embracing components, equipment, systems, and controls, beginning at the conception of the building project and extending through site selection, design, construction, landscaping, commissioning, operation, maintenance, renovation, deconstruction/demolition, removal, and recycling (FRDAZ, 2008; EPA, 2005).

Passive systems, coined in the early 1970s (Balcomb,1992), refers to the systems that use ambient conditions or renewable energies to heat, cool, and ventilate buildings. *Natural systems* include passive systems and in a broader sense embrace the illumination of buildings through daylighting (Strong & Burrows, 2017; Ewing, 2006). These two terms will be used together as passive/natural systems in the dissertation.

Passive solar systems in contrast to active solar systems, are those systems that operate without reliance on external energy sources (e.g. pumps and fans). By using only ambient conditions, passive solar systems capture solar energy to heat a space, or store the heat for release at a later time (CEF, 2018). Table 1.1 shows a comparison of passive and active solar systems for cooling and heating according to Chan et al. (2010). Using Chen et al.'s definition, passive solar systems relate to building envelope design while the active solar systems relate to the application of solar collectors to heat a fluid that then heats a space.

Table 1.1 Comparison of passive and active solar systems for cooling and heating based on (Chan et al., 2010).

Type of solar system	**Heating**	**Cooling**
Active solar: Uses electrical or mechanical equipment, such as pumps and fans, to increase the usable heat in a system	• The solar collector is used in which the absorber component absorbs solar radiation energy, converts it to heat, and transfers the heat to a transport medium or fluid. The fluid flows through the collector. The collected solar energy is carried from the fluid to a storage tank or heat exchanger to provide heating. • Devices: examples include flat plate, parabolic trough or evacuate tube collectors.	• The collected solar heat is used as the source energy for air-conditioners, which are recognized as solar assisted air-conditioning systems. • Devices: examples include absorption and adsorption chillers, solid or liquid desiccant systems.
Passive solar: Works without using active mechanical devices; the system does not use or uses only small amount of external energy	• Heat is gained through passive solar energy. Heat from solar radiation is absorbed, stored or used to preheat ventilation air. • Devices: examples include façade or roof building components.	• The airflow is generated and channeled to create cooling effects by removing the heat; natural ventilation is the most typical passive cooling. • Devices: examples include facade or roof building components.

Sustainability as defined by ASHRAE provides “for the needs of the present without detracting from the ability to fulfill the needs of the future” (ASHRAE, 2013, p. 35.1). Accordingly, sustainable buildings are designed and constructed in accordance with practices that significantly reduce or eliminate the cradle-to-grave negative impacts of buildings on the environment and occupants in five broad categories: Sustainable Site Planning, Safeguarding Water and Water Efficiency, Energy Efficiency and Renewable Energy, Conservation of Materials and Resources, and Indoor Environmental Quality (ASHRAE Green Guide, 2010).

2. LITERATURE REVIEW

2.1. Sustainable Architectural Design

2.1.1. Trends in Sustainable Architectural Design

Creating buildings that meet the needs of the present without compromising the ability of the future generations to use natural resources is one of the fundamental definitions of sustainable design (Hawken et al., 1999). History reveals many examples about different civilizations that vanished when they outnumbered their resources (Iyengar, 2015). Uncontrolled use of fossil fuels in buildings section since the industrial revolution has increased the atmospheric concentration of greenhouse gases (GHG) incessantly. Due to heat trapping, GHG emissions can cause unwanted environmental effects such as global warming. Unfortunately, CO2 levels have climbed from 280 parts per million (ppm) in 1760 to 403.3 ppm in 2016. These changes accelerated in the last decade in which the global daily CO2 concentration hit a record of 412.63 parts per million (ppm) on April 26, 2017. As a result, in the current decade the Earth has experienced the fifth warmest January in 2018 with 1.28°F (0.71°C) increase in temperature (NOAA-ESRL, 2018).

A question to ask at this point is can green buildings slow down the process of climate change and provide solutions for preserving natural resources for future generations? Edward Mazria has contested that the building industry is responsible for almost 50% of the total GHG emissions (Brown, 2009). However, beyond this claim, answering the question demands a deeper investigation of the current and future trends of green building design. The website interestingengineering.com has listed the top five global trends of green building design in 2017 (Nichols, 2017). These trends include: solar panels in all shapes and sizes, home energy storage, energy management systems, passive building design, and sustainable building materials. From another perspective, which considers solar panels and energy storage systems together as one trend, the net zero energy buildings were also included in the top five trends of sustainable building design (DBSG, 2017).

All of these top five trends of sustainable design revolve around the theme of energy usage in which the main environmental motivation behind green construction can be identified as the reduction of carbon emissions. Therefore, using clean renewable energies in buildings can considerably contribute to the project of sustainability through both reducing the use of non-renewable energies and delaying the fast pace of unwanted environmental changes due to carbon emissions. Additionally, it is understandable that natural systems and passive design strategies alongside active system/building technologies are under serious consideration among the top recent trends of green building designs.

A portion of this rise of green building trends worldwide is a result of the United Nations 2030 Agenda for Sustainable Development (UN, 2016). Although the growth rate of green building certification practices is slowing down (BDC, 2015), based on the report on World Green Building Trends (DODGE, 2016) from 2015 to 2018 the percentage of

Figure 2.1 Level of worldwide green building activity based on (Dodge Data and Analytics, 2016)

global builders with minimum 60 percent certified green projects will be doubled (Figure 2.1). The United Nations 2030 Agenda has been followed by other agendas on local scales such as the Architecture 2030 Challenge in the US, which challenges the design and construction community to reduce fossil fuel consumptions.

According to the 2030 Challenge, new constructions and major renovations should be designed to reach a 70% reduction of fossil fuel use and GHG emissions as well as energy consumption performance below the regional averages for that building type. This fossil fuel reduction should reach to 80% in 2020, 90% in 2025, and carbon-neutral in 2030. The 2030 Challenge extends that these targets may be accomplished by implementing innovative sustainable design strategies, generating on-site renewable power, and/or purchasing (20% maximum) off-site renewable energy (Architecture 2030, 2015).

The 2030 Challenge proposes a two-step approach to reach net-zero carbon buildings. The first step is to integrate sustainable and passive design with low-cost or no-cost strategies to reach a 70%-80% reduction of carbon use. Examples include orienting a building, shading the glass, incorporating daylighting and passive heating/cooling strategies, and using specific materials and systems. “The second step is to provide fossil-fuel-free energy, ideally from on-site renewables, or from off-site district or utility-scale renewable energies” (Challenge 2030 Solution, 2015).

While the 70% to 80% reduction through passive design strategies seems idealistic at first sight, it could be achievable by breaking down different design approaches for energy savings. As an example, the Department of Energy (DOE) has provided a set of sustainable passive and active design approaches (Table 2.1) for residential buildings that supports the possibility of such deep energy savings in certain climatic conditions (Casey, 2016).

Table 2.1 Simple active and passive home energy saving strategies (Casey, 2016; Ref. DOE, 2016)

Recommended Action	**Potential Savings (% of utility bills)**	**Average annual savings in $ (based on EIA Average End-use expenditures; actual savings will vary)**
Exterior low-e storm windows	12%-33% annually on heating/cooling bills	$100-$274
Seal uncontrolled air leaks	10%-20% on annual heating/cooling bills	$83-$166
Plant shade trees	15%-50% of annual air conditioning costs	$35-$119
Use a power strip for electronic equipment and turn it off when not in use	Up to 12% of electric bill per year	$100
Replace old toilets (6 gal/flush water usage) with watersense models		$100
Turn back thermostat 7 to 10 degrees (F) for 8 hrs./day	Up to 10% annually on heating/cooling bills	$83
Weather-strip double-hung windows	5%-10% annually on heating/cooling bills	$42-$83
Replace your home's five most frequently used light fixtures with Energy Star models	9% annually on electricity bill	$75
Lower water heating temperature	4%-22% annually on water heating bill	$12-$60
Insulate water heater tank	7%-16% annually on water heating bill	$20-$45
Fix leaky faucets: one drip/second wastes 1661 gallons of water		$35
Sleep mode and power management features on your computer	Up to 4% of annual electric bill	$30
Insulate hot water pipes	Save 3%-4% annually on water heating bill	$8-$12
Total Potential Savings		$723-$1,182
Average annual energy expenditure per household in the US include: space heating ($593), water heating ($280), air conditioning ($237), refrigerator ($153), and other expenses.		

2.1.2. Conceptual Trends in Sustainable Design: Nature/Passive Versus Active Systems

The trends toward green building design can be also scrutinized from the perspective of architectural design approaches. In this case, biomimetic and technological solutions define two fundamentally different notions of sustainable design approaches. The debate over the last decade over the applicability of the biologically or technologically inspired concepts in fashioning the built environment (Cohen and Naginski, 2014), while substantiating their flaws and potentials, has led to the formation of two extremes: designers who are subversive to nature or subservient to technology. In some cases, designers idolize the role of nature in a design to the point of neglecting any accompanying technological achievements. In other cases, human design creativity is restricted because of imposed technological constraints to the point of repetitive boredom.

Therefore, a vision integrating the two extremes seems to be a plausible approach toward sustainable design. Here, biomimicry, defined as the abstraction of good design from nature and "…the conscious emulation of nature's genius…" (Benyus, 2002), can be compared with the technological approach that represents applied engineering (Kaplinsky, 2006). The former designs a building like nature would build, with the aim of continuity, while the latter may interrupt or transcend natural design by joining parts together into a unique structure without pursuing continual evolution (Kiesler, 1939). Both approaches have unique features that can be combined to develop a more comprehensive method for designing improved building envelope, lighting, and HVAC systems.

However, attempts to identify and connect these two domains have not been properly addressed in the previous literature. Although, in practice, technological solutions have been responsive to human needs for centuries, the new designs resulting from biomimetic approaches in architecture have rarely reached the implementation phase or mass productions. Yet, beneath the surface of many of today's technologies are biologically similar systems. For example, a quick review of the U.S. National Aeronautic and Space Administrative (NASA) and Science Journal websites helps substantiate this claim, because each website shows de facto and potential biomimetic achievements.[3] Examples are numerous, ranging from highly efficient LEDs inspired by fireflies to the strong metal materials inspired by skeleton bones to the bio-inspired exploration systems emulating aerial fliers. These examples could point to one reason why biomimicry has been predicted to be one of the main tools in our transition between now and 2050 from an industrial age to an ecological age (Pawlyn, 2011).

However, very few biologically inspired architecture projects have been built (Mazzoleni and Price, 2013) reflecting a gap in the architectural design world where

---

[3] NASA's Jet Propulsion Laboratory, Pasadena, California. (2003, May 01). NASA's Jet Propulsion Laboratory,
Pasadena, California. Retrieved December 03, 2017, from
http://www.techbriefs.com/component/content/article/ntb/tech-briefs/mechanics-and-machinery/961

biological concepts rarely turn into built functional forms (Spiller, 2007). A critical review/synthesis of the previous studies in biomimetic architecture, outlined in the following paragraphs, reveals that despite any theoretical connection there is no well-accepted, practical method to connect the findings from an example at the scale of nature to the application at the scale of building envelopes and HVAC systems.

In contrast, the prevailing belief is that technological solutions rather than biological solutions provide the most effective response for our design problems: in other words, biological languages and analogies that idolize nature might hinder the real achievement of today's designers (Kaplinsky, 2006). Not considering combinations of technology and biomimicry as an integrated approach could be one reason for such a loose connection between nature-inspired concepts and their practical application. This loose connection usually gives way to designers for selecting technological solutions over biomimetic solutions.

A more practical approach in the design of building components lies at the intersection of biomimetic/natural and technological solutions. Such an approach would not only be guided by the laws of physics, but also would learn from nature including biological forms, functions, and processes, where appropriate, to produce an improved architectural design.

A review of four areas of the previous research reveals the limitations of each approach as well as the advantage of their integration. These include:

1- A review of the existing biomimetic methodologies from Badarnah & Kadri (2015), Biomimicry 3.8 (2010), Vincent et al. (2006), Vakili and Shu (2001), PBG (2011), and Goel, Rotter, and Vattam (2009)

2- A review of an example of biomimetic design for a building envelope component (Badarnah, 2015)

3- A brief analysis of the mechanism of a cooling system utilized in the EastGate Mixed-use Center in Zimbabwe, Africa, which claims to have been inspired by termite mounds (Turner and Soar, 2008)

4- A brief review of specific physical laws that form the basis for today's technological solutions found in building envelope and HVAC systems.

In general, existing biomimetic design approaches are divided into two categories of solution-based (Table 2.4) and problem-based (Table2.3) approaches used by different groups who study biomimicry (Badarnah & Kadri, 2015). Solution-based approaches are those approaches inspired by an observation of nature, which leads to a design product. In contrast, problem-based approaches are those approaches that are seeking a solution from nature for a specific engineering problem.

Table 2.2 shows five groups (abbreviated with G1 to G5) of biomimicry advocates who have used solution-based and problem-based approaches:

- Group 1. Biomimicry 3.8 including AskNature (2008), Biomimicry 3.8 (2010), and Benyus (2002)
- Group 2. BioTriz including Bogatyreva et al. (2003) and Vincent et al. (2006)
- Group 3. Biomimetics for Innovation and Design Laboratory led by Shu (Shu, 2010; Vakili & Shu, 2001)
- Group 4. Design and Intelligence Laboratory led by Goel (Goel, Rotter, & Vattam, 2009)
- Group 5. Plants Biomechanics Group (PBG) led by Thomas Speck (PBG, 2011)

While all of these groups have drawn on the problem-based approach, some (i.e. Groups 1, 4, and 5) have also utilized the solution-based approach as shown in Table 2.2 and Table 2.4.

The general steps of the problem-based approaches (Table 2.3) include:

1. Definition of the problem
2. Exploration/investigation of the natural models for solving that problem
3. Development of solution ideas based on the findings from nature.

For example, Group 1 and Group 2 approaches include the following steps with minor differences in their order:

1. Defining the problem/challenge to be solved
2. Finding the related functions in nature responding to this challenge

3. Developing an analogy between nature and the required functions in reality

4. Abstracting the functions found in nature and extracting their identified principles to be used for design concept generation

5. Developing a design concept by emulating these principles and evaluating them against life's principles. Examples of nature's life principles include running on sunlight; using only the energy you need; fitting form to function; recycling everything; rewarding cooperation; relying on diversity; and demanding local expertise (Benyas, 2002).

Table 2.2 Examples of groups that apply biomimetic design strategies, adapted from (Badarnah and Kadri, 2015)

Groups	Strategies	Problem based	Solution based
G1	Biomimicry 3.8	■	■
G2	BioTriz	■	
G3	Biomimetics for Innovation and Design Lab led by L. H. Shu	■	
G4	Design and Intelligence Lab led by Goel	■	■
G5	Plants Biomechanics Group led by Thomas Speck	■	■

The solution-based approach follows the same steps of the problem-based approach, only in reverse (Table 2.4):

1. Biological domain investigation for finding a natural system, model, or solution

2. Transferring the findings into solutions and design principles

3. Trying to connect to the technological domain by defining the corresponding problem, emulating the nature's design principles, and testing/prototyping solutions.

Table 2.3 Problem based steps for biomimetic design (Badarnah and Kadri, 2015)

Steps	Group 1	Group 2	Group 3	Group 4	Group 5
Definition of the problem	Identifying function; defining context; integrating life's principles into brief design	Defining and analyzing the problem/challenge to be solved	Problem definition	Problem definition; reframe problem	Formulating the problem
Exploration/investigation of the natural models	Discovering natural models; abstracting biological strategies into design principles	Finding functional analogy from nature; comparing solution from nature and TRIZ	Search for biological analogies; assessing biological analogies	Searching biological solution; defining the biological solution; principle extraction	Seeking biological analogies; finding corresponding principles; abstracting the biological model
Development of solution ideas	Brainstorming bioinspired ideas; emulating design principles; evaluating through life's principles	Listing principles from both nature and technological domains; developing ideas	Applying biological analogies	Principle application	Implementing technology through prototyping and testing

Table 2.4 Solution-based steps (Badarnah and Kadri, 2015)

Steps	Group1	Group4	Group5
Biological domain	Discover nature models	Biological solution identification; define the biological solution; extract principles	Identifying a biological system; analyze biomechanics, functional morphology, and anatomy; perceiving the principles
Transfer phase	Abstract nature strategies into design principles; identify function and define context; brainstorm bioinspired ideas	Solution reframing	Abstracting biological models
Technological domain	Integrate life's principles; emulate design principles; evaluate using life's principles	Searching and defining problems; applying principles	Implementation through prototyping and testing

Badarnah and Kadri (2015) took issue with these biomimetic approaches (i.e. Table 2.3 and Table 2.4), summarize their systematic design mechanisms as was explained. In their article *A Methodology for The Generation of Biomimetic Design Concepts* they maintained that the transition of a function found in nature to a function appropriate for architectural design concept generation, was a vague and challenging process. Therefore, they proposed the BioGen methodology to generate biomimetic design solutions (Figure 1). Their BioGen methodology follows six steps to reach its outcome:

1. Defining the design challenge; 2. Exploring possible scenarios and identifying exemplary

organism/system in nature for a particular adaptation strategy (i.e., pinnacles); 3. Analyzing selected pinnacles 4. Deriving imaginary pinnacles (i.e. the most appropriate pinnacles related to the required functions for mimicking); 5. Outlining the design concept, which is the superposition of the imaginary pinnacles to determine the dominant features to be addressed in the next step; 6. Generating a preliminary design concept.

Although BioGen seems to be a comprehensive design tool and, according to the authors, is easier to be used for biomimetic design, in the end, its outcome is still conceptual and challenging to be converted into a real product. The authors themselves mention this shortage: "…the main limitation of the BioGen methodology is that it does not provide a transition from the concept phase to the emulation phase." (Badarnah & Kadri, 2015, p.131). This shortage of the trending biomimetic design approaches, including the most recent BioGen method, indicates the first gap in the literature: that the current methods and approaches of biomimicry are very general leaving the result at a level of rough conceptualization.

A review of the application of these methods in architecture reinforces this flaw and their methodological inefficiency in practice. For example, several studies employing the BioGen method have focused on the optimization of the building envelope's performance.[4] However, because of overly simplified vision they seem to be too idealistic to reach the implementation phase in the building industry.

To analyze one of these studies in detail, in the article *Solutions from nature for building envelope thermoregulation* Badarnah, Farchi, and Knaack (2010) after discussing a performance taxonomy of organisms for thermoregulation, present a possible application to building envelopes through an assembly of bio-inspired components. The main component of this assembly is the stoma brick made of a porous material, which also is supposed to mimic the human eyelids at the outer layer to remove the dust from the air passing through the envelope. Few details for this component have been provided by the authors. Inspired by the pinecone skin, a veneer shutter controls opening/closing of the envelope modules in accordance to a humidity gradient. Although the pinecone skin

---

[4] These studies include: bio-inspired ventilating envelopes mimicking the human lung system (Badarnah et al., 2008); shading and energy generating skins emulating the features of plants leafs (Badarnah and Knaack, 2008); water harvesting envelope inspired by the Namib Beetle (Badarnah and Knaack, 2015); and evaporative cooling systems inspired by plant's stomata, pine cones, and human skin (Badarnah et al., 2010).

usually opens due to dryness to pop up the seeds, the idea applied here is that its skin reacts to both lack and presence of humidity to retake its original or new shapes after falling from the tree. The inner layer of the stoma brick uses a HEPA filter for air cleaning and the innermost layer is spongy to hold moisture for evaporation in dry climates or absorption in humid climates. An irrigation cycle in dry climates will be added to the system to irrigate the bricks. Would this system in reality perform as described here?

The authors claim this system can operate at different climates: "…in hot and humid weather, the veneer shutter deforms when humidified to allow the air to get inside passing through the spongy structure." (Badarnah et al., 2010, p.10). Clearly, the authors did not fully consider the impact of humidity on this system. In the most idealistic condition, when the spongy component absorbs the moisture in the air at some point it will be saturated with 100% humidity. Then, after no more moisture absorption, the additional humidity leads to the formation of water droplets on the walls' surfaces: the result will be an indoor environment with too much moisture as well as deterioration of the building envelope due to moisture accumulation. Additionally, the HEPA filter performance depends on the key factor of face velocity of the air flow through the filter and requires a large pressure difference to force air through the filter. Therefore, in conditions with normal wind speed, the HEPA filter may not perform effectively to remove the unwanted particles from the incoming air.[5]

This example epitomizes two flaws traceable to other similar biomimetic designs: First, focusing on one influential environmental impact (i.e., air circulation) to the point of neglecting other important factors (i.e., humidity, pressure drop, etc.); and second, proposing inefficient envelope components because of a literal translation of a design concept to a physical product following the existing biomimetic design methods. These methods do not link their conceptual products, at the last step, to the resulting building system/envelope component through a visibly systematic and scientifically grounded process.

---

[5] The most five common types of air purifiers include: HEPA Technology, Activated Carbon Technology, UV Technology, Negative Ion, and Ozone (Koo, 2017).
High efficiency particulate air (HEPA), originally called high-efficiency particulate absorber, is a type of air filter with many applications such as clean rooms for IC fabrication, medical facilities, automobiles, aircrafts, and homes. The filter must satisfy certain standards of efficiency such as those set by the United States Department of Energy (DOE) To qualify as HEPA by industry standards, an air filter must remove (from the air that passes through) 99.97% of particles that have a size greater-than-or-equal-to 0.3 μm (ASME AG-1a–2004). The HEPA filter is a very fine fiber-like material that has been folded back and forth to create the shape of an accordion. This accordion shape creates a maze of randomly arranged fibers and presents a very large surface for air to be pushed through by the air purifier fan. Airflow must have an opportunity to pass through the filter in order for it to be cleaned. The more times airflow passes through the filter in an hour, the cleaner the air will become. As the HEPA filter becomes full, air will no longer be able to pass through and a new filter will be needed; however, a HEPA filter will typically last 2 to 4 years. Large particles will not be able to pass through the openings of the fibers and will immediately get caught. The smaller particles will get caught by one of three mechanisms. The first is when particles come within one radius of a fiber and stick to it. This mechanism is called interception. The second mechanism, called impaction, is when larger particles collide with fibers and embed into them. Finally, they get caught by a mechanism called diffusion. Diffusion is when the smallest particles collide with gas molecules. This, however, slows down their velocity and makes the first two mechanisms more likely (Koo, 2017).

In one example, that shows promise as a real application of biomimicry, the cooling system of the Eastgate Mixed-Use Centre, in Zimbabwe, Africa, cools the outside air to save on energy consumption by 90% compared with a conventional air conditioning system. It is claimed that large termite mounds inspired this building's cooling system (ArchDaily, 2011). The reason is that a large termite mound includes an elaborate matrix of ventilation holes, air passages, and air pockets, which enhance natural ventilation through convection. This process keeps the termite mound temperature between 84.2 and 89.6°F in a hostile climate with fluctuating temperature of 35°F at night to 104°F during the day.

Two models for the termite mound ventilation are commonly accepted: thermosiphon air flow driven by heat and induced air flow driven by wind (Abou-Houly, 2010). In the case of capped mounds, which rely on thermosiphon flows, the hot air created by the nest rises to the top of the mound where it is evaporatively cooled with water vapor through the porous mound walls. This denser, moist air then drops down to the nest below, where the cycle is repeated.

The induced air flow also applies to mounds with a chimney at the top and uses the stack effect: since the chimney helps to accelerate the buoyancy-driven flow. The unidirectional flow draws fresh air from near the ground into the nest, where it passes through the chimney and ultimately to the outside through the top of the mound. In the Eastgate Center building, both buoyancy-driven and wind-driven flows used through an extensive tube system within the walls and floors, moves the air through the building. In the Eastgate Center internal heat gains along with the stored heat within the structure creates a thermosiphon-effect that draws air up toward the rooftops where large chimneys are located to help to induce air flow.

Although termite mounds inspired part of the concept behind the design of the Eastgate Center, which is highly admired as a biomimetic design, other mechanisms, such as its air conditioning system that draw on technology, have been ignored in the existing analyses. For example, the building uses low speed fans during the day, and high speed fans during the night to keep the air from being too stagnant. This process effectively replaces the hot air that builds up during the day with cool air during the night. Smaller fans run during daytime hours to keep the indoor environment comfortable while the walls store the heat from the outside. Larger fans run during the nighttime, pulling the stored heat out of the walls, and push the heat out through the ducting in the ceiling and walls. By the next morning, the walls are ready to release the stored cooling again.

Although the combination of passive and active systems here saves on using expensive air conditioning technology, clearly, no termite mound utilizes fans (Turner and Soar, 2008). Therefore, this building in the absence of technological contribution could not perform effectively and cannot materialize its biomimetic design concept. This brings into mind that a sustainably high performance building is a result of integrating both technological solutions and biologically inspired solutions.

2.1.3. Natural/Passive Systems and Human Well-being

The impact of the application of natural systems and passive design strategies on human wellbeing can be also studied from the perspective of the possible positive/negative outcomes for the occupants in residential/commercial buildings. The purpose of this section is to discuss some of these outcomes, with a focus on residential buildings and healthcare facilities as two examples of building typologies, since they are more in direct relationship with human health. In a healthcare facility, patients and staff can use nature and natural systems for a beneficial experience. For example, increased productivity and well-being, shorter length of stay, better infection control, lower level of stress, and lower energy consumption.

Building occupants also spend a considerable part of our daily life at home where accessibility to daylighting and fresh air through natural/passive strategies can affect both the energy cost and the health of the occupants. Therefore, daylighting and natural ventilation are two important passive strategies contributing to these beneficial experiences which have been discussed in the following paragraphs.

2.1.3.1. Daylighting and Human Well-being

The impact of daylighting can be analyzed from two perspectives: the impact on human's well-being and the impact on infection control/prevention. In regards to well-being, research has shown a close relationship between exposure to daylight and the adjustment of human circadian rhythms. Studies have shown that exposure to ultraviolet light causes melatonin production to control circadian rhythms, sleep cycles, work productivity, and cancer cell development (Bullough et al., 2006). A lack of ultra violet light reduces melatonin production and can cause circadian imbalance, which is followed by negative outcomes, such as depression and disease vulnerability. Laboratory research shows that artificial lighting with features similar to sunlight can improve alertness, cognitive function, and vigilance (Zadeh et al., 2014).

Such an effect can benefit both hospital staff and patients. In one study conducted by Alzubaidi et al. (2013), 134 hospital staff members were asked for their preference about daylighting. Among the participants 79% identified daylight in patient rooms as a work-facilitating factor. The same participants mentioned that daylight availability in patient rooms helps them in examining the patient recovery based on the changes of the skin color. All the participating doctors in the survey claimed faster recovery and a reduced length of stay for patients through exposure to sunlight. This impact of daylighting on patients' Average Length Of Stay (ALOS) has also been investigated in several other studies. In one study researchers evaluated the ALOS in relation to the physical, environmental, and daylighting conditions of a general hospital in Incheon, Korea (Choi et al., 2012). The collection and categorization of data in this study was based on patients' positions of the head and rooms' orientations. The results showed that rooms with more sunlight, such as in southeast orientation, had 16% to 40% shorter ALOS compared to other rooms, such as in rooms with northwest orientation.

In another study 174 patients were observed in a hospital in Edmondo, Alberta, Canada (Beauchemin and Hays, 1996). The researchers found a reduction of 2.6 days in the length of stay among seasonal affective disorder patients in sunny rooms compared with sunless rooms of the hospital. The benefits of sunlight on patients with psychological disorders have also been identified, where the findings show a 30% reduction in ALOS in the summer and a 26% reduction in the autumn for patients with bipolar depression in eastern rooms versus western rooms (Benedetti et al., 2001). West-side sunlight in northern hemisphere is usually more intense than other directions and reduces visual comfort due to glare. Additionally, the western sunlight is accessible in the afternoon until evening, which limits daylight benefits for the occupants. Further research is required to find out if there is any correlation between these features of the western sunlight and increase/reduction of the ALOS.

The impact of sunlight on health can go beyond circadian rhythm adjustments, length of stay reductions, and psychological disorder improvements. Sunlight may even contribute positively to the task of infection control and prevention. Some historic experiments conducted in the late 19th and early 20th century reported that sunlight projecting through exterior glazing can stop the growth of bacteria (Hobday & Dancer, 2013). However, these experiments have not been verified. The WHO guidelines for preventing infections mention the use of sunlight, although it does not provide further information for its reasons (2002).

Hobday and Dancer elaborate the positive role of sunlight on preventing several infection types of bacterial growth related to tuberculosis, streptococci, meningococci, and staphylococci. In this elaboration both the direct and diffuse daylight were influential in killing bacteria. However, the impact of direct sunlight is usually more powerful than the diffuse daylight. For example, according to Buchbinder streptococci cannot survive more than five minutes in the direct sunlight, or more than an hour in diffuse daylight (1942). However, in these studies the potency of this bacteria remain unchanged for a long period in indoor conditions away from daylight (Buchbinder, 1942).

The general impact of sunlight on health and wellbeing can also contribute to the improvement of comfort conditions. For example, the use of sunlight for direct solar gain can bring the cold indoor temperature into the comfort zone without drying our skin which is usually the consequence of temperature adjustment by mechanical systems decoupled from seasonal and daily variations (Loftness and Synder, 2011). However, further research is required to systematically analyze such an impact on physiological conditions of the human body.

2.1.3.2. Natural Ventilation and Human Well-being

The use of natural ventilation in hospitals was more common in the era before the emergence of mechanical systems. Florence Nightingale was one of the pioneers who underlined the importance of air quality and natural ventilation in the treatment of hospital patients through her book in 1863 (Nightingale, 1863). In the book she criticized mechanical systems that created constant indoor temperature that decoupled buildings from seasonal variations. In the book she felt that the air temperature variation was a requirement for human health and that the unhealthy conditions in hospitals, to some extent, were linked with the inefficient ward space layout lacking natural ventilation (Iddon, 2017).

In 1864, John Simon used natural ventilation in hospital wards, where, similar to Florence Nightingale, oblong wards had sash windows reaching to the ceiling along the two long sides of the wards. Each bed in the hospital wards would be located between these windows (Hobday & Dancer, 2013). Most recently, in 2007 the WHO (World Health Organization) in its guidelines for the infection control, introduced natural ventilation among the effective measures of infection control/prevention in health care facilities (WHO, 2007).

Natural ventilation can contribute to infection control through its microbicidal impact on the airborne transmission of pathogens. Thus far, four mechanisms of pathogen transmission have been identified: contact; dust; respiratory droplets, and droplet nuclei. The WHO guideline defines droplet nuclei as “dried-out residuals of droplets less than 5 μm in diameter” (WHO, 2007, p. xxi). In this report, droplets are respirable particles larger than 5 μm in diameter, which can be deposited on upper respiratory tract levels and mucosa. Depending on the size of the particles, respirable droplets can be divided into large droplets, fine inhalable aerosols, and droplet nuclei (WHO, 2007, p. xxv). Large droplets usually fall on horizontal surfaces and can be transmitted with dust, which can be suspended as the result of indoor activities such as dressing or sweeping. Such droplets have a travel range less than 1 meter and usually do not affect any person standing beyond this distance.

Small droplets are more prone to causing infection. These airborne particles can actively transmit infection for a longer time ranging from minutes to hours (Hobday & Dancer, 2013). Therefore, special ventilation controls are usually required to prevent diseases from being transmitted over a long distance by droplet nuclei (Gardner, 1996). However, some recent researches indicate that, independent of the size of the droplets, airborne infection control should be considered in healthcare facilities (Gralton et al., 2011). Influenza, common colds, smallpox, tuberculosis, methicillin resistant staphylococcus aureus (MRSA), norovirus, hantavirus, severe acute respiratory syndrome (SARS) all are examples of the possible pathogens infecting hospitals through airborne transmission (Hobday & Dancer, 2013).

Factors such as temperature, humidity, atmospheric pollutants, UV (ultra violet) radiation, ventilation airflow, air changes per hour, and thermal gradients can affect the existence and dispersion of these pathogens (Hobday & Dancer, 2013; Nielsen, 2009). For example, many of the microbes causing airborne infections cannot survive outdoors temperature variations. This fact could be a reason for making the indoor condition similar to the outdoor condition in Nightingale wards. Another example, discovered at the end of the19th century, is the reduction of the malignant effect of tubercle bacillus (TB) in the case of exposure to fresh air.

The tuberculosis used to be the number one killer in the U.S in the 19th century. The tuberculosis could spread through sneezing and coughing. Therefore, by the early 19th century, large hospitals or sanatoriums were built across the US to isolate patients and provide a place to offer the best treatment of the day: fresh air and sunlight (Doucleff, 2013). Tubercle bacillus is killed relatively quickly by sunlight, and therefore, transmission usually occurs indoors. Tubercle bacillus can live in the air for only a short time, about 4 hours, and therefore, fresh air or increased air changes per hour can reduces the risk of TB infection (DOH, 2018). In summary, these findings about the microbicidal impact of outside air led to the introduction of new terms such as “open air factor” (OAF) in the 1960s. (Hobday & Dancer, 2013; Ransom & Delepine, 1894).

To discuss another example with more details, Wells-Riley equation can be used to explain the impact of ventilation rate on the cross infection of airborne transmitted diseases. Per Wells’ idea of quantal infection, a certain dose of pathogens is necessary to cause infection to a new susceptible (Wells, 1948; Qian and Zheng, 2018).

On this basis and using the Poisson distribution[6], Riley predicted the risk of airborne infection through Wells-Riley equation (Riley, 1978): $P=C/S= 1-\exp(-Iqpt/Q)$
The nomenclature for this equation is as follows: P= risk of cross infection; C=number of case to develop infection; S=number of the susceptible; I=number of infectors; p=pulmonary ventilation rate of each susceptible (m3/h); Q=room airflow rate (m3/h); q=the quanta produced by one infector (quanta/h); and t=duration of exposure (h). According to Wells-Riley equation the risk of infection can be reduced considerably through ventilation rate. Natural ventilation can contribute to delivering large ventilation rates with lower energy consumption and in higher rates compared with mechanical ventilation, thereby reducing the airborne infection risk (Qian and Zheng, 2018).

However, it is still a point of discussion among professionals either the increase in the level of outside air could be more effective using mechanical systems or using natural ventilation systems such as operable windows (Loftness & Synder, 2011). There are many studies using the Sick Building Syndrome (SBS) as an index of measuring the human health and well-being related to indoor ventilation. These studies compared mechanical systems with natural systems to reveal the benefits of natural ventilation in reducing headaches, mucosal symptoms, colds, coughs, circulatory problems, and SBS (Robertson et al., 1990; Kelland, 1992; Seppanen & Fisk, 2002; Preziosi, 2004). Beyond

---

[6] Named after French mathematician Siméon Denis Poisson, Poisson distribution is a discrete probability distribution thaexpresses the probability of a given number of events occurring in a fixed interval of time or space if these events occur with a known constant rate and independently of the time since the last event. The Poisson distribution can also be used for the number of events in other specified intervals such as distance, area, or volume (Haight, 1967).

SBS symptoms, newer studies about respiratory illness question which strategy could be more effective: the increased rates of outside air for diluting the indoor air or the higher level of oxygen and other gases indoors. These studies give more credit to the natural delivery of the outside air, which is fresher than the mechanically delivered outside air mixed with returned air or delivered through sometimes less clean ducts (Loftness and Synder, 2011).

There is evidence that natural ventilation can be effective compared with mechanical ventilation for preventing pathogens transmissions. For example, during the 1918 influenza pandemic the number of survived patients in outdoor spaces exceeded the number of patients who survived in hospital wards (Hobday and Dancer, 2013; Brooks, 1918). The effectiveness of natural ventilation versus mechanical ventilation has been investigated in several previous studies (Hobday and Dancer, 2013). Based on a study in 2007, tuberculosis patients who were in naturally ventilated rooms were compared with mechanically-ventilated, negative-pressure, isolation rooms, which used a tuberculosis infection airborne model. In this study the highest risk of infection was found in rooms with mechanical ventilation and sealed windows, although these rooms used the low recommended air changes per hour. The findings showed that among the studied rooms the pre-1950 hospitals with partially-opened windows had the best infection protection.

Another reason for the advantage of using natural ventilation is its higher air change rates. Normally twelve air changes per hour (ACH) have been measured for isolation rooms in general wards while in wards with open doors and windows it can reach as high as 14 ACH and 31.6 ACH, and with cross ventilation can reach up to 69 ACH (Hobday & Dancer, 2013). Such a high rate of air change with cross ventilation has been found to be successful in controlling SARS transmission (WHO, 2009).

Natural ventilation can be also reviewed in relation to the concept of Passive House (PH), which was first introduced in Europe and then in the US, as described in the section 2.2 Brief History of Passive Building Design in the US. The PH concept advocates extremely high levels of airtightness and high levels of insulation to achieve very high standards of energy efficiency as part of their efforts to meet carbon reduction targets. Air tightness of residential buildings can decrease air leakage and heat loss/gain which in turn reduces heating/cooling demands.

However, it is important to provide enough ventilation to maintain a healthy indoor environment due to the variety of indoor chemical emissions through interior materials and furniture (Ürge-Vorsatz et al., 2012). ASHRAE has proposed a range of allowable CO_2 concentrations from 1000 ppm to 2500 ppm, as well as ventilation requirements of 10 liters/sec (about 20 cfm) per person to address these health issues. Some of the revised building standards stipulate that air change rate in the living rooms of new constructed buildings must be at least 0.5/h (Ürge-Vorsatz et al., 2012). In this case, ASHRAE Standard 62.1-2013 mentions that primary outdoor air fraction (Z_p) should be determined for ventilation zones based on the following equation: $Z_p = V_{oz}/V_{pz}$

V_{oz} is the zone outdoor airflow (i.e., the outdoor airflow rate that must be provided to the ventilation zone by the supply air distribution system) and V_{pz} is the zone primary air flow rate. This ASHRAE Standard explains that max Z_p refers to the largest value of Z_p in Table 2.5 with the corresponding E_v, which is the mechanical system ventilation efficiency.

Table 2.5 System Ventilation Efficiency and primary outdoor air fraction. Reprinted with Permission ©ASHRAE www.ashrae.org Standard 62.1-2013

Max (Z_P)	**E_v**
≤0.15	1.0
≤0.25	0.9
≤0.35	0.8
≤0.45	0.7
≤0.55	0.6

Due to the high levels of airtightness, PH requires the installation of a mechanical ventilation system, particularly a Mechanical Ventilation Heat Recovery system (MVHR) for maximum energy efficiency. The energy required to run the MVHR system is low. However, the heat recovered through such a system will reduce the need for heating systems (PHIUS, 2018). In this case it is important to be cautious that MVHR systems will not necessarily resolve Indoor Air Quality (IAQ) problems. Relatively low levels of air change may be sufficient to provide enough air to comply with building regulations and for occupants to breathe but this may not be enough to remove concentrations of Volatile Organic Compounds (VOCs) or hazardous chemicals and particles. Therefore, these systems should be accompanied with appropriate exhaust systems, which usually are not provided in residential buildings due to additional costs for implementing these systems.

PH advocates claim that mechanical ventilation with heat recovery systems are adequate to maintain good IAQ, despite possible emissions from new construction materials (PHIUSP, 2018). Most certified PH projects are built with conventional masonry or timber-frame construction using non-breathable petrochemical insulation materials, synthetic materials, and plastic membranes. It has not been possible to find anything in the PH standards about safeguarding occupants from indoor pollution emissions such as formaldehyde, VOCs, and other hazardous materials. There are some examples of PH projects that have been built using ecological and natural materials[7], but under the current PH standard, IAQ is usually dependent on MVHR.

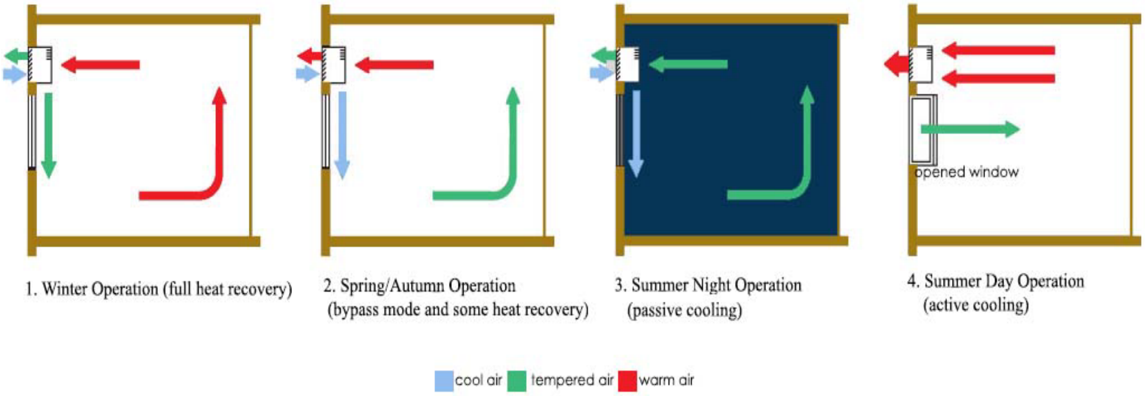
The literature includes evidence that the PH approach might be problematic because occupants do not manage the system well or fail to understand it (Woolley, 2016). The MVHR outdoor air systems are usually noisy and, if used without mufflers, occupants tend to switch off the MVHR fans because of not understanding the operation concept of the system. When this occupants' behavior becomes regular, a passive house can be

---

[7] Examples of these certified Passive Houses with straw panels, wood, cellulose insulation and clay plaster can be found at http://www.createrra.sk/page/19/straw-panels-ecococon.html Retrieved February 2019.

actually too air-tight. Tenants have also been found to be concerned about the maintenance and the cost of running the fans. MVHR systems and filters that are not changed regularly can get clogged, which reduces the fresh air (Woolley, 2016). Overheating is also another issue associated with the airtightness of passive houses. Research has found that even in temperate climates, such as Netherlands, the increasing number of highly insulated and air-tight buildings can lead to a concern about overheated indoor conditions and related comfort/health issues (Barbosa et al., 2015).

On the other hand, there is a belief among many architects and engineers that natural ventilation cannot ensure sufficient air changes or an adequate supply of fresh air. Although natural ventilation has worked for centuries in hot climates by combining thermal mass with roof vents, shading, and courtyards for cooling; the long term, stable, climatic patterns of the past are changing today due to issues such as air pollution and global warming. Still today some effective modern passive ventilation systems can be found to be used in passive buildings. These intelligent systems should not be considered completely passive because their monitoring/controlling components need electricity for operation. These systems, beyond natural ventilation, also offer capabilities such as passive heat recovery, passive night-time cooling, and low energy comfort cooling without using mechanical systems. These systems can be integrated with a building's design depending on the required ventilation model such as the "wind-hive" models for stack ventilation and "in-vent" passive and "in-vent" active for façade integrated systems using both cross and stack ventilations (Ventive, 2018). Figure 2.2 shows an example of the operation of an in-vent passive intelligent system.



1. Winter Operation (full heat recovery)

2. Spring/Autumn Operation (bypass mode and some heat recovery)

3. Summer Night Operation (passive cooling)

4. Summer Day Operation (active cooling)

Figure 2.2 Operation of an in-vent passive intelligent system, adapted from (Ventive, 2018)

Another option to increase natural ventilation is humidity sensitive mechanical hybrid ventilation systems. A range of these systems are now available which are claimed to be more energy efficient than MVHR. Many of these systems avoid the need for expensive and complicated ducting components. Demand controlled ventilation is a case in point in which the mechanical system extract only runs when humidity rises. Such hybrid arrangements provide possibilities for a ventilation stack to operate in either a completely passive mode or mechanical mode in the same system.

2.2. Brief History of Passive Building Design in the US

2.2.1. From Early Attempts until the 1940s

There exists a rich history of passive heating traditions throughout the world. While passive heating strategies have been used for thousands of years, their application appears to follow a cyclical trend in which periods of great interest are followed by periods of indifference (Grondzik & Kwok, 2014). Historically there is evidence of a widespread application of passive design strategies in the pre-modern era. For example, to keep out the cold winter winds, Aristotle mentioned that builders sheltered the north side of the house. Socrates, who experienced living in a solar-heated house, observed that for houses looking facing the south, the sun penetrates the portico in winter (Perlin, 2013). In Roman architecture, solar design was also of high importance such that sun-right laws were passed to prohibit builders from blocking access to the winter sun in solar-designed structures. Additionally, Vitruvius advised builders in the Italian peninsula that "buildings should be thoroughly shut in rather than exposed toward the north, and the main portion should face the warmer south side" (Purlin, 2013).

Native American communities in the American Southwest applied passive heating strategies in their pueblos and cliff-dwellings in search of appropriate building orientation. The Ancient Pueblos at the Mesa Verde cliff dwellings, Colorado today, captured the free heating and cooling of nature without electricity or modern building techniques. (Dodge, 2014). Acoma as the North America's oldest continuously inhabited city represents a case in point, where each unit is tiered such that all dwellings could catch the winter sun while the summer solar gain is minimized (Murgula et al., 2015). In another example, closer to the time of Industrial Revolution interests in passive heating flourished and concepts such as greenhouse became a necessity for the upper-class Europeans (Lechner, 2009). Although these interests diminished during the Industrial Revolution, the early twentieth century again witnessed a surge in the application of passive strategies (Perlin, 2013).

In the early 20th century, architects such as William Atkinson, a fellow of Boston Society of Architects, conducted research on solar heating in buildings. Similar to the polymath Horace B. de Saussure's hot box model , Atkinson used a "sun box" model for his solar studies with the exception that Atkinson's box built was to simulate a window and a room.[8] He observed from summer tests that the east and west windows of the box would admit too much summer sunlight. His most interesting observation was that on December 22, when the outdoor temperature was only 24°F, the temperature of a south-facing box rose up to 114°F. From these observations Atkinson concluded that sun's rays can impact with different values the heating of our houses with proper locations and orientations (Perlin, 2013).

---

[8] In 1767, the Swiss polymath Horace B. de Saussure started to study the effectiveness of glass in trapping solar heat. Saussure built a rectangular box from wood, which was insulated with black cork and covered at the top with glass. A similar but smaller glass-covered box was placed inside. By tilting the box toward the sun, the temperature of the inner box rose above the boiling point of water. This device became known as a Hot Box. The hot box became the prototype for solar thermal collectors used to heat water and homes. Saussure's hot boxes also modeled the dynamics of global-warming with considerable precision. He used glass acting as an atmosphere soaked with excess carbon dioxide which would play the role of stopping solar heat absorbed by the earth from re-radiating into the sky (Perlin, 2013).

Atkinson tried to promote the findings of his hot box studies as well as solar building design in America. He built a “sun house” near Boston which would reach high indoor temperature during freezing days and also wrote a book to show how most builders ignore the possibilities of using the sun energy in buildings (Mckinley, 1995). Such sporadic efforts on solar designs/studies were followed later by the presence of the avant-gardes of modern architecture such as Marcel Breuer and Walter Gropius of the Bauhaus school in Germany who brought similar design concepts to America prior to WWII. For example, Walter Gropius House (1938) was designed by Walter Gropius to reflect the traditions of New England architecture while adhering to Bauhaus principles. The result was a combination of locally popular materials with new concepts like glass block in an avant-garde design, which included design concepts such as passive solar heating and natural ventilation (Alexander, 2009).

The modern architecture movement led to the generation of new architectural interests in passive solar design which were practiced by architects such as George Fred Keck in Chicago and Frank Lloyd Wright (Derez, 2013). Therefore, while the majority of the findings related to passive design strategies stem from the events and activities of the 1970s and the 1980s, the origin of the modern passive building design should be attributed to the architectural design practice of the 1940s and earlier in a few cases, such as Atkinson’s sun house as explained above. In 1940, the Chicago architect George Fred Keck built the Sloan House in Glenview, Illinois, to pioneer the modern solar design through simple strategies in a building that could save 40% on the heating bill (Derez, 2013).

The Chicago Tribune used the term “solar house” to describe the Sloan House which was the first modern use of the term (Denzer, 2013). The applied passive strategy of an all- glass, south-facing wall was the result of Keck’s earlier unconscious effort for the design of the *House of Tomorrow* with two key model structures for the Century of Progress Exhibition in Chicago in 1933 (Roth, 2003). He found that this house is warm inside on sunny winter days prior to installing a furnace and this observation became a basis for his other passive house designs (Boyce, 1993).

After the war, Keck was hired by a nation-wide construction firm, which advertised solar house as “The most talked about home in America.” The family occupying one of Keck’s solar houses, for example, reported in 1979, according to the Chicago Sun Times, “The temperature can dip to zero [outside], but if the sun is shining, the family turns off their furnace as soon as they get out of bed in the morning. Otherwise the house gets too warm.” The Sun Times reported later that during a visit on a hot day in August the indoor temperature was pleasant in the living room without any of the air conditioners operating (Perlin, 2013).

2.2.2. From the 1940s until 2010

Other famous architects were also contributing to the foundational practice of solar design in the 1940s. In 1943 Frank Lloyd Wright designed the Hemicycle House in Madison, Wisconsin. He called this house “Solar Hemicycle” since it incorporated the fundamental elements of passive solar design such as orientating the long façade to the south with large glasses for harvesting solar energy, using concrete floor slabs for thermal mass, minimizing the window openings on the other sides of the building, utilizing broad overhangs to shade the south glazing in summer, and insulating the exterior walls.

The research on solar heating of buildings funded at MIT by Godfrey Lowell Cabot, a wealthy Bostonian, added scientifically to the professional achievements of individual architects. One of the first projects funded by Cabot was Solar I, a structure built in 1939 to be the first house in the United States heated with solar energy and the first of six “solar houses” designed and constructed by the MIT faculty between 1939 and 1978 (Levy, 2016). In the first project, the roof was covered with solar water heater collectors. The water would go into a 17,400-gallon storage tank and the air blown over the tank could warm and circulate the hot air into the house when it cooled down.

In another attempt at MIT, in search of a more cost-effective system, the functions of collecting, storing, and distributing solar heat were combined into a single unit. Water cans were stacked behind a south-facing glass façade of a long narrow laboratory envelope including ten cubicles. The water in the cans would be heated during the day. Insulating curtains separated the interior of the cubicles from the warm water cans when the interior was too hot and could be opened when any of the cubicles needed heat. In between the glass and the heated cans, the insulating shades were shut at night to avoid heat loss through radiation into the night sky. These water walls, though simple, could supply up to 48% of a cubicle's heating demand throughout the very cold New England winter (Perlin, 2013; MIT Solar History, 2018).

Equations related to solar energy collectors derived from such attempts to calculate the useful heat energy from the incident solar radiation. The most famous equation is the Hottel-Whillier-Bliss equation to express the thermal performance of a collector under a steady state (Struckmann, 2008): $Qu= F_R A [I\tau\alpha - U_L(T_i\text{-}T_a)]$

In this equation A is the collector area (m2); F_R is the collector heat removal factor; I is the intensity of solar radiation (W/m2), Qu is the useful energy gain (W); Ti is the inlet fluid temperature (°C); Ta is the ambient temperature (°C); U_L is the collector overall heat loss coefficient (W/m2); τ is the transmission coefficient of glazing; and α is the absorption coefficient of the plate. Hottle, Whillier, and Bliss (Hottel and Willier, 1958; Bliss, 1959; Willier, 1977) explained the relationships for the design of tube and sheet case collectors through the application of a collector efficiency factor (η). In this case, the equation below (Norton, 2018; Goudarzi et al., 2014) explains the relationships between the collector efficiency factor, the absorbed energy (FR($\tau\alpha$)e) and the loss energy ($-F_R U_L$): $\eta =F_R (\tau\alpha)_e - F_R U_L(T_i\text{-}T_a)/I$

The climax of the MIT research activities in combining solar heating with architectural design was not to be realized until late 1970s when Solar V and later Solar VI structures were built. For example, Solar V, was a structure erected in 1978 on the MIT campus used as an experimental studio/classroom by the Department of Architecture. Different from the previous solar houses studied, Solar V would work with no requirements for mechanical equipment such as solar collectors, pumps, or fans. In the Solar V project all elements of solar heating were incorporated into the building materials (MIT Solar History, 2018).

Although, interest in solar homes peaked in the early 1950s, following the cyclical trend of interest in passive building design, the low price fossil-fuel after the end of World War II resulted in a lack of interest in passive solar heating systems. However, the energy crisis of the 1970s became an enormous catalyst for an architectural movement that was focused on energy efficiency in buildings. In this decade, demonstration houses such as Doug Balcomb's house in Santa Fe, New Mexico, and Doug Kelbaugh's solar house in Princeton, New Jersey, explored the potential of integrating a variety of different passive solar components. For example, in Balcomb's house integration of adobe materials with a hybrid system of fans passing the hot air through underfloor rock beds along with a large sunspace would keep the temperature swing inside the house small within the comfort zone. In this house while the outdoor temperature fluctuates between 18F to 55F in sunny winter days, the indoor temperature swings between 65°F and 74°F (Lechner, 2009).

In another example, Dough Kelbaugh's passive house design in 1975 in Princeton was the first case to utilize a Trombe' wall.[9] In addition, alongside the practice of passive solar building design in the 1970s, publications such as Edward Mazria's Passive Solar Energy book in 1979 assisted other designers in mastering the basics of solar design. Mazria's book, although an important contribution, was more focused on the general picture of passive solar design and its rules of thumb for designers. Therefore, a guideline with detailed procedures and calculations in passive solar design was needed.

Mazria's book was followed in the early 1980s by publication of other important solar design researches and guidelines. For example, in 1983 passive solar design guidelines for sizing direct and indirect solar gains such as Trombe' walls were developed by Balcomb for locations inside the US at Los Alamos National Laboratories. The goal of this work was to assist in reducing homeowners' heating bills through the proper sizing of glazing and window openings that used the solar energy for passive heating of buildings. Some of these concepts had been pursued sporadically in the 1960s, but did not produce a systematic approach to provide design guidelines. An example is the Trombe' wall named after the French Professor Felix Trombe' in 1966. [10] In this indirect

---

[9] The top of the wall could be opened in the summer to help boost ventilation and prevent from overheating. The house originally designed as a rectangular plan, was modified in 1976 with a south-facing greenhouse. For further information please see Kelbaugh Solar House at https://centralnjmodern.wordpress.com/princeton-modern/kelbaugh-solar-house/ last accessed February 2018.

[10] Similarly, some other solar concepts were studied earlier by European researchers from the 1760s until the end of the 1800s. Examples include studies about the first solar motors by the French mathematics professor, Augustine Mouchot, or the "solar hot box" by the Swiss polymath Horace B. de Saussure (Perlin, 2013).

solar gain system, the thermal mass consists of a concrete wall just inside the south-facing glazing. The blackened wall surface facing the sun gets hot during the day that causes heat flow into the wall and the adjacent indoor space during the evening (Iyengar, 2015).

The research and development activities of the 1970s and the 1980s for passive solar building designs could not have occurred if the vital 1974 Solar Energy Act had not been approved (H.R.16276 — 93rd Congress, 1974). Prior to that the depth of knowledge about solar radiation in the US was limited because the data collected by the National Weather Service (NWS) was not recorded in units that facilitated a solar thermal analysis. The Solar Energy Act of 1974 led to a solar energy determination and assessment program to prepare national and regional appraisal of all solar energy resources including data on solar insolation, wind, ocean thermal gradients, and the potential for photosynthesis conversion (Balcomb, 1992).

Once these data had been compiled it became possible to establish a National Radiation Data Base (NSRDB) for the US, which provided hourly solar radiation and meteorological data for sites throughout the United States from 1961 to 1990 and from 1991 until 2010 (NREL, 2018). The 1961-1990 NSRDB contained 30 years of solar radiation data and supplementary meteorological data from 237 NWS sites in the U.S., Guam, and Puerto Rico. The updated 1991-2010 National Solar Radiation Database holds solar and meteorological data for 1,454 locations in the US and its territories.[11] The latest version of solar data is the NSRDB 1998-2014 Update which includes 30-minute solar and meteorological data. These data were developed using the Physical Solar Model (PSM) for about 2 million surface pixels—nominally of about 4 km2 divided in 0.038-degree latitude by 0.038-degree longitude increments (NREL, 2018).

The up and down of passive building design continued until the surge of the green building movements such as Net Zero Energy (NZE) and Net Positive Energy (NPE) which have rekindled interest in passive/natural systems. Beginning in the late 1990s a number of new technological changes were introduced to the design of NZE and NPE, which had limited impact on the NZE/NPE components/concepts. However, the scale of the buildings being designed and constructed to use them increased (Grondzik and Kwok, 2015). Between 2008 and 2013, researchers from different countries, including US, collaborated under the International Energy Agency (IEA) Solar Heating and Cooling Program Task 40 / Energy in Buildings and Communities (EBC) in the research "Towards Net Zero Energy Solar Buildings" Annex 52 to promote the Net Zero Energy Building feasibility on the market.[12] These newer green building design trends will not be discussed here, since they have been already discussed in earlier sections of this

---

[11] For further information, please see National Solar Radiation Data Base at https://rredc.nrel.gov/solar/old_data/nsrdb/ accessed February 2018

[12] These countries include Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Republic of Korea, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, United Kingdom and the US.

thesis. However, one of the important trends that need to be addressed here with respect to the historical trend of national green building design interests is the establishment of the Passive House Institute US (PHIUS).

2.2.3. Passive House Institute US (PHIUS)

The root of the PHIUS goes back to 2003, when a passive single family residence in Urbana, Illinois was designed and built by Katrin Klingenberg (PHIUS Mission, 2018). This was one of the very first homes in the US built following the passive building energy standards similar to those in Europe, in particular Germany. To further investigate the viability of her experience in applying passive design principles in the US, Klingenberg cofounded a construction laboratory in Urbana, Illinois with the builder Mike Kernagis in 2003 as a non-profit affordable housing developer. Working in partnership with the City of Urbana, the lab became a Community Home Development Organization (CHDO) to build single-family passive house projects as affordable housing units. Following the growth of passive building design in the US, this lab was expanded into the Passive House Institute US (PHIUS) in 2007. PHIUS is now a leading passive building standard setting, research and information provider, training, and certification institute in North America, that supports the growth of the community of passive building professionals.

However, the concept of passive house pursued by the US institutions today, such as PHIUS, is very different from the legacy passive building systems, which required installation of add-on systems to save energy through the ambient conditions. Instead, in a PHIUS certified house, the focus is more on the design or selection of individual building envelope components such as glazing materials, insulation types, and thermal bridges to reduce a building's energy consumption. In this perception of passive design, "the Passive House is a quantitative, performance-based energy concept for buildings based on the understanding of the relationship between the influence of the thermal quality of the envelope and the resulting sizing of the mechanical system" (Antretter et al, 2013). One of the goals of the PHIUS is to reach the concept of low energy homes. The current International Energy Conservation Code (IECC) recognizes extremely-low-load homes, defining them as homes with a peak load smaller than 1 W/ft2 for heating in Section *101.5.2 Low Energy Building* (ICC 2018). It is interesting to note that many of the concepts practiced by the PHIUS were similar to the concepts promoted by William Shurcliff in late 1970s and early 1980s.

William Shurcliff, a physicist at Harvard at the time, published many books on the passive solar and superinsulation concept in the late 1970s and early 1980s (Antretter et al, 2013). Shurcliff first used the term passive house in his 1982 self-published book "The Saunders-Shrewsbury House." In his later writings he defined the same set of principles and metrics that define today's five principles of passive house design recognized by the PHIUS. These principles were defined at the same time that the concept of superinsulation began to emerge. Shurcliff's five main principles of *superinsulation,* also known as *passive housing* in his 1986 article in the *Energy Review* journal, include:

1) thick insulation,

2) airtight construction,

3) prevention of moisture migration into cold regions within the walls, and other regions where much condensation could occur,

4) optimum sizing of window areas, and

5) a steady supply of fresh air

The last two principles have been further expanded by PHIUS: first, in addition to the specification of window sizes, the area of high-performance windows should be specified according to climate; and second, constant fresh air supply, in most climates via a mechanical ventilation system with heat and/or moisture recovery is required (PHIUS, 2016). It should be mentioned that Shurcliff had provided additional details about the components resulting from these principles such as triple pane windows, heat recovery ventilators, thermal bridge free designs, airtightness design strategies, vapor retarders, and wood stove as the house heat source (Antretter et al, 2013). In his book *Superinsulated Houses and Air-To-Air Heat Exchangers (*1988) Shurcliff explains that in the future further improvements in window technologies, vapor retarders, and compact minimized mechanical systems will occur.

In the early1990s the German physicists Wolfgang Feist conducted research that was a further development of Shurcliff's work in Europe. He codified the impact of highly improved envelope components (including triple-pane windows) on minimizing the potential of the heat load in low-energy buildings (Feist 1992). Feist used the same US energy metrics of 1 W/ft2 peak load and realized that an energy efficient construction in Central Europe should have a maximum of 15 kWh/m2-yr annual heating demand. This metric soon became a standard across Europe for energy efficient homes.

In 2002 Katrin Klingenberg used these principles and the Passive House tools to build the first residential building in Urbana, Illinois. Since then many projects have been built across all U.S. climates that are not listed in the 300 buildings on the PHIUS database (2016). This collective experience from the passive house certification has proved that its principles work in all climatic locations. However, its standards require climate-based adjustments (Klingenberg, 2013). For example, the superinsulated external walls in Alaska's cold climate do not need to be applied the same way in California where, comparatively, little insulation is required. The resulted in the Climate-Specific Passive Building Standards (Wright and Klingenberg, 2015), which are now used as criteria for PHIUS+ project certification and Quality Assurance/Quality Control (QA/QC) measures.

The PHIUS+ passive building certification is a voluntary program. ENERGY STAR[13], EPA Indoor airPLUS[14], and Zero Energy Ready Home (ZERH)[15] specifications are the program's prerequisites for the residential sector.

Table 2.6 Performance requirements for PHIUS Certification adapted from(PHIUS, 2015)

Building Type	Heating Demand/Load (maximum climate specific)	Cooling Demand/Load (maximum climate specific)	Air Tightness	Source Energy Demand	Renewable Generation for Source Zero
Single family	1-16.8 kBtu/ft2-yr 0-7.6 Btu/hr-ft2	1-23.4 kBtu/ft2-yr 1.3-9.5 Btu/hr-ft2	0.05	6200 kWh/person-yr	>Source energy demand
Commercial				38kBtu/ft2-yr	
Multifamily			0.08*	6200 kWh/person-yr; 38kBtu/ft2-yr	
Retrofit	As above, plus allowance for existing thermal bridges	As above, plus allowance for existing thermal bridges	0.05;0.08*		

* For buildings with more than five stories and with noncombustible construction
Other considerations include window U values: 0.4-0.08 Btu/hr-ft2°F (varies by climate); HRV or MHRV with 53%-95% efficiency and fan efficiency of 0.27-2.23 W/cfm (varies by climate); and thermal bridge-free construction <0.006 Btu/hr-ft °F.

---

[13] Energy Star is a voluntary program launched by the U.S. Environmental Protection Agency (EPA). It is now managed by the EPA and U.S. Department of Energy to help businesses and individuals save money and protect the environment through superior energy efficiency. A ccessed February 2018 from https://www.energystar.gov

[14] Indoor airPLUS is a voluntary partnership/labeling program to help home builders improve the indoor air quality by requiring construction practices and product specifications that minimize exposure to airborne pollutants and contaminants. Accessed February 2018 from https://www.epa.gov/indoorairplus

[15] A DOE Zero Energy Ready Home (ZERH) is a home that meets all of the criteria found in the DOE Zero Energy Ready Home National Program Requirements. Examples of these criteria include: thermal enclosure,
HVAC quality installation, water management, and comprehensive indoor air quality. DOE Zero Energy Ready Homes are verified by a qualified third-party and are at least 40%-50% more energy efficient than a typical new home. This generally corresponds to a Home Energy Rating System (HERS) Index Score in the low to mid-50s, depending on the size of the home and its region. Accessed February 2018 from https://www.energy.gov/eere/buildings/doe-zero-energy-ready-home-partner-central

PHIUS+ 2015 and Source Zero Certification define the next steps in the DOE High-Performance Home Staircase as shown in Table 2.7 Key requirements beyond those programs include: 1. Space conditioning maximum requirements which is set to optimize the building enclosure; 2. Source energy requirement which is set to minimize overall energy use and carbon footprint; 3. Air-tightness requirement and moisture design criteria which is set to ensure building durability. Table 2.6 summarizes the specific performance requirements for PHIUS.

Table 2.7 DOE High-Performance Home Staircase, adapted from (PHIUS, 2015)

						PHIUS+ SourceZero
					PHIUS+	Source zero renewable energy system
				ZERH	Balanced ventilation HRV/ERV	Balanced ventilation HRV/ERV
				Solar Ready depends on climate	Solar Ready Always	Solar Ready Always
				Efficient Comps. & H_2O Distribution	Efficient Comps. & H_2O Distribution	Efficient Comps. & H_2O Distribution
				EPA Indoor Air Package	EPA Indoor Air Package	EPA Indoor Air Package
		ENERGY STAR v3	**ENERGY STAR v3.1**	Ducts in Conditioned Space	Ducts in Conditioned Space	Ducts in Conditioned Space
		HVAC QI w/WHV	HVAC QI w/WHV	HVAC QI w/WHV	Micro-load HVAC QI	Micro-load HVAC QI
		Water Management	Water Management	Water Management	Water Management	Water Management
IECC 2009	**IECC 2012**	Independent Verification	Independent Verification	Independent Verification	Independent Verification	Independent Verification
IECC 2009 Enclosure	IECC 2012 Enclosure	IECC 2009 Enclosure	IECC 2012 Enclosure	IECC 2012/15 Encl./ES Win.	Ultra-Efficient Enclosure	Ultra-Efficient Enclosure
HERS 85-90	HERS 70-80	HERS 65-75	HERS 55-65	HERS 48-55	HERS 35-45	HERS < 0

Currently the PHIUS+ 2018 is under a pilot study. Based on the current information the PHIUS+ 2018 remains a pass/fail passive building standard, serving as an update to replace PHIUS+ 2015. It remains a “performance-based” energy standard that includes prescriptive quality assurance requirements based on three pillars: Limits on heating/cooling loads (both peak and annual); Limits on overall source energy use; Air-tightness and other prescriptive quality assurance requirements. PHIUS+ 2015 recognized that there are diminishing returns on investment in energy-conserving measures, and an optimum level in a life-cycle cost sense.

Climate plays a large role in determining where the point of diminishing return is. For PHIUS+ 2015, researchers studied optimization in 110 cities, and developed interpolation formulas to set heating and cooling (space-conditioning) energy targets for 1000+ cities across the US and Canada. The same criteria applied to buildings of all sizes. The probable changes under the current pilot release of PHIUS+ 2018, includes the space-conditioning targets which are less granular in terms of climate. Instead, these targets will be set by climate zone including the 17 climate zones referenced in the International Energy Conservation Code (IECC). Additionally, due to the impact of size and occupant density on the optimal path to a low energy building, the new space-conditioning criteria implement continuous adjustments for a range of different building sizes and occupant densities.

Today the PHIUS 2018 guidelines and certification requirements are the most notable use of passive building design in the US. According to PHIUS 2018 a passive building is designed and built in compliance with these five building-science principles:

1-Employs continuous insulation throughout its entire envelope without any thermal bridging.

2-Uses an extremely airtight envelope to prevent infiltration of outside air and loss of conditioned air.

3-Employs high-performance windows (typically triple-paned) and doors.

4-Uses some form of balanced heat- and moisture-recovery ventilation and a minimal space conditioning system.

5-Manages to exploit the sun's energy for heating purposes in the heating season and to minimize overheating during the cooling season.

2.3. Models and Approaches of Passive Building Design

In this section models and approaches used for designing passive systems or estimating their performance will be reviewed. In this process, the focus will be more on resources that are used in university education since the review can also demonstrate the level and content of the education about passive systems to architecture students. Such a review can be better linked with the findings of the research survey from educators in the field of passive design, which will be discussed in section 5. Additionally, the source books which are the focus of this review, in fact use the same design models that are also applied by professionals. Examples of these books include Mechanical and Electrical

Equipment for Buildings (Grondzik and Kwok, 2015), Heating, Cooling, and Lighting for Architects (Lechner,2009; Lechner, 2014), and The Building Environment Active and Passive Control Systems (2006). Meanwhile a wide range of other articles and online professional resources were used to enrich the content of the literature review.

2.3.1. Natural/Passive Heating of Buildings

Natural heating in buildings usually occur through solar radiation which in turn could lead to natural energy flows including radiation, conduction, and natural convection. These energy flows may directly or indirectly occur in the occupied space. On this basis, passive solar systems are divided into two broad categories of direct gain and indirect gain systems (Athienitis and Santamouris, 2013). The direct gain system would let sunlight into the space to warm up the exposed thermal mass surfaces, while in indirect gain system solar radiation first warms the thermal mass and then only heat is passed to the adjacent occupied space (Grondzik and Kwok, 2015). If in the indirect gain system, the heated space becomes insulated and separated from the system, then it may be called isolated gain system (Athienitis and Santamouris, 2013) such as in the case of sunspaces and greenhouses.

Athienitis and Santamouris have listed the basic principles that should be addressed by passive solar design techniques as follows (2013):

- Transmission and/or absorption of the maximum possible quantity of solar radiation during winter to minimize or reduce the heating energy consumption to zero
- Utilization of received solar gains to cover instantaneous heating load and storage of the remaining heat in embodied thermal mass or specialty built thermal mass storage devices
- Reduction of heat losses to the environment through the use of insulation and windows with high solar heat gain factors.
- Utilization of natural ventilation to transfer heat from hot to cool zones in winter
- Ground heating to transfer heat to/from the deep underground surface which stays at more or less a constant temperature
- Strategically planted deciduous trees or shading devices which allow solar gains in winter but would block them in summer
- Application of solar radiation for daylighting through effective distribution of daylight into the work plane
- Developing building integrated envelope devices such as windows with integrated photovoltaics (PV) for shading or roofs with PV integrated shingles to increase the cost-effectiveness of the system through dual energy roles (electricity production and thermal gain prevention)
- Integration of passive solar systems with active heating/cooling systems in the design and operation phases of a building

The authors maintain that the last principle is the most important one, which is usually overlooked due to lack of design integration and collaboration between architects applying qualitative passive solar design principles and mechanical engineers overestimating the HVAC system sizing by ignoring the passive solar design potentials. The key factors of passive solar design include the area, orientation, and type of fenestrations; amount of insulation; type location, and area of shading devices; and effective thermal storage area/amount which is insulated from outdoor and could be applied in two types (i.e. sensible heat storage such as in concrete materials or latent heat storage such as in phase change materials).

The following paragraphs explain about each of these systems and the advantages and issues of their application.

2.3.1.1. Natural/Passive Heating Design/Calculation

Grondzik and Kwok (2015) propose a detailed process for the design of a passive solar building which builds upon the method proposed by Stein and Reynolds (2000). Stein and Reynold's method, also explained by Grondzik and Kwok, can be explained in four steps. In their procedure, the first step is to consider a passive solar building's rate of heat loss compared to a conventional building. The reason is that there is no advantage in heating a leaky building no matter if it uses active or passive systems. Balcomb et al (1980) proposed a whole building heat loss criteria to check if the heat loss of a small passive building in early design phase is less than a conventional building heat loss rate.

The U value and area of each building envelope component is multiplied and added to find the UA of the envelope. For heat loss through infiltration the number of air change per hour (ACH) and a constant representing the density and specific heat of air can determine the UA of infiltration as follows:

ACH volume m3 × 0.33= UA infiltration (SI)

ACH volume ft3 × 0.018= UA infiltration (PI)

The UA results will be used in the equation below to determine the whole heat loss for a conventional building and its corresponding passive solar design.

(UA envelope + UA infiltration) × 24 h/ total heated floor area (ft2) =Btu / DD ft2

(UA envelope, except for south glass + UA infiltration) × 24 h/ total heated floor area (ft2) =Btu / DD ft2

An ACH of 0.75 is usually considered for a passive solar building, but with careful air barrier installation and crack sealing it can reach 0.33 ACH. By comparing the results from the last two equations and by using Table 2.8 one can determine if the passive design would work properly or not. Looking at the equations above there is a trade-off between higher solar heating energy and higher heating loss through infiltration since these two factors are very dependent on glass area and sealing. Additionally, a solar building has a higher indoor temperature swing compared to usual buildings.

In the second step, this design process estimates the solar saving fraction (SSF) which shows a building’s solar heating performance. The SSF is a comparison of the auxiliary energy that will be used by the solar building to the auxiliary energy of the reference building (Grondzik and Kwok, p. 301). Similar to Lechner's table (Table 2.9), Grondzik and Kwok through a table show the South Glass/Floor Area and the corresponding SSF ranges for glazing with both standard and superior performance as well as standard glazing with movable insulations.[16] It should be mentioned that there is no difference between direct, indirect, and isolated gain systems in this table. In this case, Lechner's table as he mentioned should be used only for double glazed windows without low-e, which limits its application (Lechner, 2015, p.174). Therefore, the table provided by Kwok and Grondzik seem to be applicable to a wider range of glazing materials.

Table 2.8 Overall heat loss criteria for passive solar design by Balcomb et al. (1980); SI conversion by Grondzik and Kwok (2015)

Maximum overall heat loss					
Annual heating degree days		**Btu/DDF ft2**		**W/DDK m2**	
(base 65 °F)	**(base 18 °C)**	**Conventional Buildings**	**Passively solar heated buildings excluding solar wall**	**Conventional Buildings**	**Passively solar heated buildings excluding solar wall**
<1000	<556	9	7.6	51	43
1000-3000	556-1667	8	6.6	45	37
3000-5000	1667-2778	7	5.6	40	32
5000-7000	2778-3889	6	4.6	34	26
>7000	>3889	5	3.6	28	20

---

[16] For further information, please see Table G.1 in MEEB Appendixes (2015)

Table 2.9 Rules for estimating optimum areas of south-facing glazing area for Trombe' wall and direct gains (Lechner, 2015)

Lechner's Climate Classification	Reference City	South-glazing area as a percentage of floor Area	Heating Load Contributed by Solar (SSF %)	
			Excluding night insulation	Including night insulation
1	Hartford, CT	35	19	64
2	Madison, WI	40	17	74
3	Indianapolis, IN	28	21	60
4	Salt Lake City, UT	26	39	72
5	Ely, NE	23	41	77
6	Medford, OR	24	32	60
7	Fresno, CA	17	46	65
8	Charleston, SC	14	41	59
9	Little Rock, AK	19	38	62
10	Knoxville, TN	18	33	56
11	Phoenix, AZ	12	60	75
12	Midland, TX	18	52	72
13	Fort Worth, TX	17	44	64
14	New Orleans, LA	11	46	61
15	Houston, TX	11	43	59
16	Miami, FL	2	48	54
17	Los Angeles, CA	9	58	72

In the third step, the amount of thermal mass area or its weight necessary to store daily solar heat admitted should be determined based on table G2.[17] As the SSF value

---

[17] This is table G.2 in the appendix of the book (Grondzik and Kwok, 2015).

increases, the area of the thermal mass becomes more important. One can see that less water surface area compared with masonry area is required for thermal mass due to higher thermal capacity of water, which can be utilized as a design advantage when there are space/area constraints in a building. The thermal mass area should be at least three times the glazing area. Masonry thermal mass beyond a depth of 4-6 inch is less thermally effective. Phase change material (PCM) could also be used as an alternative for massive thermal surfaces. Lechner proposes a table similar to Table 2.10 which provides similar information but also relates the thermal mass thickness to the ratio of surface area to glazing and includes PCMs materials. PCMs can store great quantities of heat with a phase change from solid to liquid. This change can be formulated to occur between 70-73 °F to prevent overheating of the space. PCMs work properly in climates with large daily temperature changes, and if applied as PCM tiles their area usually is one to three times the area of the solar opening (Johnson, 1981).

In the fourth step, the orientation of the proposed building should be studied which should be within 30° of south. Grondzik and Kwok, drawing on the Passive Solar Design Handbook (Balcomb et al., 1980) determine the average penalties for off-south orientation as follows:

- 5% decrease in SSF at 18° east or 30° west of true south
- 10% decrease in SSF at 28° east or 40° west of true south
- 20% decrease in SSF at 42° east or 54° west of true south

These four steps for passive heating design were also proposed earlier by Stein and Reynold (2000). However, all of these methods are in fact inspired by Balcomb et al. (1980) method for passive heating design.

Table 2.10 Design guidelines for passive solar thermal mass. From Balcomb et al. (1980) and Grondzik and Kwok (2015)

Expected SSF %	**Thermal Storage by Weight/Collector Area**				**Recommended Effective Thermal Storage Area Per Unit Area of Solar Collection Area**	
	Water		**Masonry**		**Water Surface Area** **Collector Surface Area**	**Masonry Surface Area** **Collector Surface Area**
	lb/ft2	**kg/m2**	**lb/ft2**	**kg/m2**		
10	6	29	30	147	0.1	0.7
20	12	59	60	293	0.2	1.5
30	18	88	90	440	0.3	2.2
40	24	117	120	586	0.4	2.9
50	30	147	150	733	0.5	3.7
60	36	176	180	879	0.6	4.4
70	42	205	210	1026	0.7	5.1
80	48	234	240	1172	0.8	5.9
90	54	264	270	1319	0.9	6.6

Table 2.11 Rules for Estimating Required Thermal Mass in Direct-Gain Systems (Lechner, 2015)

Thermal Mass	**Thickness in inches (cm)**	**Surface Area to Glazing Area Ratio**
Masonry or concrete exposed to direct solar radiation (dark color)	4–6 (10–15)	3
Masonry or concrete exposed to reflected solar radiation (light color)	2–4 (5–10)	6
Water exposed to direct solar radiation	6–12 (15–30)	About 1/2
Phase change material exposed to direct solar radiation	1–4 (2.4–10)	1

Grondzik and Kwok expand the method proposed by Stein and Reynold through a discussion on more detailed information of the applied passive design strategies including CLR and glazing performance. For this purpose, their focus is on worst hourly heat loss in buildings as a concept connected to the design of any building including a solar building. Since a solar building aims to provide part of a conventional heating need as much as it can, they continue the above four steps by calculating the worst hourly heat loss and comparing it with worst hourly heat loss for a solar building.

A conventional building heat loss calculation assumes no internal heat gains (lights, people, etc.), no solar gains for the indoor condition, and the design lowest temperature for the outdoor condition. A solar building heat loss assumptions are the same except for the inclusion of solar gains in the calculation. By adding heat transfer through building envelope's exposed components (q) and through air infiltration (qv) the total heat loss can be calculated. Equations below show this process. Δt shows the difference between indoor temperature and outdoor design temperature.

q total = $q + qv$, in which $q = (\Sigma UA)\Delta t$ and $qv = 1.1\ V\ \Delta t$ (PI units) $=1.2V\ \Delta t$ (SI units)

The worst hourly heat loss calculations can help in sizing the heating equipment for both conventional and solar buildings. It identifies opportunities for energy saving and better thermal comfort. For example, in the case of a high qv, inserting a heat exchanger between ingoing and outgoing air or educing mechanical ventilation rate can save on energy.

The hourly heat loss from a building also helps in estimating the hourly rate of fuel consumption thereby calculating the heating season fuel consumption.

Fuel consumption rate (gal/h) = Btu/h capacity or heat loss/ (heat value of fuel in Btu/gal × furnace efficiency)

A particular outdoor temperature called "balance point" defines the basis of calculating heating season fuel consumption. In balance point the heat lost through the building's skin and infiltration matches the heat gained through solar load plus internal loads. This point defines the temperature at which space heating/cooling is required and can be determined through the following equation:

$T_b=T_i -Qi/ UA_{total}$

T_b = balance point temperature

T_i = average interior temperature over 24 hours, winter

Q_i = internal gains + solar gains (Btu/h or W)

Q_{i} = internal gains (Btu/day)/24h + [January insolation (Btu/ft2 day average) × vertical south glass area]/24h

In skin-dominated buildings with SSF less than 10%, the above equations are applicable for calculating heating season fuel consumption. Since Qi at $\mathrm{T_b}$ *equals* q_{total} then Qi can also be estimated by combining the envelope/skin losses and the infiltration/ventilation losses. $\mathrm{T_b}$ is useful also to find the relative importance of heating versus cooling for a specific building and climate by plotting it on a graph of monthly outdoor temperatures.

Additionally, T_b of individual zones in a building can help understand how these zones interact in terms of the possibility of using one zone's surplus heating for heating another zone.

Using the concept of DD (degree days) an estimate of the average yearly heating fuel energy (E) is achievable through the following equation:

$E\ (kWh\ or\ Therm) = UA\ (\text{DD balance point})\ (\text{24h})/AFUE\ (V)$

In this equation UA is the total heat loss rate from envelope and infiltration in Btu/h°F, or W/°C); DD is based on the balance point; and $AFUE$ is the annual fuel utilization efficiency.

Thus far, besides calculation of worst hourly heat loss and annual heating fuel consumption, passive solar heating was based on the concept of SSF which distinguishes only between standard and superior system performance. Grondzik and Kwok, drawing on passive solar heating analysis by Balcomb et al. (1984), introduce the concept of LCR (Load Collector Ratio) as a more detailed approach through 9 steps for calculating annual SSF and auxiliary energy needs in solar building design. These steps include:

1. Finding a location from a reference table closest to the design site
2. Selecting a tentative size for the solar opening based on ventilation, daylighting, and SSF design guideline

3. Calculating the rate of heat loss through building envelope and infiltration, which excludes the southern solar opening (UA_{ns}), to determine the Building Load Coefficient (BLC): $UA_{ns} \times 24$ h = BLC (Btu/DD)
4. Dividing BLC by floor area as Btu/DD ft=BLC/floor area (ft) and comparing it with Table p3 to determine the poor or proper solar performance of the building. The result can reveal if you need design changes such as increased insulation, reduced infiltration, or reduced non-south glazing areas
5. Find the vertical projection of the solar opening (A_P)
6. Find the LCR as Btu/DD ft2 through BLC/ A_P
7. According to the found LCR, consult a reference table for the desired passive system (i.e. direct, isolated, indirect gain systems) close to your design idea and location. This step gives you the annual SSF from the reference table.[18]
8. Use the following equation to determine the annual auxiliary heat:
   $Q =(1-SSF) \times BLC \times DD$
9. Compare the design guideline predicted relationship between collector size and SSF to the actual one calculated. If the SSF is smaller, by decreasing BLC (improve conservation), increasing the collector size, or choosing another passive system with a better SSF for the same LCR. If the SSF is larger, then the decision will be between selecting more fuel savings, smaller collector size, or a less-efficient passive system with other architectural design advantages.

---

[18] Table I.3 in the MEEB Appendices (Grondizk and Kwok, 2015).

2.3.1.2. Direct Natural/Passive Solar Gain systems

A building with south facing glazing surfaces could simply be a direct gain system. Solar radiation will hit the thermal mass of the interior space components, such as walls, floors, and furniture, which directly receives much of this incoming radiation as heat. The minimum thickness of the thermal mass is 4 inches and its area should be three times the area of the south facing glass to keep the space from overheating during sunny hours (Grondzik and Kwok, 2015). Following outdoor temperature changes, a low-mass passive solar building experiences a wider span of indoor temperature swing while a high-mass passive solar building will experience a smaller indoor temperature swing (Lechner, 2015). The solar scientist Doug Balcomb has said that “orientation is 80% of passive solar design” which signifies the importance of building orientation in direct gain system (Lechner, 2009, p.147).

The key factors in the design of a direct gain system include window type, glazing area, and thermal mass quantity (Athienitis and Santamouris, 2013). AS explained in the previous section, Lechner after dividing US and Canada into 17 climatic regions proposes two tables for the design of a direct gain system (2015): one for estimating optimum areas of south-facing glazing (Table 2.9) and one for estimating required thermal mass quantities (Table 2.11).

The main advantage of a direct gain system is its simplicity for implementation. The solar energy is directly absorbed through a room’s thermal mass and will be distributed through convection/conduction. No heat transfer medium is required which in turn will reduce the heat loss through removing any inefficient heat transfer medium from the system. Based on Table o3 a direct gain system can contribute from 19% up to 72% to energy savings during winter. The system requires large amount of interior thermal mass to absorb solar radiation in winter, and therefore, it will also work effectively in most climates in summer to cool the building through night ventilation with thermal mass. Examples of the drawbacks in using direct gain systems include overheating and glare on sunny days, large amount of radiant heat loss at night toward the glazing area and sky, change of the color of the interior materials, and fading of the furniture exposed to direct sunlight.

2.3.1.3. Indirect and Isolated Natural/Passive Solar Gain Systems

In addition to direct gain solar systems, which use the direct sunlight to heat the interior of a building or utilizes the roofs, walls, or floors to store the heat, indirect and isolated solar are the other two solar energy gain systems, indirect and isolated solar gain systems can have a variety of types. The indirect solar gain systems manly include Trombe' walls with water and their variations, Trombe' walls without water and their variations, and transpired solar wall system. Trombe' walls are thermally more stable with less diurnal temperature swing. Many of other passive systems such as solar chimney or glass double-skin facades use the same mechanism of the Trombe' wall to heat or cool their adjacent zones. Therefore, the current review will be more exhaustive of Trombe' walls compared to other passive systems.

Cleanliness of the space near the Trombe' wall's solar-gain surface, and loss of view and daylight could be the most significant challenges of using Trombe' walls. Since they transfer heat mostly through radiation, there should not be an object to intercept this process within the occupied living space. Because of the stack effect in ventilation, the vented Trombe' wall deliver warmer air sooner than an identical Trombe' wall which is unvented. The vented Trombe' wall is also more efficient because it does not lose the heat trapped between the thermal mass and glass through thermal connection with the outdoor environment.

Table 2.12 Comparison of glass and plastic as the exterior surface in a Trombe' wall

Glass	**Plastic**
Advantages: 1. Excellent transmissivity (above 90%) 2.Superior thermal stability (Up to 400 F) 3.Low thermal contraction/Expansion 4.Resistant to abrasions(wear and tear)	**Advantages:** 1. Reasonable transmissivity (above 85%) 2.Superior weather conditions 3.Light weight (compared to glass) 4.High impact resistance
Disadvantage: 1. Low impact resistance 2 .cost	**Disadvantages:** 1. Susceptible to abrasions 2.High thermal contraction/absorption Examples: Polycarbonates, fluorocarbons, and polyvinyl fluorides

The performance of the glazing material of a Trombe' wall is also important for the Trombe' wall whole performance. The glazing surface should be able to trap heat from the incoming solar radiation; should allow maximum transmission of solar (short wave) radiation; should keep heat loss to a minimum by preventing long-wave transmission;

and should possess good thermal stability. The glazing surface could be even made of plastic which has its own advantages and disadvantages as shows in Table 2.12.

Two important design considerations in a Trombe' wall include preventing the reverse airflow process at night and overheating during daytime. This consideration can be implemented by including seasonal switches at the top of the wall, which even can provide building ventilation via the Trombe' wall in summer. Avoiding overheating of the space can be achieved through an appropriate design of a shading device to block the sunlight in summer, but not in winter, from reaching the Trombe' wall (Gan, 1998). Table 2.13 shows several examples of indirect solar gain systems and their features, particularly Trombe' walls.

Table 2.13 Several examples of indirect solar gain systems and their features, particularly Trombe' walls

Type of The Passive Heating System	**Features of the System**	**Reference**
Vented Trombe' wall	-Vents on the upper and lower side of the wall provides direct connection between air gap and living space to increase heat transfer in day times. -Assists the natural ventilation during summer. -Provides winter ventilation by warmed air: thermo-circulation.	(Jaber, 2011)
Non-vented Trombe' wall	-The heating energy is stored in thermal mass during daytime to be radiated/conducted into the living space. -There is no direct convection of air between air gap and living space. -Could be suitable for homes where thermal storage is required for night heating.	(Saadatian, 2012)

Table 2.13 Continued

Type of The Passive Heating System	**Features of the System**	**Reference**
Zigzag Trombe' Wall	-Designed to reduce the excessive heat gain and glare of sunny days. -Its walls should face three directions: -South: to perform as a Trombe' wall system -Southeast: to provide heat and light in the cold morning when immediate heating is required - Southwest to store heat for redistribution during the cold night hours	(Saadatian, 2012)
Insulated-Trombe' Wall	-Includes a transparent outer cover, an enclosed air layer, a storage wall, a ventilated air layer, and finally an insulation layer in which two vents have been drilled. -Traps the majority of the gained solar beams through the glazing; this energy transfers into the room by radiation and convection through the ventilated channel. -Solves two deficiencies of typical Trombe' walls:(1) heat loss during cloudy winter days and nights; (2) avoids unwanted heat inputs in hot weather conditions. -Good heat resistance due to the presence of the insulation layer and the air layers -Little infiltration of cool air through the outside cover -Users can control the rate of heating by controlling the airflow into the ventilated channel -Requires a mechanism to prevent reverse thermo-circulation, which occurs when the storage wall becomes colder than the ambient air of the building's internal space -The insulation material is heated up slowly, and at night the heat stored in the heat storage cannot be effectively supplied to heat the room	(Zalewski, 2002)
Porous Trombe' wall	-From outside to the inside of the room includes a glass cover, an air gap, a porous absorber, an air flow channel, and a thermal mass wall with vents at the top and bottom of the wall. -Solar radiation, absorbed by the porous layer, is used to raise the air temperature and the temperature of the thermal storage wall. -During the heating period, the surface of the porous absorber has a comparatively higher temperature -When solar radiation is not available, as the heat has already been stored in the massive thermal storage wall, the porous layer could serve as an insulated layer. - The porous Trombe' wall can prevent overheating in hot days; reduce heat loss at nights and winter days; absorb more heat; perform as a semi-thermal insulator when solar radiation is not available; reduce the convection of the thermal storage wall and outside environment	(Chen and Liu, 2004)

Table 2.13 Continued

Type of The Passive Heating System	**Features of the System**	**Reference**
Transpired Solar Wall	-Uses a perforated steel skin with prefinished treatment to enhance its absorbance of solar energy - An air cavity is created between the metal skin and the wall/roof surface - The heat in the system comes mainly from three sources including: the exterior surrounding areas of perforations, the edges of the perforations, which heat up the passing air, and the cavity-facing side of the steel skin - Can also have a summer by-pass vent on the top to let the hot air out in summer - has a low maintenance/operation costs and a long life span	(NREL, 2019; Van Decker et al., 2001; Kutscher, 1994)
Fluidized Trombe' wall system	-Works based on the classic Trombe' wall but the gap between the Trombe' wall and glazing is filled with a highly absorbent, low-density fluid. -A fan transfers the solar energy gained by the absorptive fluid by moving the heated air to the room.	(Tunc and Uysal, 1991)
Trombe'–Michell wall	-Is similar to vented Trombe' wall, but designed for cold climatic conditions has a steel panel backed with polystyrene	(Chan et al., 2010)
Trans Wall	-Is built on a metal frame that holds a water container constructed from glass walls and a semi-transparent absorbing plate positioned between the walls -Partially absorbs and partially transmits the solar radiation -Combines features of direct gain and indirect gain -Suitable for location where daytime temperature is high Advantage: -Installation of transparent baffles overcomes this deficiency of convective heat transfer. -Rapid heat transfer due to convective heat transfer through water and direct heat gain -Reduced heat loss as most of the solar radiation is absorbed in center (through absorber) and close to/at the living space by direct gain, heat loss to ambient air is less. -It allows the visual transmission thereby reducing the lighting load (during day times). Disadvantage: -The transmission of light through water may cause glare. -There may be a problem of overheating due to direct gain in day times -Inefficient for night heating since time/phase shift between heat flux and solar flux.	(Saadatian, 2012)

Table 2.13 Continued

Type of The Passive Heating System	**Features of the System**	**Reference**
PV-integrated Trombe' Wall	- Is constructed by attaching the PV cells to the back of a glass panel -The thermal energy on the surface of PV cells is removed by the air flow between the glass panel and the wall. Therefore, the temperature of PV cells decreases and the PV system efficiency in producing electricity increases. -The PV-Trombe' wall could be considered an aesthetic approach in designing Trombe' walls	(Jie 2007)
Solar wall	-Similar to Trombe' wall, consists of glass cover, air gap, black metallic plate, and insulator - Its temperatures increase with increased wall height and decreased gap. - In very hot season, providing residents' comfort is insufficient by natural ventilation but it is able to reduce the heat gains which in turn reduces the cooling load.	(Hirunlabh et al., 1999)
Solar chimney	-Works similar to Trombe' wall systems - Solar radiation increases temperature rises and air velocities -Temperature rise decreases with air gap depth -No reverse air flow circulation has been observed even at a large gap of 0.3 m. - Solar chimney can also reduce indoor temperature by 1.0–3.5 C compared to the ambient temperature of 32–40 C. - Indoor temperature can be further reduced by 2.0–6.2 8C with combination of spraying of water on the roof.	(Ong and Chow, 2003; Chungloo and
Single-sided heated solar chimney	-Adjacent walls are insulated. -The optimized height can be determined according to the optimized section ratio of breath to height and available practical field conditions.	Limmeechokchai, 2007)

Table 2.13 Several examples of indirect solar gain systems and their features, particularly Trombe' walls (continued)

Table 2.13 Continued

Type of The Passive Heating System	Features of the System	Reference
Water wall or water Trombe' wall	-The structure includes water contained in drums/pipes as a storage medium. -Water (0.55 w/m K) has lower thermal conductivity compared to brick (0.77 w/m K) -The water Trombe' wall transfers the heat into the room through radiation -A Drum water wall system with a thin concrete layer behind it can have a higher efficiency, since this insulated film increases the wall's efficiency. Advantage: -higher specific heat capacity compared to normal brick wall -due to convection process in water the transfer of heat to the interior space occurs faster than classic Trombe' walls without water Disadvantage: -the wall thickness/volume increases for the given amount of storage requirement -difficulty in containment and maintenance of liquids such as water compared with masonry materials	(Li et al., 2004)

Transpired solar wall systems is one of these systems which is made of a perforated steel skin with prefinished treatment to enhance its absorbance of solar energy. The steel skins will be installed on south-facing walls or roofs to create a cavity between the metal skin and the wall/roof surface areas. The exterior area surrounding perforations on the face of the steel skin heats up the air before it is drawn through the perforations (Kutscher, 1994). The heat in the system comes mainly from three sources including: the exterior surrounding areas of perforations, the edges of the perforations, which heat up the passing air, and the cavity facing side of the steel skin (Van Decker et al., 2001). Similar to the vent switches described in the Trombe' wall, the transpired wall can also have a summer by-pass vent on the top to let the hot air out in summer. In this case, the system works similar to a solar chimney to cool the building by intensifying the buoyancy effect.

The low maintenance/operation costs and a long life span can make transpired solar walls more favorable choices, particularly for commercial buildings (NREL, 2019). Additionally, on the wall that the transpired solar system is installed the steel skin can block the interior heat loss and return it with the hot air provided within the cavity back to the building. This system operates usually in combination with a fan or HVAC system to reduce the energy required for heating the air before blowing it to the adjacent zones. The air cavity with hot air behind the steel skin also reduces heating requirements by providing an extra layer of insulation.

Another type of Trombe' wall include water walls, which can have different variations based on the type/content of the water containers applied in the wall. The containers should have space for water expansion and in the case of using steel containers they should be treated with rust inhibiting materials. Preventing the growth of algae in water due to daylight passing through immovable water is another design consideration in water walls. Algaecide is one solution to consider in this case. In some cases, the container might be painted black on the exterior face to better absorb short-wave solar radiation.

Although roof ponds are usually sized for their summer cooling effects, they can also be used as an indirect gain system similar to water walls. The difference is their locations on rooftops which can prevent the installation of skylights and roof monitors. This system is more applicable in southern less humid and warm climates of the US, because higher sun altitude during daytime and lack of snow facilitate the absorption of sun radiation and movements of roof insulation panels. For roof pounds with double glazed cover and movable night insulation panels Mazria (1979) recommends roof pond area about 85% to 100% of floor area for 25° to 35°F winter average outdoor temperatures (−4° to +2°C) and 60% to 90% of floor area for 35° to 45°F winter average outdoor temperatures (2 to 7°C).

The time lag for heat transfer from outside to the occupied space is an important design consideration in indirect gain systems. Time lag could be the result of material and thickness of the tombe wall. For example, a 12 inch Trombe' wall made of stone can delay the arrival of maximum solar gain to the interior about 8 hours (Olgay, 1963).

Isolated gain systems are usually in the form of sunspace or greenhouses in buildings. These systems are called isolated systems because they can store and isolate the solar energy from adjacent living spaces to be used when needed. Isolated systems can also be in the form of unoccupied storage spaces to integrate with direct gain systems. One example is the rock beds usually placed directly beneath a concrete floor slab to store the additional generated heat in a direct gain system. The disadvantage of rock beds below grade includes potential mold growth due to condensation or groundwater surfaces and difficulty in cleaning such locations. According to Mazria (1979) Rock bed volume (ft3) per ft2 of solar opening is ¾ to 1½ in cold climates and 1½ to 3 in temperate climates. If the rock bed surface area is in contact with the floor above then its recommended area is 75% to 100% of floor area above in cold climates, and 50% to 75% in temperate climates (Grondzik and Kwok, 2015).

The heat stored in a sunspace can be transferred to living spaces next to it through immediate doors and windows. However, a common wall between the sunspace and living space can provide a better control over comfort condition in the living space. Both masonry and insulated common wall sunspace system should include top and bottom vents with 8ft distance from each other and area of about 3% of the common wall for thermos-circulation (Grondzik and Kwok, 2015). Sunspaces should have a thermally massive, perimeter-insulated slab on grade floor. The shape of the sunspace rather than its dimensions influences the sunspace performance.

2.3.1.4. Temperature Swing in Passive Heating Design

Temperature swing and the extent that indoor temperature will be higher than outdoor temperature on a clear winter day (Δt solar) are of high importance to a passive solar design. Δt solar can be approximated from reference graphs in relation to LCR and latitude of a design site (Balcomb et al., 1980).

After finding the Δt internal from the below equation, the winter indoor temperature can be determined by adding up the average January outdoor temperature, Δt internal from heat gains, and Δt solar:

Δt internal= total internal gains (Btu/day) / BLC+ (UA_s × 24)

In this equation UA_s is for the solar area only. Usually Δt internal is 5-7 F for residential buildings. Δt swing can be determined based on Δt solar and Table 2.14 (Balcom et al., 1980; Grondzik and Kwok, 2015).

Table 2.14 Indoor Δt swing based on 45 Btu/ft2F thermal storage mass capacity (Balcomb et al., 1980; Grondzik and Kwok, 2015)

Passive solar system	**Δt swing**
Direct gain system with mass to glass area ratio of 1.5	1.11 × Δt solar
Direct gain system with mass to glass area ratio of 3	0.74 × Δt solar
Direct gain system with mass to glass area ratio of 9	0.37 × Δt solar
Water wall	0.39 × Δt solar
Trombe' wall vented for 3% of wall area	0.65 × Δt solar
Trombe' wall unvented	0.13 × Δt solar

It seems that our bodies are so used to the limited span of temperature swing and comfort condition provided by modern day mechanical systems that it is difficult to accept the passive systems' temperature swings anymore. Therefore, calculation of temperature swings in a passive solar building and its impact on the occupants' comfort range of temperature is of high importance in the design and implementation of a solar building.

2.3.2. Natural/Passive Cooling and Natural Ventilation

The extent of design strategies for natural cooling of buildings is more diverse compared to natural heating. The general approach for the adoption of passive cooling design strategies begin with plotting the average monthly data on the building bioclimatic chart (Figure 2.3) prepared by Milne and Givoni (1979). The maximum and minimum dry bulb temperature and their corresponding relative humidity will be plotted on the chart with a line connecting these two points. Each zone for the four passive cooling design strategies covering the line can be a potential cooling design strategy.

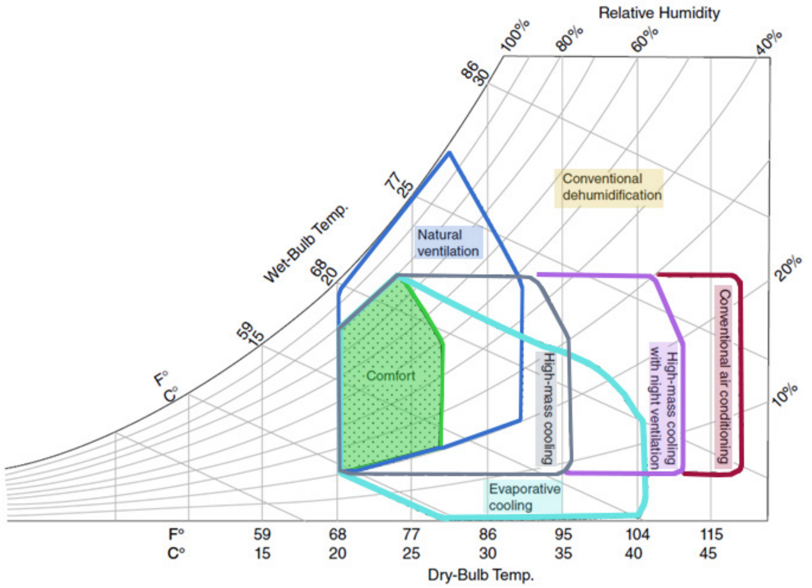


Figure 2.3 Passive cooling strategies on a building bioclimatic chart (adapted from Milne and Givoni, 1979; Kwok and Grondzik, 2015)

Also locating a point on this chart corresponding to the summer DB and mean coincident WB temperature, based on the available climate data, can reveal the applicable cooling design strategies. The boundaries of the proposed strategies in this chart can vary to some extent based on different factors such as physiological, behavioral, and cultural factors. Today software programs such as Climate Consultant tailor this chart to each climate with potential passive cooling and heating design strategies. One example of using this software along with potential passive cooling/heating design strategies is shown in Figure 2.4 for Las Vegas, Nevada.

The rest of this section will briefly review different passive/natural cooling strategies:

Cross ventilation is a well-known natural cooling strategy which also provides fresh air and if needed can help increase the rate of air changes per hour at no cost. Grondzik and Kwok through a reference graph chart explain how the inlet area as a percentage of total floor area is related to wind speed and heat removal capacity in cross ventilation (Grondzik and Kwok, 2015, p.344). The graph assumptions include: 3F° (1.7C°) internal temperature above the exterior temperature(Δt), a wind direction not quite perpendicular to the openings, and a wind effectiveness factor of 0.4. On this basis, for an inlet area which is between 0 to 15% of the floor area and for a wind speed between 0 to 15 mph, the cross ventilation capacity can vary from 15 to 150 Btu/ ft2-hr. A key factor in cross ventilation design is to have outlet openings equal or larger than the inlet. The same can be said for internal partitions. If the temperature difference of more than 3F was found appropriate then the actual percentage of inlet area can be determined by multiplying the percentage found from the mentioned graph with the ratio of 3F°/ Δt.

Stack ventilation, or gravity ventilation, similar to cross-ventilation is related to stack inlet area as a percentage of total floor area. The stack height also impacts the ventilation capacity. These relationships can be shown on a similar chart for a 3F° differential when indoor temperature is 83°F and an exterior temperature is 80°F (Grondzik and Kwok, 2015, p.344). Accordingly, for a stack area of 0 to 30% of the floor area and for 0 to 50 ft stack height difference the stack ventilation heat removal capacity can vary from 15 Btu/ ft2-hr to 75 Btu/ ft2-hr. For a higher temperature difference the same multiplying ratio of 3F°/Δt is applicable. A good example of stack ventilation is solar chimney which was also shown in the table Trombe'-1 for passive heating systems. The reason is that gravity ventilation works based on thermal buoyancy effect. Therefore, when it is used for connecting an air inlet in lower levels to heat the air through the chimney, before reaching to the diffusers in upper level floors, it can be a heating system. The solar chimney performs as a cooling system when through the buoyancy effect it exhausts the hot air from an outlet to be replaced by the cold air from the surrounding inlet vents/openings.

The rate of air circulation is a dependent of air temperature, height difference between the inlet/outlet vents (H), and areas of the vent (Bradshaw, 2006): $Q= 9.4\ A\ (H.\Delta T)^{1/2}$

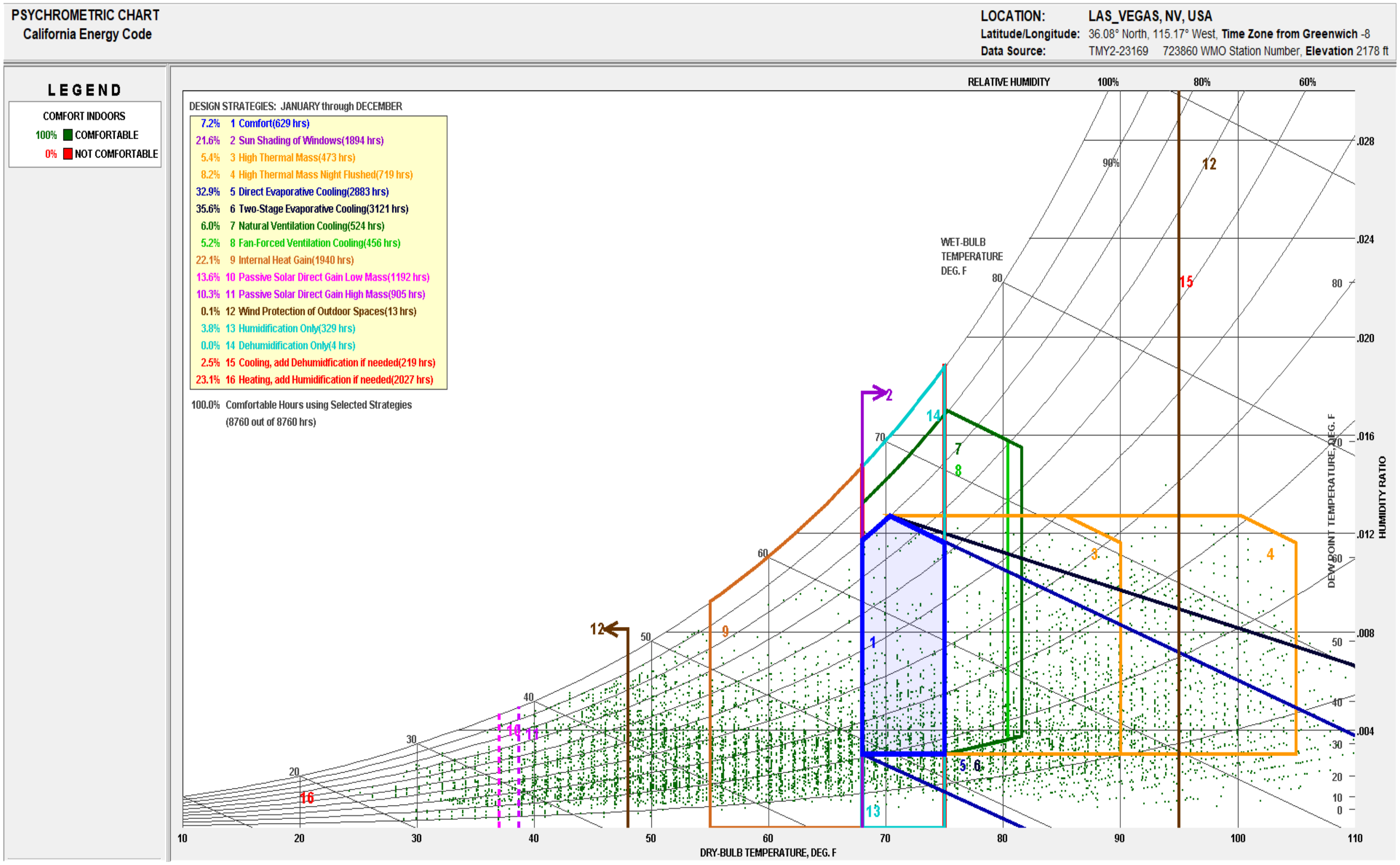


Figure 2.4 Passive cooling and heating design strategies for Las Vegas, Nevada using Climate Consultant

Q is the air flow rate in CFM (L/sec), A is the smaller free area of the inlet or outlet vents ft2 (m2), ΔT is the temperature difference between in incoming and outgoing air F (C), and 9.4 is a proportionality constant (116 for SI units). For effective stack ventilation the outlet area and its cross-sectional passage area should be at least equal to the inlet area. The air inlet should be located as low as possible in areas with lower temperature such as on the north side of the building (Bradshaw, 2006).

The airflow induced by stack effect has also been expressed through the equation below (Iyengar,2015): $Q_{stack}=Cd \times A \times (2gh \times \Delta T/T_i)^{1/2}$

Q_{stack} is the ventilation rate (m3/s), Cd equals 0.65 as a discharge coefficient, g is the gravity acceleration (9.8 m/s2), A is the smaller free inlet/outlet opening, h is the height difference between the inlet and outlet midpoints (m), ΔT is the difference between average indoor and outdoor temperatures (K), and T_i is the average indoor temperature (K).

Natural ventilation without thermal mass could be the only dependable natural cooling approach in hot and humid climates as the temperature difference between day and night is not considerable due to high relative humidity. The thermal mass is not required in such climates and the building should be made of lightweight materials because the night breeze is not cool enough to remove the heat stored during the daytime. This strategy can be a type of cross ventilation but it occurs during night time when the wind is cool enough to remove the heat from a building.

Natural ventilation with thermal mass or night flushing can be used in climates that night time temperature falls below comfort zone to store coolth through natural ventilation in the thermal mass of the building. The thermal mass will act as a heat sink compared to the indoor condition of the building during daytime until it becomes warm gradually when the night arrives to repeat the storage of coolth. Since night time hours are less than daytime hours in summer the ventilation should occur quickly at night to make the thermal mass cool enough for application during the day. In this case the night purge (night flushing) could be assisted with fans to expedite the wind speed at night which is usually lower than wind speed in daytime.

Courtyard has been a long-established natural cooling strategy in vernacular buildings which is also used in contemporary building typologies. In climates with warm dry summers this strategy, in combination with high thermal mass, is very effective. The thermal mass of the floors/walls and the courtyard with open windows will store the coolth during night time when the temperature is much lower than daytime. During the day the windows are closed to keep the heat outside and the stored coolth inside the building. The high thermal mass of the building will delay the heat transfer through the envelope until night time when again the temperature is low. In some places the courtyard might be covered with movable shading devices during daytime that can be opened to sky for night time radiation.

Evaporative cooling is a useful strategy in hot and dry climates where adding humidity to the air is a necessity to reduce the air dryness while reducing the dry bulb air temperature. In this case the water added to the air will bring a point on a bioclimatic chart to left along the constant wet bulb temperature. Evaporative cooling might be applied to a hot dry condition through different designs and devices such as wind blowing over a pool or wind blowing through wetted vegetation. In some cases, a fan might be used to blow through a moistened material which is being constantly wetted with water to introduce moist cool air into an occupied space. This fan driven cooling is usually seen in evaporative coolers which is more an active design strategy than passive.

Radiant cooling is a natural cooling strategy in which radiation from a heat source to a heat sink can occur directly or indirectly to reduce the temperature of the heat source. The direct radiant cooling occurs through radiation of a building's envelope components, in particular its roof and yard, to the night sky. If a medium such as a heat transfer fluid is added to this system, the fluid will cool down by radiating the heat back to sky which in a next step can also cool the building. This cooling process is called indirect radiant cooling (Lechner, 2015).

Roof ponds which were explained in passive heating systems can also cool a building through the use of passive radiant cooling method in summer. During summer nights, roof ponds lose heat through heat radiating to sky since the sky becomes a heat sink with lower temperature. During daytime, roof ponds are covered with an insulation layer to avoid sun exposure and to be used as a heat sink for the indoor environment. In winter, roof ponds work similar to Trombe' walls with the additional capacity of storing heat to be used later at night. During daytime in winter roof pond is exposed to sunlight, but at night an insulation layer covers the roof pond to avoid losing its heat through sky radiation. Due to cosine law this system works better for non-flat roofs and in latitudes below 30°. Roof ponds can have different configurations as shown in Table 2.15 (Sharifi and Yamagata, 2015).

Table 2.15 Different types of roof ponds in the literature (Sharifi and Yamagata, 2015)

Type	Sub-type
Open roof ponds	Open pond with sprays Open pond without sprays
Roof ponds with movable insulation (covered daytime)	Pond with continuous spray Pond with nighttime spray Pond without spray Skytherm
Roof pond with floating insulation	Energy roof (Roof pond with floating insulation) Cool roof
Walkable roof ponds	-Roof pond with insulation embedded within the pond -Walkable roof pond with night water circulation
Roof ponds with gunny bags	-Roof pond with wet gunny bags -Shaded roof pond with wet gunny bags
Shaded roof ponds	-Shaded pond with water enclosed in watertight bags -Shaded pond with water spray -Shaded pond without water spray -Cool-pool
Ventilated roof ponds	-
Closed roof ponds	-Evapo-reflective roof pond -Roof pond with additional insulation layer

Earth contact can increase the coolth of a building in summer as in earth sheltered buildings. Solar radiation will be blocked and temperature swing will be dampened due to a more stable temperature and high-mass cooling of the earthen material. The earth contact can directly or indirectly be used as a natural cooling strategy. In direct contact with earth a building can lose heat directly to the earth while in indirect contact the air passing through an earth tube reaches lower temperature before entering the building. In some cases, for this strategy the term earth coupling has been used instead of earth contact (Lechner, 2014).

Green roofs similar to soil materials in earth sheltering create an insulation layer on rooftops, reduce ambient air temperatures, and decrease building energy consumption. Green roofs besides reducing energy consumption provide water retention, green space, and improved water and air quality. Up to 30% of nitrogen and phosphorus released into receiving waterways come from the accumulated dust on rooftops. Acting as natural bio-filtration materials, green roofs can also reduce this water contamination (WBDG, 2017).

Green roofs may be implemented in three different categories from extensive green roofs with 2.5”-8” thickness to semi-intensive green roofs with 4.5”-10” thickness and intensive green roofs with 6”-39” thickness. The level of maintenance and the depth of vegetation’s roots increase with the increase of the green roof thickness (Palette 2030, 2018).

Green roofs reduce their ambient temperatures, since grass and vegetation absorb part of the solar radiation for photosynthesis. In an experiment the temperatures of five ground covering materials were measured at 10 am and 2 pm on the campus of Frostburg State University in Maryland. The results showed the lowest temperature for grass surfaces. Rankings from coolest to hottest surfaces included: grass surface, concrete surface, brick surface, filed track surface, asphalt surface, and Astroturf surface. In another experiment summertime data recorded showed significantly lower peak roof surface temperatures and higher nighttime surface temperatures for the green roof. The maximum average day temperature for the green roof surface in this experiment was 91°F (33°C), or 39°F (22°C) lower than the conventional roof surface temperature (Sonne, 2006).

While vegetation on green roofs reduces the ambient temperature, there are some discussions about green roofs' effectiveness compared with roof insulation materials (Lstiburek, 2011). The same comparison between reflective membranes on rooftops and green roofs may indicate that green roofs are not necessarily the least expensive and most efficient passive cooling strategies available (Lstiburek, 2011).

Shading: shading a building from direct and diffuse sunlight can considerably reduce the cooling load of a building. With the same logic if the shading design is not properly matched with the location/latitude of the site it can considerably increase the heating load of a building. For example, any fixed overhang deep enough to shade a southern window during the overheating season can also shade the window more than needed during the under-heated period (Lechner, 2014). In this case blocking the direct and reflected sunlight in hot and dry climates and blocking the diffuse radiation in hot and humid climates are important.

Therefore, a variety of shading devices may be more appropriate in different climates. For example, removable overhangs are more useful in hot and dry climates to block the direct sunlight when needed, while different types of louver systems in hot and humid climate may better block the diffuse radiation and allow the direct sunlight when needed. Use of deciduous and evergreen plants is another possibility to consider for shading. Particularly when a shading device needs to be removable in winter to allow for harvesting the direct solar radiation, deciduous trees if planted in the right place may better fulfil this requirement.

The orientation of a building façade can also determine which shading device should be selected. Typically fixed shading devices can be in the form of vertical fins, horizontal fins, or their combination as in the case of eggcrate shading devices. Vertical fins are more appropriate for eastern and western sides of a building while horizontal shading devices are more usable on the southern face to avoid under-heating or low level of daylighting. The overhangs and fins in some cases may be slanted to better shade the windows in overheating period. Proper design of a shading device needs the sun path of a certain location and then reflecting the performance of the shading device on the sun path. Lechner has discussed the procedure for such a design (Lechner, 2009, p.228).

Lechner has provided several tables for the design of shading devices in different latitude of the US and for both skin dominated and internal load dominated buildings (Lechner, 2009, p230-p236). Table 2.16 is one example showing the relationship of the angle between the projected shade line and the normal vector on the east/west façade of a building in plan (Angle D) and the latitude of the building. Use of this angle for slanting the vertical fins on east/west of a building towards the north can provide shade from the direct sunlight for the whole year between 7 AM and 5 PM (Lechner, 2009, P.236).

Table 2.16 Table for vertical fins slanted to the north and installed on east/west façade (Lechner, 2009)

Latitude	**Angle D**
24	18
28	15
32	12
36	10
40	9
44	8
48	7

The location of installing a shading device as being an interior or exterior device can also change the energy performance of building. Interior shading devices such as louver systems can cause heat built up between the louvers and the glazing inside the building thereby increasing the cooling load. However, installing the same louver system outside as an exterior shading system can resolve this issue. In this case, other design factors such as exposure of the louver slats to the outdoor weather condition and durability of the system should be considered in selecting between an interior or exterior shading system.

With the advance of the technology, dynamic shading devices have emerged which in fact are integrated parts of building components. A case in point are windows with electrochromic shade or sensor control. In electrochromic windows materials change color or switch from transparent to opaque through the application of an electric voltage. A blue electrochromic window glazing can gradually become transparent over a few minutes when the electric current passes through it. Such smart windows can considerably save on a building's total energy consumption. In a building performance simulation, the electrochromic windows reduced electricity consumption for cooling by 49%; reduced the peak electrical demand by16%; and lowered the lighting costs by 51% (Verrengia, 2010). A drawback of these glazing systems is their cost which is currently several times more expensive than the usual type of glazing materials.[19] Additionally, the durability of the electrochromic materials are questionable.

Finally, it should be kept in mind that shading a building is not only a matter of design for energy and comfort, but also is a matter of integration with other design factors such as visual comfort and architectural aesthetics. Double roof as a passive cooling design

---

[19] A single large smart window typically comes in at around $500–1000 dollars (about $50–100 per square foot). For further information, please see https://www.explainthatstuff.com/electrochromic-windows.html accessed December 2018.

strategy in hot climates is one example, which can be used to not only shade a building but also to add to the formal features of a building through a floating structure above the actual occupied building. In this case, the second roof structure located immediately above the actual roof shades the roof. This structure allows the buildup warm air between the roof and the structure to escape through the air cavity through natural ventilation. This structure can also become a design opportunity to integrate the cooling function with formal aesthetics. In hot climates direct sunlight is the major cause of increased building cooling load, and therefore, shading a roof as the major recipient of direct sunlight in a building will reduce cooling requirements (Palette 2030, 2018). The extend roofline can shade exterior walls, and cross ventilation or ridge vents can ventilate the air cavity between the roofs.

Downdraft cooling strategies usually are based on the evaporation of water at the top of a cooling tower to create a downdraft of cooled air for circulation inside a building. The increased moisture density of the air at the top of the cooling tower along with the force of the desired winds will push the air down the tower to replace the stale warm air, which is sometimes exhausted through the tower because of a solar chimney effect. The amount of cool air from the tower depends on the outdoor humidity, tower height, and the amount of evaporated water (Palette 2030, 2018). The general rule of thumb in designing a cooling tower is to consider its height at least two times the height of the building with a cross-sectional area of about 33 ft2 (3 m2) for residential buildings and 64 ft2 (6 m2) for commercial buildings. The outlet opening should be as large as the cross-section of the cooling tower. As the height of the tower increases the amount of its air delivery increases as well (Palette 2030, 2018; Givoni,1994).

The airflow of a cooling tower can be predicted through the equation below:

Vwind= KAV

Vwind is the volume of airflow (m3/h), K is a constant as the coefficient of effectiveness, A is the area of smaller opening (m2), and V is the outdoor wind speed (mph). K depends on the angle of the wind and the relative size of inlet/outlet openings: it varies from 0.4 for wind blowing at a 45° angle of incidence at the inlet to 0.8 for wind blowing directly at 90° (Iyengar, 2015).

To conclude the review of passive cooling design strategies and to have a flow of decision making, Grondzik and Kwok provided a table, which summarizes the steps to be taken for design and calculation of the set of passive cooling strategies. Below is a synopsis of these considerations. In selecting these strategies, the right match between a climate and a design strategy should be studied first (Grondzik and Kwok, 2015).

Design Guidelines and Detailed Calculations Considerations:

Cross-Ventilation

- Assume 3F° [1.6C°] Δ*t*
- Assume window is oriented to wind
- Use actual Δ*t*
- Use actual window orientation to wind

Stack Ventilation

• Assume 3F° (1.6C°) Δ*t* • Use actual Δ*t*

Night Ventilation of Thermal Mass

- Assume ratio of mass area/floor area
- Assume cooling during hour of maximum Δ*t*
- Assume maximum Δ*t* for natural ventilation estimation
- Find total cooling and required air flow rate
- Use actual exposed mass area
- Use actual mass heat capacity
- Use actual hourly chart of air and mass temperatures

Evaporative Cooling (Active)

- Assume 2.67 cfm/ft2 floor area (13.6 L/s m2)
- Assume 83°F (28.3°C) exhaust air
- Find allowable Δ*t* as air passes through indoors
- Then cfm = (Btu/h)/(1.1) (Δ*t*) [L/s = W/(1.2)(Δ*t*]
- Use actual outdoor temperature for analysis
- Determine actual indoor air temperature

Cool towers (Passive, Evaporative)

- Find approximate exit air temperature
- Find approximate flow rate
- Then Btu/h = (cfm) (1.1) (Δ*t*) [W = (L/s) (1.2) (Δ*t*)]
- Use actual outdoor temperature and wet-bulb depression
- Find actual exit air (supply) temperature

- Find actual exit airflow rate

- Then Btu/h = (cfm) (1.1) (Δt) [W = (L/s) (1.2) (Δt)]

Roof Ponds

- Assume pond maximum temperature of 80°F (26.7oC)

- Estimate pond minimum temperature

- Assume 30% gain through roof insulation

- Assume pond depth from 3 in. to 6 in. (75–150 mm)

- Find pond depth and area

- Use actual outdoor temperature, resulting pond temperature

- Use actual heat gain through roof insulation

- Consider actual hours of internal heat gains

- Find pond depth and area

- Determine size of backup cooling

Earth Tubes

- Assume 65°F (18.3°C) soil temperature

- Assume soil conductivity

- Does not specify depth

- Assume 85°F (29.4°C) outdoor air

- Assume 500 fpm (2.5 m/s) velocity

- Choose diameter and length to match cooling load

- Actual underground temperature; assume resulting tube temperature is within 4F° (2.2 C°)

- Actual soil conductivity
- Actual depth
- Actual outdoor air temperature
- Assume 500 fpm (2.5 m/s) velocity
- Calculate actual cooling capacity

2.3.3. Building Envelope

It seems that today the phrase “passive design” has expanded its boundary of definition to include building envelope features, such as air-tightness, thermal bridges, R-Values, and U-Values of building envelope components, as passive design strategies. This expansion of the definition of passive design even in some cases has rendered the use of legacy passive systems obsolete as was reviewed in the section 2.2 on the history of passive design.

Meanwhile, the inclusion of building envelope design as a passive system strategy seem to be more plausible if we consider its integration with legacy passive design strategies. Use of Phase Change Materials (PCM) in building walls or roofs is one example of this kind, which was explained earlier in the design of Trombe’ walls in section 2.3.1. A good example of integrating legacy passive systems with building envelope components could be double skin facades. Double Skin Facades (DSF) have a mechanism similar to indirect or isolated solar gain systems. This type of facades, in fact, with a layer of air cavity behind the first glazing skin can form compact sunspace areas in front of the second skin of a building. In the case of using an opaque material for the first outside skin, the system will perform more as a Trombe' wall. Transpired solar wall systems are examples of this kind where active systems, such as fans and HVAC components, are integrated with the passive system. This performance integration was explained in section 2.3.1.

DSFs might be categorized in four different types depending on the form of their air cavity between the two skins (Barbosa and Ip, 2014). These categories include: Box window (i.e. air cavity is divided to smaller cubic forms by vertical and horizontal elements of the facade) shaft-box (i.e. air cavity is divided to vertical cubic forms by façade elements) corridor (i.e. air cavity is divided to horizontal cubic forms divided by façade elements) multi-story double skin façade (air cavity is connected and expanded throughout the whole façade). Table 2.17 shows different types of DFS along with design comments developed through studies conducted in specific locations/climates on DSFs (Ghaffarianhoseini et al, 2016).

The issue of overheating and fire safety could be two of the main design considerations in using double skin facades. With the exception of box-window DSFs, the air cavity in other types of DSFs can accelerate fire distribution throughout the whole building.

Table 2.17 Examples of the types of DSFs used in different locations and their findings (Ghaffarianhoseini et al., 2016).

Type of DSF	**design Location/climate**	**Comments**
Naturally ventilated DSF	Sub-tropical Hong Kong	A set of correction factors for OTTV calculation of air-conditioned commercial buildings constructed with naturally ventilated DSF
Novel photovoltaic DSF	Sub-tropical climate	Ventilated PV-DSF provides the lowest solar heat gain coefficient (SHGC), while the non-ventilated PV-DSF better reduces heat loss
Multistory DSF	Sunny summer day, Uccle, Belgium	The night natural ventilation is highly effective
Single floor DSF equipped with a venetian blind	Not specified	The distance between the blind and the external glazing has significant influence on the velocity profiles inside the facade channel.
DSF with thermal mass	Not specified	Mechanically ventilated DSFs can save energy from 21% to 26% in summer and 41–59% in winter
Typical DSF (clear, absorptive or reflective glass)	Hong Kong	DSF system with single clear glazing as the inner pane and double reflective glazing as the outer pane results in an annual saving of approximately 26% in building cooling energy. (other energy saving studies: clear glazing 4.8%, reflective single glazing 22.1%, clear double glazing 0.3%)
Typical DSF	Seoul, Korea	Use of DSF is credited with providing 5.62% reduction in energy consumption. Decreasing the cavity depth of the DSF resulted in decreasing the energy consumption
DSF with plants	Not specified	Temperature of each layer of the DSF was approximately twice lower forthe case with plants than with blinds. Use of plants in the DSFs (in naturally ventilated buildings) decreases the operation time of ventilation in the warm period and increases the operation time in the cold period.

Table 2.17 Continued

Type of DSF	design Location/climate	Comments
Typical DSF	Kitakyushu of Japan	10–15% energy saving for cooling in summer plus 20% to 30% energy saving for heating in winter
Typical DSF	Central European moderate climate	7% cooling energy saving compared to double/triple glazed façades.
Ventilated opaque DSF	Not specified	Exhaust air facade configuration (EAF): heat loss reduction between 43% to 68%, Supply air facade configuration (SAF): pre-heating efficiency between 9%-20%
Mechanical DSF	Summer time, Tokyo, Japan	Temperature reduction of double-skin space by 1 °C
Double skin Glazed Façade (DGF)	Sunny Mediterranean climates, Northwest region of Argentina, spring/summer	Well-designed DGFs can decrease the summer energy consumption of buildings, even using West DGFs, in sunny climates.
Multi-story naturally ventilated DSF	Belgrade, Serbia	DSF does not necessarily decrease energy consumption
Typical DSF	Hot and dry climate, Iran	Increasing airflow velocity within the cavity solves the overheating problem and allows DSFs to perform in hot and dry climates.

Another type of advanced use of passive systems could be found in adaptive facades, which can include different technologies for reaction through the use of ambient conditions. Kinetic facades and curtain walls with switchable glazing materials could be two examples of this kind. Adaptive facades can be categorized based on their purpose of use, response function, operation mechanism, components, response time, installation integration, and degree of adaptability. Table 2.18 shows examples of the possibilities for designing adaptive facades based on these categories.

Table 2.18 Possibilities for the design of adaptive façades

Category	**Design Consideration Possibilities**
Purpose	Thermal comfort, energy performance, IAQ, visual comfort, acoustic performance, control
Responsive function	Prevent, reject, modulate, and collect
Operation	Intrinsic and extrinsic
Components (materials and systems)	Shading, insulation, PCM, switchable glazing, solar tubes, integrated solar systems, and shape memory alloys
Response time	Seconds, minutes, hours, day, seasons, years
Installation integration	Building material, façade element, wall, window, roof, and whole building
Degree of adaptability	On-off or gradual

Adaptive facades can react based on a change in environmental conditions such as wind velocity, air pollution, temperature, humidity, noise, or solar radiation. In a review study conducted by Aeleneia et al. (2016) solar radiation together with outdoor temperature found to be the most common external factors associated with the reaction of adaptive façades. Meanwhile, it should be kept in mind that adaptive facades could not be considered passive systems if they use active systems, such as mechanically-assisted actuators or non-renewable energy sources, for reaction in different environmental conditions.

2.3.4. Daylighting

About 40% of commercial buildings energy consumption is associated with electric lighting (Lechner, 2015). Daylighting can significantly reduce this percentage of energy consumption as a free natural system. The importance of daylighting is such that it is the only natural system strategy recognized by LEED rating system with 1 point if 75% of the building is daylit and 2 points if 95% of the building is daylit (LEED BD+C, 2017). Additionally, a major part of cooling loads and heating loads in buildings can be compensated through a well-integrated design for daylighting and solar radiation control. Lechner has proposed a three-tier approach in lighting design which includes: tier one for color/material of finishes and lighting geometry such as building orientation or opening dimension; tier two, daylighting; and tier three, electric lighting (2015).

Unfortunately, issues such as glare, overheating, and shallow depth of sunlight penetration in buildings limit the usability of daylighting as a natural design strategy. For example, only the first 15 ft. distance from a window can be fully daylit. The next 15 ft will be only partially daylit and beyond that the use of artificial light is necessary to illuminate the interior space (Reinhart, 2014). This depth of illumination can be changed through small changes in the exterior form or the interior layout of a building. For example, inserting an atrium in the core of a building larger than 30’ by 30’ can fully illuminate the whole interior with the help of sidelights. A variety of light guiding systems such as skylights exist which similar to an atrium can contribute to the promotion of the interior illumination. Table 2.19 represents a summary of examples of light guiding systems in buildings along with their strength/weakness.

Other approaches to bring daylighting to the core of a building include: roof light, light shaft, light duct, light pipe, skylights, light shelves, light louvers, and external reflectors.

Roof lights can have different form as skylights, roof monitors, clerestory windows, or saw-tooth rooftop skylights. Meanwhile, the percentage of rooftop openings usually is kept between 3 to 5% of the roof area (ASHRAE 90.1-2013) due to issues such as overheating or air infiltration/leakage, which can increase a building’s energy consumption.

Light shelves are more useful if installed outside of a window than inside, since they can collect more daylighting to be reflected to the indoor space. Additionally, outdoor light shelves can better shade a window is summer and their impact on limiting the field of view through a window for occupants is less tangible. Light shelves not only expand the light penetration distance through reflection, but also they can reduce glare by turning the direct sunlight to diffuse sunlight.

Louver systems can have different functions such as blocking views, reducing glare, or distrusting the direct sunlight through reflections inside a building. The performance of louver system depends on the shape and form of its blind modules. Concave, convex, or flat blind modules can have different impact on the level of illumination inside a building. In some cases, a combination of these forms can shape a profile section for each blind module to block the intense summer daylight while allowing the winter daylight to the inside for better passive heating.

A criterion to measure the appropriateness of the level of daylighting inside is daylighting factor (DF) which is expressed as a percentage ratio of the interior illuminance to the outdoor unobstructed horizontal illuminance (Grondzik and Kwok, 2015). However, in the last years, new metrics have been added to daylighting studies and are being developed due to insufficiency of the DF for daylighting analysis. Metrics such as Annual Solar Exposure (ASE) and Spatial Daylight Autonomy (SDA) are examples on this ground.

Light shafts or light wells or. Light wells become more efficient as the ratio between the width of the light well to its height increases because less light is absorbed by the reduced number of reflections (Lechner, 2015). Using reflective materials for the finishes of the light well/shaft can increase the transmission of light to the bottom of the light well/shaft. Light ducts similar to light shafts use the light reflection mechanism to transmit/guide the light to a desired point usually located at the core of a building. The difference between light ducts and light shafts is in their transmission direction: light ducts usually guide the reflected light horizontally and light shaft guide the light vertically to the depth of the shaft.

Light pipe is the most recent technology for light guiding systems, and also the last system to be reviewed here. In some cases, light pipes' and light tubes' terminologies might be used interchangeably. Different from light tubes or tubular skylights, which use surface reflection, light pipes are hollow and made of prismatic plastic films to transmit light by total internal reflections. Light pipes can also work as active systems if they use electric sources of energy and integrate with fiber optics to transmit the light (Grondzik and Kwok, 2015).

Table 2.19 Strengths and weaknesses of light guiding systems by previous researchers. (Wong, 2017)

Light guiding system	Tilt-able	Solar Shading	Ease of application	Ease of maintenance	Thermal reduction	Allow view
Light guiding shade	No	Yes	Window	Easy	Yes	Yes
Reflective blinds	Yes	Yes	Window	Easy	Yes	Limited
Venetian blinds	Yes	Yes	Window	Easy	Yes	Limited
Movable blinds	Yes	Yes	Window	Easy	Yes	Limited
Light shelves	No	Yes	Window	Easy	Yes	Yes
Prismatic louvers	Yes	Potential	Window	Easy	Yes	Limited
Mirror systems	No	Yes	Fixed louvre	Difficult	Yes	Limited
Prismatic glazing	No	Potential	Window & roof	Difficult	Yes	Limited
Translucent louvers	Yes	Yes	Window	Difficult	Yes	Limited
Transparent insulated glazing	No	Potential	Inside double glazing	Easy	Potential	Limited
Toplight on roof	No	No	Roof	Difficult	Potential	Limited
Solar screens	No	Yes	Window	Difficult	Yes	Limited
Skylight on roof	No	No	Roof	Difficult	Potential	Limited
Lightscoop skylight	No	No	Roof	Difficult	Potential	Limited
Shed-type rooflight	No	No	Roof	Difficult	Potential	Yes
Holographic films	No	Yes	Inside double glazing	Easy	Potential	Yes
Active modular glazing panel	No	Yes	Window	Easy	Yes	Yes
Three-layered rooflight	No	No	Roof	Difficult	Potential	Limited
Façade panels with PCM	No	Potential	Inside double glazing	Easy	Potential	Limited

2.4. Factors Influential in Passive Systems Applications

The increase or reduction in the application of passive/natural systems in buildings in the US can be assigned to a number of institutional and implementation factors. Examples include: building standards and rating systems, simulation tools, client and design team collaboration, knowledge for integrating mechanical and passive systems, climate, and experience of the design team. This section will discuss these factors and their possible impacts on the use of passive systems with a focus on the US geography.

2.4.1. Building Standards and Rating Systems: The Status Que

One of the obstacles for the implementation of passive/natural systems in buildings could be the low level of attention for providing incentive credits for the application of passive/natural systems. Although the passive design approach has been recognized in recent years in the latest green building rating systems worldwide, it seems that the focus of these ratings systems is mostly on building envelope features including: walls, roofs, fenestration, insulation materials, and air-tightness, versus any treatment of add-on passive systems.

2.4.1.1. Rating Systems and Codes in Relation to Active/Passive Design Strategies

Consideration of the growth of the number of rating systems in the world can better indicate the scale of the unutilized potential energy saving from the incorporation of assessment categories for passive design in rating systems. These rating systems began with BREEAM (Building Research Establishment Environmental Assessment

Methodology) in 1990 in UK and spread worldwide, such as is the case of BREEAM CH for Switzerland in 2014. The World Green Building Council currently lists 45 green rating systems from across the world from which Table 2.20 lists some examples with their first year of establishment and relevant assessment categories (WGBC, 2018).

Most of the rating systems in Table 2.20 evaluate the synthesized performance of a building by considering their fulfilment of prerequisite credits and summing up the weighted set of other credits achieved for all performance categories. There are some exceptions such as in the case of Green Globes rating system, which does not include any prerequisite credits or CASBEE which calculates the ratio of environmental quality to environmental load reduction through its rating system. Among these rating systems, LEED v4 is the green building rating system in the US, which has also been adopted on an international scale. While the LEED program has promoted its assessment of the use of renewable energy in buildings in version 4, compared with other global rating systems it still has very few credit scores assigned to the use of passive systems in buildings.

A comparative examination of five representative rating systems selected from Table 2.20 will better indicate the lack of LEED's attention to the use of passive systems in buildings. These rating systems include BREEAM (Building Research Establishment Environmental Assessment Method), LEED (Leadership in Energy and Environmental Design), CASBEE (Comprehensive Assessment System for Building Environmental Efficiency), BEAM (Building Environmental Assessment Method) Plus and GBL-

ASGB (Green Building Labeling–Assessment Standard for Green Building).[20] Although these green building rating systems use different category weightings, they assign the highest weighting score to their energy use and carbon emission reduction categories.

Table 2.20 Examples of Green Building Rating Systems and their features

Rating System (Country/Body)	**Year of Establishment**	**Ratings**	**Assessment Categories**
BREEAM (UK/BRE)	1990	Pass/1 star (≥30%); Good/2 stars (≥45%); Very good/3 stars (≥55%); Excellent/4 stars (≥70%); Outstanding/5 stars (≥85%)	Management; Health and well-being; Energy; Transport; Water; Materials; Waste; Land use and ecology; Pollution; Innovation
HQE Haute Qualité Environnementale or High Quality Environmental Standard (France/Cerway)	1996	Three possible performance levels for the 14 environmental targets including: prerequisite, performing, high performing. For example, for the target 4 «Energy», it is necessary to obtain more than 30% of points for the «Performing» level and 50% of points for the «High Performing» level (2012-2013)	14 environmental targets including: Energy; Environment (Site, Components, Worksite, Water, Waste, Upkeep-Maintenance) Health (Quality of spaces, Air quality, Health quality of water); Comfort (Hygrothermal, Acoustic, Visual, Olfactory).

---

[20] For further information on these rating systems please see the following websites:
https://www.breeam.com/

http://www.ibec.or.jp/CASBEE/english/

https://www.hkgbc.org.hk/eng/NB_Intro.aspx

http://www.gbig.org/collections/14970

Table 2.20 Continued

Rating System (Country/Body)	**Year of Establishment**	**Ratings**	**Assessment Categories**
BEAM Plus (Hong Kong)	1996	The Overall Assessment Grade is determined by the percentage (%) of the credits gained under each performance category and its weighting factor. It is necessary to obtain a minimum percentage (%) of credits for the three categories of SA, EU and IEQ, in order to qualify for the overall grade as follows. Platinum/Excellent (≥75% with min 70% for the above 3 categories); Gold/Very Good (≥65% with minimum 60% for the 3 categories); Silver/Good (≥55% with minimum 50% for the 3 categories); Bronze/Above Average (≥40% with minimum 50% for the 3 categories)	Management; Site Aspects; Materials and Waste Aspects; Energy Use; Water Use; and Indoor Environmental Quality
LEED (US/USGBC)	1998	Platinum (≥80 points); Gold (60-79 points); Silver (50-59 points); Certified (0-49 points)	Sustainable sites; Water efficiency; Energy and atmosphere; Materials and resources; Indoor environmental quality; Innovation and design process; Regional priority
Green Globes (Canada/GBI)	2000	To become Green Globes-certified, each project must achieve a minimum of 35% of the total applicable points. Certified projects are assigned a rating of 1 to 4 Green Globes. 4 Globes (85-100%); 3 Globes (70-84%); 2 Globes (55-69%); 1 Globe (35-54%)	Project Management; Site; Energy; Water; Materials & Resources; Emissions; Indoor Environment
CASBEE (Japan/IBEC)	2001	Poor C (0-0.5); Slightly poor (0.5-1); Good B+ (1-1.5); Very good A (1.5-3); Superior S (≥3)	Energy efficiency; Resource efficiency; Local environment; Indoor environment

Table 2.20 Continued

Rating System (Country/Body)	**Year of Establishment**	**Ratings**	**Assessment Categories**
Green Star (Australia/GBCA)	2003	One star (10-19 points); Two star (20-29 points); Three star (30-44 points); Four star (45-59 points); Five star (60-74 points); Six star (≥75 points)	Management; Indoor environment quality; Energy; Transport; Water; Materials; Land use and ecology; Emissions; Innovation
Green Mark (Singapore/BCA)	2005	Platinum (≥90 points); Gold Plus (85-89 points); Gold (75-84 points); Certified (50-74 points)	Energy Efficiency; Water Efficiency; Environmental Protection; Indoor Environmental Quality; Other Green Features and Innovation
LiderA (Portugal)	2005	From A++ to E: Class E is the common practice, and other ratings will be assigned based on how it surpasses this performance, for example: 25% will be a C class, 50% an A class, four times an E class is an A+ Class, and ten times an E class is an A++ Class.	Site and Integration; Resources; Environmental Loads; Environmental comfort; Socio-economic adaptability; Environmental Management and Innovation
GBL–ASGB (China)	2006	Three-Star (Overall≥80, Each Category≥40), Two-Star (Overall≥60, Each Category≥40), and One-Star (Overall≥50, Each Category≥40)	Energy saving and utilization; Water saving and utilization; Material saving and utilization; Land saving and outdoor environment; Indoor environment quality
DGNB (Germany)	2009	Bronze (≥35% points); Silver (≥50% points); Gold (≥65% points); Platinum (≥80% points)	Environmental quality; Economic quality; Sociocultural and functional quality; Technical quality; Process quality; Site quality

Table 2.20 Continued

Rating System (Country/Body)	**Year of Establishment**	**Ratings**	**Assessment Categories**
IGBC (India)	2009	Certified (40-49 points); Silver (50-59 points); Gold (60-74); Platinum (75-100)	Sustainable Architecture and Design; Site Selection and Planning; Water Conservation; Energy Efficiency; Building Materials and Resources; Indoor Environmental Quality; Innovation and Development.
Green Building Index (Malaysia)	2009	Certified (50-65 points); Silver (66-75 points); Gold (76-85 points); Platinum (86-100 points)	Energy Efficiency (EE); Indoor Environment Quality (EQ); Sustainable Site Planning & MANAGEMENT (SM); Materials & Resources (MR); Water Efficiency (WE); Innovation (IN)
GreenShip (Indonesia)	2010	For level of Design Recognition (DR) achievement includes Platinum (Minimum 73% with 56 points); Gold (Minimum 57% with 43 points); Silver (Minimum 46% with 35 points); Bronze (Minimum 35% with 27 points) For level of Final Achievements (FA) includes Platinum (Minimum 73% with 74 points); Gold (Minimum 57% with 58 points); Silver (Minimum 46% with 47 points) Bronze (Minimum 35% with 35 points)	Appropriate Site Development; Energy Efficiency and Conservation; Water Conservation; Material Resources and Cycle; Indoor Health and Comfort; Building Environment Management

Most of the credits of energy categories are associated with building performance assessments that are conducted through whole-building energy simulations by comparing the predicted energy use of a new building with a reference basecase energy consumption. A simpler approach for gaining credits in energy categories through green building rating systems is the prescriptive approach, in which each component of the building should be built to a certain standard (e.g. roof R-value 20). Chen et al. (2015) have considered this contribution of the building envelope components to energy saving through the prescriptive approach as passive design. These passive design strategies could be classified into building layout, envelope thermophysics, building geometry, and air-tightness/infiltration.

Comparison of the weighting score of the five rating systems based on the contribution of their passive design strategies indicates that LEED has the lowest weighting score for passive design relative to its total credit scores in energy categories. On this basis, passive design weighting in energy section is 50%, 47.7%, 22.1%, 13.3%, and 9.1% for CASBEE, BEAM Plus, GBL-ASGB, BREEAM, and LEED rating systems respectively (Chen et al., 2015). The low percentage of LEED contribution to passive energy saving calls for further attention considering that two-thirds of the occupants' discomfort could be eliminated by using simple passive designs such as proper envelope thermophysical properties and envelope configurations (Ralegaonkar and Gupta, 2010).

A closer look at the credits achievable through passive design shows that, first, in all the rating systems there is a potential for introducing credits for passive systems beyond building envelope features and airtightness; and second this potential is much higher for the LEED rating system which focuses mainly on building envelope features.

For example, BREEAM passive design credits include 2 points for the two assessment criteria of “passive design analysis” and “free cooling.” Passive design analysis criterion can achieve one point by meeting the thermal comfort requirements, identification of opportunities for passive design solutions in concept design, and demonstrating a reduction of total energy consumption as a result of passive design.

If the BREEAM criterion of passive design analysis is met, then the free cooling criterion can also achieve one point either through identifying opportunities for the implementation of free cooling solution or by demonstrating the consideration of appropriate technologies from the followings strategies:

- night-time cooling, which could include the use of exposed thermal mass
- ground-coupled air cooling
- displacement ventilation not linked to any active cooling system
- ground water cooling
- surface water cooling
- direct or indirect evaporative cooling
- desiccant dehumidification and evaporative cooling using waste heat, and

- absorption cooling using waste heat
- the applied technology could also show that the building does not require any significant form of active cooling or mechanical ventilation (i.e. is naturally ventilated).

Among the five rating systems, CASBEE seems to consider the highest level of importance for the incorporation of passive/natural systems in buildings. This rating system assigns 2.5 points to passive design through two assessment criteria including building thermal load and direct use of natural energy. Building thermal load can achieve credits through the use of:

- appropriate building site plan
- high insulation construction methods and materials in buildings such as in roofs/walls
- sun-shading methods
- measures such as high insulation multi-pane windows, airflow windows, and double skin facades.

Direct achievement of natural energy credit in CASBEE is also possible through the use of natural light, natural ventilation, geothermal energy, and other natural energy sources excluding mechanical systems.

BREEAM Plus 16, similar to CASBEE promotes the use of passive design strategies through its assessment criteria. BEAM assessment criteria includes:

- Site planning/building orientation including site permeability compared to PNAP-APP 152 requirement[21] by Building Department of Hong Kong (BDHK) or calculation of solar radiation on a building's façade
- Building envelope including Overall Thermal Transfer Value (OTTV) calculation[22]
- Natural ventilation: prescriptive approach of single sided or cross ventilation room design or performance based approach according to Area-Weighted Average Wind Velocity (AAWV)
- Daylighting: compliance of the Vertical Daylight Factor (VDF) of the habitable rooms and kitchens with PNAP APP-130[23] requirement by BDHK

---

[21] Practice Note for Authorized Persons (PNAP) is a set of building and construction requirements by the Building Department of Hong Kong for registered practitioners in Hong Kong. The related requirement documents include appendices to consider in design and construction such as APP-150. Further description of these documents can be found here at https://www.bd.gov.hk/en/resources/codes-and-references/practice-notes-and-circular-letters/index_pnap.html

[22] OTTV is a measure of heat transfer into the building through its envelope. It can be an index to compare the thermal performance of buildings if the same method is used for calculating OTTV. The concept of OTTV assumes that the building envelope is completely enclosed. OTTV is composed of two values: Envelope Thermal Transfer Value (ETTV) and Roof Transfer Value (RTTV). ETTV is a measure of heat transfer through the walls or envelope of the building, while RTTV is a measure of heat transfer through the roof of the building. The total sum of ETTV and RTTV defines OTTV (Hui, 1997; Vijayalaxmi, 2010).

[23] PNAP APP-130 describes the lighting and ventilation requirements as a performance-based approach in which the Building Authority of Hong Kong accepts a vertical daylighting factor (VDF) of 8% for habitable rooms and 4% for kitchens. As for natural ventilation the acceptable numbers include 1.5 ACH for habitable rooms and 1.5 for kitchen (Plus 5 ACH for mechanical).

GBL-ASGB, ranked third among the five rating systems, considers 5.3 credits for passive design, which is about 22.1% of the possible energy saving. These credits can be achieved through three assessment criteria including:

- Site condition appraisal and building design optimization such as building form, orientation, window to wall ratio, etc.
- Operable glazing ratio: over required percentage of window or curtain wall area
- Thermodynamic properties of the building envelope: beyond the reference value required by national building energy saving standard

Among these rating systems passive design strategies are not granted the same credit value as a traditional whole-building energy simulation approach except for BEAM Plus and CASBEE. Even LEED indirectly discourages passive design by reducing the credits available through prescriptive approaches, which do not need whole-building simulations. With 9.1% of energy saving from passive design measures, LEED receives the lowest weighting score for passive design. For energy efficiency measures in building envelopes and fenestrations LEED considers an option of prescriptive compliance with Chapter 4 of ASHRAE 50% Advanced Energy Design Guide, and introduces three methods for achieving daylighting credits including measurement or simulation of a building's sDA and ASE (LEED BD+C, 2017).

Except for daylighting and selected building envelope components, LEED does not offer credits exclusive to the use of passive or natural systems in buildings (LEED BD+C, 2017; ASHRAE 90.1, 2013, 2016). For example, throughout the whole LEED BD+C 2017 document (LEED for Building Design and Construction) the term/concept "passive" is used only two times. In the first case, for the Energy Performance Optimization Credit (1-20 points) LEED mentions "Analyze efficiency measures, focusing on load reduction and HVAC-related strategies (passive measures are acceptable) appropriate for the facility" (LEED BD+C, 2017, p.74). In the second case, for Thermal Comfort Credit to achieve one point LEED requires compliance with Option 1, ASHRAE Standard 55-2010, or Option 2, ISO and CEN Standards. LEED extends that for warehouses, where one point is achievable by meeting the thermal comfort compliance for office portions of the building, and for the regularly occupied areas of the building's bulk storage, sorting, and distribution areas, it can include one or more of six design alternatives. One of these alternatives can be "passive systems, such as nighttime air, heat venting, or wind flow" (LEED BD+C, 2017, p.129).

In relation to codes and guidelines, the PHIUS (Passive House Institute US) is probably the most recognized institute in the US in charge of a certification process that contains guidelines for passive buildings. PHIUS introduces seven principles for the design of passive buildings along with built/certified examples in the US (Klingenberg et. al., 2009). As reviewed in section 2.2 of this thesis, these principles include:

- superinsulation
- airtightness
- thermal bridge elimination
- heat and energy recovery ventilation
- high performance fenestration
- passive solar and internal heat gains optimization, and
- modeling of energy gains/losses using PHPP (Passive House Planning Package)

Among the PHIUS certified built examples, the passive design strategies applied focus only on building envelope features, insulation/airtightness, and direct solar gain while other potential passive design strategies are not used or have been left to neglect.

Most recently, PHIUS has published PHIUS+ 2015 Certification Guidebook V.1.03 in July 2016.[24] Unfortunately, as a guide for commissioning and certification the scope of the strategies discussed does not go beyond building envelope and ventilation, and considers active photovoltaic systems as part of passive design. However, the guide elaborates more on the role of modeling software WUFI[25] for passive certification and

---

[24] Currently PHIUS is conducting a pilot study for its PHIUS+ 2018 Certification Guidebook which has not been officially published.

[25] WUFI performs dynamic simulations of coupled heat and moisture transfer in buildings/building components under actual climate conditions. For boundary conditions, measured outdoor climates including driving rain and solar radiation are used. WUFI Passive allows a double assessment of buildings based on the same building model: a monthly energy balance method is used for the design and verification of buildings meeting the passive house criteria following EN 13790. WUFI Plus is used for the detailed dynamic assessment of the hygrothermal behavior of buildings or their components meeting the passive house criteria. For more information, please see https://wufi.de/en/software/wufi-passive.

design. PHIUS has also provided a certified project database of passive buildings through its PHIUS +2015 Certification process. The database currently includes 350 buildings, though less than ten of them are commercial buildings, and all of them use only direct solar gain and building envelope insulation as passive design strategies (PHIUS Project Database, 2017).

2.4.1.2. Standards and Codes: IECC and ASHRAE

The energy efficiency standards and codes for residential and commercial buildings can play an important role to promote or limit the application of passive systems in practice. The two most important examples in the US include ASHRAE standard 90.1 and IECC 2018 (International Energy Conservation Code) which provide performance codes and prescriptive codes for practitioners to build energy efficient buildings.

Prescriptive codes require that building components including its envelope and systems meet certain standards such as R-value for the walls or COP for mechanical heating/cooling systems. Performance codes require that a building's whole performance meets or exceeds the performance of a building built based on prescriptive codes.

Both ASHRAE and IECC include mandatory provisions for residential and commercial buildings that should be fulfilled for a building to be constructed. Examples include proper mechanical equipment sizing and thermal envelope properties in different climatic zones of the US. However, a brief overview of the contents of both references on building codes and standards indicates underestimating the inclusion of passive design strategies in buildings through codes or standards. In this case, IECC 2018 has better addressed the inclusion of incentives for passive building design, though indirectly, through its section C402.1.1 Low-energy buildings.

Section C402.1.1. mentions that three categories of low-energy buildings are exempted from the requirements of section C402 for thermal envelope provisions. This incentive is also applicable, as IECC mentions, for portions of a building which is separated by building thermal envelopes complying with IECC section 402 requirements. The three exemption categories include:

- Buildings with a peak design of less than 1 watt/ft2 (10 W/m2) for space conditioning
- Those that do not include conditioned spaces, and
- Greenhouses

Other than this explanation there is not any specific code or section assigned to passive building design in IECC 2018, since it considers only four code compliance requirements for building envelopes. These include: roof solar reflectance and thermal emittance (C402.3), fenestration in building envelope assemblies (C402.4), air leakage (C402.5), and thermal envelope compliance for the opaque portions of a building (C402.2 for insulation; C402.1.3 for R-value; C402.1.4 for U-, C-, and F-factor, or C402.1.5 for a component's performance alternative).

Similarly, the manual of ASHRAE standard 90.1 version 2017 considers no incentive or prescriptive path for passive heating/cooling design strategies. The only exception is in the explanation of the relationship between fenestration and energy use, in which the manual mentions the possibility of passive solar gains for buildings with lower internal heat gains (ASHRAE manual 2017, p.82). Other than this point, the ASHRAE standard 90.1 only has a focus on R- values or U- values of different building envelope assemblies for different US climates. Therefore, it is concluded that the exiting manuals, standards, and codes for the energy efficiency of buildings in the US do not invest on providing exclusive requirements for passive building design compliance. Therefore, there is an opportunity for the incorporation of compliance path for passive design strategies in buildings in the US.

2.4.2. Climate

The word climate comes from the Greek term klima meaning the slope of the earth in regards to the sun. The Greeks on this basis divided the world into tropic, temperate, and arctic zones. Therefore, it would not be inappropriate to say that the climate or average weather is primarily a function of the sun. (Lecnner, 2009). In other words, while there are factors such as topography, altitude, and land-water relationships, latitude of a geographic location has the dominant role in determining the climatic character of that location. A low latitude usually has a warm/tropic climate due to its location closer to the equator. With the same logic middle latitudes have seasonal/temperate climates and high latitudes have arctic climates. Today the influential components of a climate are broader and better recognized. These components may include, but are not limited to: solar radiation, temperature and its fluctuations, precipitation, humidity, air movement, air pollution, sand and dust (Fislisbach and Zollikon, 1993).

These components together can form an outdoor climatic condition as either hostile or friendly for a design that pursues the occupants' comfort. "Design for climate requires that homes be designed or modified to ensure that the occupants remain thermally comfortable with minimal auxiliary heating or cooling in the climate where they are built" (Reardon and Downton, 2016, p.90). The authors of this guide added that passive design is the significant component of this type of design, which is working with the climate, but not against it.[26]

There are different design terms which reveal the close relationships between a climate and the use of passive systems, such as in "bioclimatic design" and "climate-responsive design." The role of climate in design is such important that the word "design" in many cases comes after the phrase "climate-responsive" as in "climate-responsive design." Climate-responsive design is based on the way form and structure of a building can moderate a climate for human well-being and comfort (Hyde, 2000, p.3). Therefore, there is a pragmatic component in a climate-responsive design which is based on the architectural form of a building and its features, which are separated from active systems

---

[26] Based on the authors' notes other components include energy efficient heating/cooling systems and smart behavior by the occupants.

such as mechanical equipment. In this regard, Hyde maintains that climate-responsive design aims to reduce environmental impacts while responding to human well-being by reducing the use of non-renewable energies. (Hyde, 2000, p.5). This environmental concern in a climate-responsive design or a bioclimatic design directs us again toward the use of passive systems, which draw on the ambient condition and renewable energy sources to function. [27]

A climate-responsive design considers the condition of different seasons for a building including sun direction, natural shades, climate data, and environmental factors. All of these conditions indicate the importance of passive strategies as they can utilize the outdoor condition for the purpose of indoor occupants' comfort. Therefore, passive design strategies are integrated components in the steps of a climate-responsive design. Evans has proposed a ten-step design guide for a climate responsive design as follows (Evans, 2018):

- perform a site analysis
- layout the building on the site
- consider building orientation toward the sun
- choose appropriate window areas and glazing materials
- consider the geographic location for weather features

---

[27] Hyde considers difference between bioclimatic design and climate-responsive design. In bioclimatic design the procedure is to start with climatic analysis before moving to the design phase. However, climate-responsive design is focused on the synthesis of selected climate-responsive design strategies (Hyde, 2000, p.8).

- reduce the building foot-print
- design for natural ventilation
- consider some flexibility in comfort standards
- conduct energy and lighting modeling/analysis, and
- iterate this process until reaching the desired result

Despite all the advantages that climate can bring to a building through passive design strategies, there are two issues with respect to the use of these strategies in different climates, particularly in the US. These issues include: climatic suitability and building typology.

2.4.2.1. Climate Suitability

The first issue is the fact that the passive strategies applied in the US mostly address heating but not the cooling of buildings, which limits their application across all climates. This issue is evident in the *Climate Specific Passive Building Standards* as a document published by Passive House Institute US for passive house project certification in North America (Wright & Klingenberg, 2015). The strategies and discussions in this document only focus on passive solar heating and do not consider passive cooling strategies. Passive heating is achievable through direct, indirect, or isolated solar gain systems. However, among these three solar gain systems, the indirect or isolated gain systems, such as Trombe' wall or solarium, have not been discussed.

With the exception of direct solar gain systems, the lack of attention in this document could come from the rare application of passive design strategies in the US.

One assumption is that climate is a significant obstacle in the application of passive cooling systems in buildings in the US. ASHRAE Standard 169-2013 has defined eight climatic zones for the US and considers three subtypes for these zones (i.e. zone A or moist, zone B or dray, and zone C or marine). Accordingly, a majority of the US cities with a hot climate are also highly humid. Therefore, passive cooling design strategies in these climates could be used for a very short period of the year when the outdoor air/operative temperature and humidity is within the comfort zone. However, a considerable area of the US, particularly on the West Coast, can benefit from the free cooling that passive design strategies can offer. The rare application of indirect and isolated solar gain systems in the US could be more a matter of complexity of the implementation and/or maintenance of these systems, rather than the condition of cold humid or cold dry climates of the US.

2.4.2.2. Climate and Building Typology

The second issue is that the passive strategies applied in the US mainly address residential buildings, while only a few parallel studies exist for commercial buildings. A large factor in this difference comes from the different priorities designers consider between the thermal performance of the building envelopes in skin-dominated and load-dominated buildings. In a skin-dominated building, such as a detached house, heat-loss or heat-gain occurs across the building envelope components including openings, floors, roofs, and walls (Hemsath and AlagheBandhosseini, 2018). For example, in a house if the outdoor temperature is lower than the indoor temperature, the heat will flow from inside of the house to the outside. In such a skin-dominated building passive design strategies can considerably reduce the site energy consumption as they mostly have a focus on the features of the exterior envelope of the house where most of the heat is gained in summer or lost in winter. Therefore, the use of thermal mass, shading devices, south-facing orientation with appropriate glazing size/material represent a few example of the possible passive design strategies to be adopted for these situations.

Compared to commercial buildings, the smaller building footprints and usually compact forms of skin-dominated residential buildings also facilitates the implementation of passive cooling strategies. For example, natural ventilation in these buildings can often be accomplished because the distance between the inlet and outlet of the air streams is small and in most cases unobstructed. Nevertheless, design factors related to the hygrothermal features of a building skin's, such as air leakage and vapor barriers, become important in implementing passive design strategies since they can interact with or contradict the performance of the passive systems.

On the other hand, internal-load dominated buildings have a high density of occupants and equipment inside that results in heat gain from equipment, lights, or occupants' activities, which demands cooling as the first priority for the building all year around.

These buildings' large footprints make the use of artificial light a necessity during daytimes because daylight cannot reach deeply into the inner zones of this building (Grondzik and Kwok, 2015). Commercial buildings and hospitals represent two examples of this typology. Therefore, a general belief/misbelief is that since commercial buildings are internal-load dominated their performance should be decoupled from seasonal variations (Hastings, 1999).

As such, independent from the outdoor weather conditions, whether it is cold, cool, or warm outside, the indoor condition is set to be cooled and dehumidified through the use of mechanical systems. Other than a sporadic implementation of daylighting strategies in commercial buildings, as in the case of atriums, avoiding the application of passive strategies in commercial buildings seems to be the general design trend. However, the high energy usage of commercial buildings suggests an opportunity for a great potential in energy saving both in cold and hot climates. Increasing the well-insulated surface area in cold climates, increasing the well-insulated roof area in hot climates, and changing the building geometry for better natural ventilation represent three examples of possible design strategies for energy savings.

However, the possible passive design strategies for commercial buildings can make a long list. Hastings (1999) reviewed twenty-two commercial/institutional case studies as well as their simulations/validations conducted by experts from twelve countries. In this review he examined the possibility and benefit of using passive heating and passive cooling strategies in commercial/institutional buildings.[28] The range of proposed strategies in Hasting's review include direct gain systems, air-collector systems, air flow windows, mass wall systems, transparent insulations, absorber walls, solar radiation controls, heat avoidance, envelope cooling, natural radiative cooling, natural air/evaporative cooling, and convective and conductive cooling. Therefore, despite the general misconception of the usefulness of passive systems in commercial buildings (Bradshaw, 2006), Hasting's review shows that there is a great potential for the application of passive design strategies in commercial buildings to save on energy.

In summary, climate of a particular location and building typology may limit the potential of using passive design strategies. However, at the same time they open new opportunities for creative designers and energy-efficiency engineers to harvest the free natural and renewable energies through their designs.

2.4.3. Simulation and Modeling Tools

Since late 2014 the Department of Energy has delegated the task of managing the directory of building simulation tools to the International Building Performance Simulation Association (IBPSA). Therefore, IBPSA is now managing the Building Energy Simulation Tools web directory (BEST Directory) which includes software with

---

[28] The actual number of case studies was 45, but 25 of them have been examined through simulation validation. This study was part of the Task XI of International Energy Agency (EIA) Solar Heating and Cooling Program.

a wide-array of capabilities--from whole-building energy simulation to water use analysis.[29] Currently the directory lists 197 simulation tools of which 67 tools have capabilities for whole-building simulations. While some of these tools, such as TRNSYS, greater capabilities for analyzing passive systems, there is no single tool exclusive for the analysis of multiple passive design strategies among the IBPSA tools' directory.[30]

There are also other considerations that can make a tool appropriate for a building specialist to choose or not to choose for a passive building performance analysis. For example, the simplicity or sophistication of using a simulation tool or whether an architect or an engineer are using the tool can make a considerable difference in the criteria of selecting a simulation tool. Such a difference is perceptible from several previous surveys and studies about simulation tools, which are discussed in the following section.

One of the earliest surveys was conducted by the US Department of Energy in 1985 (Rittelmann and Ahmed, 1985) as the Task 8 of International Energy Agency (IEA) for the Passive and Hybrid Solar Low-Energy Buildings. The purpose of this report was to

---

[29] For further information, please see the IBPSA-USA website at https://www.buildingenergysoftwaretools.com.

[30] In this case, Climate Consultant is an exception with capabilities for analyzing a location's weather data for proposing passive design strategies, qualitatively speaking. However, the tool is not capable of analyzing a building's passive performance.

inform designers and builders about the availability of a wide variety of design tools for passive and hybrid solar buildings. The report presented key information on the characteristics of these tools to aid the tool selection process. A number of different individual experts in different countries completed a set of the tools' survey forms. Some of the findings from the survey included (Rittelmann and Ahmed, 1985, p.12):

- Many design tools had little or no credible verification undertaken
- The number of design tools have proliferated from 164 to 230 between 1982 and 1984
- Most of the design tools for active solar energy use the F-chart method or a component based simulation method. Most of the design tools for passive solar energy systems use the Solar Load Ratio (SLR) or a thermal network method.
- When design tools are developed for simplicity and ease of use during design process, they are generally incapable of evaluating the more sophisticated strategies that an energy-conscious designer is interested in investigating. Consequently, the desire for accuracy in analyzing unusual design features and the need for fast, easy-to-use, inexpensive design tools have been incompatible features.

The results of this survey exclusively talks about the use of SLR method in simulation tools for passive solar design, which indicates in the past there was a greater passion for passive design and therefore identification of its required simulation tools. Another important finding of this survey, which is still applicable today to simulation tools, is the lack of verification studies for many of the existing simulation tools. This issue is more intense for tools with capabilities in simulating passive building systems, because of the complexity of passive building simulation and verification methods. Table 2.21 provides information about the pros and cons of simulations validation techniques (NREL, 2008) which is based on the ANSI/ASHRAE Standard 140 for validation of the building energy use analysis. For example, a comparative study involves a direct comparison of the results obtained from two or more building energy analysis simulations using equivalent inputs. In empirical validation a real building or test cell is instrumented and the calculated results from building energy analysis simulations are compared to the measured results obtained from the instrumentation (NREL, 2008).

Another survey, which was conducted by Athienitis et al., has established an understanding of how design tools are applied to the design of Net Zero Energy Solar Buildings (NZESBs). This survey was conducted within the IEA SHC Task 40/ECBCS Annex 52 project Towards Net Zero Energy Solar Buildings (2010). The objective of the survey was to determine which and how many tools are being used and to determine gaps of current tools or of the design process. In total 32 national experts from the Task 40 responded. The findings showed that about 60% of respondents create an energy model of the building at the conceptual stage of the design process. The survey has also identified NZESB design tools' shortages as well as the desired future of these tools. Table 2.22 and Table 2.23 outline the key findings of this survey.

Table 2.21 Pros and cons of simulations validation techniques (NREL, 2008)

Technique	Advantages	Disadvantages
Comparative Relative test of model and solution process	- No input uncertainty - Any level of complexity - Inexpensive - Quick: many comparisons possible	- No truth standard
Analytical Test of numerical solution	- No input uncertainty - Exact truth standard given the simplicity of the model - Inexpensive	- No test of model - Limited to cases for which analytical solutions can be derived
Empirical Test of model and solution process	- Approximate truth standard within accuracy of measurements - Any level of complexity	- Measurement involves some degree of input uncertainty - Detailed measurements of high quality are expensive and time consuming - A limited number of data sites are economically practical

Table 2.22 Stages of the design process in which first energy model is created (Athienitis et al., 2010)

Stages of Design	Use of Simulation tools
Conceptual/early stage design	59%
After a design is complete, but opportunities remain for improvement	34%
After a design has been finalized	6 %

Table 2.23 Features of the NZESB design tools that are lacking (Athienitis et al., 2010)

Technical features	Other features
- Building-integrated solar technologies - Phase-change materials - Adiabatic cooling - Thermal bridges - Coupling of thermal and daylighting performance for double facades	- User-friendliness for integration of renewables. - Optimization - GUI for HVAC in EnergyPlus - Should identify key parameters and opportunities for decoupled models - Solar potential analysis - Simple models for complex integrated systems (e.g., SDHW with GSHP)

The most important outcome of the survey was mapping the future needs of simulation tools (Athienitis et al., 2010), which include:

- Faster feedback
- Guidance towards better designs
- Design evolution
- Facility for batch runs with optimization
- Direct calculation of primary energy, emissions, and costs.
- Design day output
- Better user interface with more examples
- Better contextual help for each feature
- Sensitivity analysis for each input
- Explanation of limitations of each model
- Include parameters such as: thermal admittance, time constants

- Faster feedback, at cost of accuracy, since we mainly care about relative performance
- Offer method for managing multiple designs
- Better post-processing (e.g., export to Excel)
- Include electricity demands of different plug loads
- Explanation of limitations of model
- Flags for inappropriate inputs
- Cost data/input
- Financial analysis
- Better interoperability between tools
- Rules of thumb built in Simplify them to allow architects to use the

Today after almost a decade, many of these features are incorporated to the current simulation tools, which is indicative of the importance of such surveys as well as the fast growing capabilities of simulation tools and the practitioner's demand for this growth.

Crawley et al. has provided a comparison of the features and capabilities of twenty major building energy simulation programs based on information provided by the program developers in several categories (2008). These categories include: general modeling features; zone loads; building envelope, daylighting, and solar; infiltration, ventilation and multizone airflow; renewable energy systems; electrical systems and equipment; HVAC systems; HVAC equipment; environmental emissions; economic evaluation; climate data availability, results reporting; validation; user interface, links to other programs, and availability. Table 2.31 shows the result of this comparison for capabilities of the tools in simulating passive features including building envelope, daylighting, and solar gain. Among the twenty tools compared, TRNSYS, ESP-r, IES VE, and Energy Plus seem to have more capabilities for such passive design simulations.

An important factor in selecting a simulation tool is having an appropriate match between the user's profession and the tool's features and analytical capabilities. This factor has been studied through a set of online surveys (Attia and Beltran, et al., 2009; Attia et al., 2012) The survey presents the results of comparing ten major Building Performance Simulation (BPS) tools. The following programs were compared through the results of surveys: ECOTECT, HEED, Energy 10, Design Builder, eQUEST, DOE-2, Green Building Studio, IES VE, Energy Plus, and OpenStudio.

The researchers defined five selection criteria to analyze the results of their surveys. These criteria are defined through table 2.24 and are as follows:

- Usability and information management (UIM) of interface
- Integration of intelligent design knowledgebase (IIKB)
- Accuracy of tools and ability to simulate detailed and complex building components (AADCC)
- Interoperability of building modelling (IBM)
- Integration of tools in building design process (IBDP)

The survey revealed that architects seek the IIKB above the UIM of the interface (Attia and Beltran et al., 2009). Attia et al (2012) by means of a literature review and two online surveys have conducted an intergroup comparison between architects and engineers. Table 2.25 to Table 2.30 show the major findings of the survey indicating a wide gap between architects' and engineers' priorities in tool ranking. Particularly a majority of passive design strategies that are ranked highly by architects are considered last priorities in tool selection by engineers. For example, while shading, solar heating, building orientation, natural ventilation, and geometry were ranked as third to seventh items by architects, engineers ranked these items as 10th to 14th among the 15 parameters asked in the survey (Table 13z). Despite this gap, there is evidence that architecture, engineering, and construction are moving towards convergence and building service disciplines are merging because of the mandatory codes and rating systems (Attia and Beltran et al., 2009).

The findings of these surveys from the past until more recently shows that further research is required to develop genuine environmental building design toolkits that integrates an intelligent knowledge-base (IIKB). Additionally, many of the major simulation tools that are very powerful and trending were not included in the previous surveys, particularly those enriched with capabilities for the design of passive systems. Examples include DesignBuilder and TRNSYS as a verified simulation tool for tax credits (DOE, 2017) and WUFI, which is used for passive house certification process of buildings (PHIUS, 2017). One reason could be that software capabilities are updated every year or new tools completely replace some earlier tools. The latest survey conducted seems to be a survey from eight years ago (Attia & Beltran et al., 2009).

Therefore, the surveys may not reflect the features of the newer versions of simulation tools or the tools emerging in recent years. In this regards, a new survey about building simulation tools with a focus on passive design is needed.

Table 2.24 Building performance simulation tool criteria (Attia et al., 2012)

Simulation tool selection criteria	**Definition and keywords**
Usability and information management (UIM) of interface	The 'usability' incorporates the functional operation of a tool. ***Keywords***: output and input representation, navigation, control, learnability, documentation, online help, error diagnostics. The 'information management' is responsible for allowing assumptions, facilitate data entry and control the input quality. ***Keywords***: input quality control, comparative reports creation, performance benchmarking, data storage, user customization, input review & modification
Integration of intelligent design knowledge- base (IIKB)	The knowledge-base supports decision making and provides quantitative and qualitative advice regarding the influence of design decisions. ***Keywords***: preset building templates & building components, heuristic/ prescriptive rules, procedural methods, building codes compliance, design guidelines, case studies, design strategies. The intelligence entails finding quantifiable answers to design questions in order to optimize the design. ***Keywords***: context analysis, design solutions & strategies optimization, parametric & sensitivity analysis, 'what if' scenarios, compliance verification, life cycle and economic analysis
Accuracy of tools and ability to simulate detailed and complex building components (AADCC)	The accuracy of tools includes analytical verification, empirical validation and comparative testing of simulation. ***Keywords***: BESTEST procedure, quality assurance, calibration, post-construction monitoring, and error range. The other part of this criterion deals with the ability to simulate complex building components with high model resolutions. ***Keywords***: passive technologies, renewable energy systems, HVAC systems, energy associated emissions, green roofs, double skin facades, chilled beams, atria, concrete core conditioning, etc.
Interoperability of building modelling (IBM)	Interoperability corresponds to the ability multidisciplinary storing and sharing of information with one virtual representation. ***Keywords***: gbXML, CAD, IFC, BIM, design phases, design team, model representation
Integration with building design process (IBDP)	IBDP corresponds to the integrating of BPS tools during the whole building design delivery process. ***Keywords***: multidisciplinary interfaces, design process centric, early & late design stages

Table 2.25 Participants' professional background (Attia et al., 2012)

Participants	**Survey 1**	**Survey 2**
Architects	249	196
Engineers	232	221

Table 2.26 The important parameters of a simulation tool (Attia et al., 2012)

Architects' Ranked Parameters	**Engineers' Ranked Parameters**
1. Energy Consumption	1.Energy Consumption
2. Comfort	2.HVAC
3. Shading	3.Controls
4. Solar Heating	4.Comfort
5. Orientation	5.Glazing and Opening
6. Natural Ventilation	6.Insulation
7. Geometry	7.Energy Efficient Lighting
8. Insulation	8.Environmental Tightness
9. Glazing and Opening	9.Daylighting
10. Daylighting	10.Shading
11. Solar systems	11. Solar Heating
12. HVAC	12. Orientation
13. Energy Efficient Lighting	13. Natural Ventilation
14. Environmental Tightness	14. Geometry
15. Controls	15. Solar systems

Table 2.27 Usability and graphical visualization importance of simulation tools (Attia et al., 2012)

Items	**Architects**	**Engineers**
Graphical representation of output results	23%	26%
Flexible use and navigation	17%	22%
Graphical representation of results in 3D	16%	17%
Easy follow-up structure	15%	15%
Graphical representation of input data	15%	12%
Easy learnability and short learning curve	14%	8%

Table 2.28 Importance of the items for intelligence of knowledge base and adaptability to design process in simulation tools (Attia et al, 2012)

Items	**Architects**	**Engineers**
Provide quick energy analysis that supports decision making	33%	23%
Allows examining sensitivity and uncertainty of key design parameters	29%	55%
Analyze weather data and suggest suitable climatic design strategies	13%	15%
Embrace overall design during most design strategies	17%	7%

Table 2.29 Architects versus engineers in BPS priorities and tool ranking (Attia et al, 2012).

Priorities for selecting simulation tools	IIKB (interrogation of intelligent design knowledge base to assist in decision making)	UIM (friendliness of the interface concerning usability and information management)	IBM (interoperability of building modeling e.g. exchange of 3D models with other programs)	AADCC (Accuracy and ability to simulate detailed and complex components)
Architects	1	2	3	4
Engineers	3	2	4	1

Table 2.30 Architects versus engineers ranking of ten simulation tools (Attia et al, 2012).

Simulation tool priority	**Architects**	**Engineers**
IESVE	1	5
ECOTECT	2	9
Design Builder	3	1
Green Building Studio	4	7
Energy 10	5	8
eQuest	6	3
HEED	7	10
Open Studio	8	6
Energy Plus	9	2
DOE2	10	4

To find the new simulation tools that are required to be the subject of a new survey, the author has used several sources to identify the most popular and regularly-used simulation tools. These sources include the IBPSA-USA BEST Directory as explained before, Survey of high performance firms by AIA (2017), The Architect's Guide to Integrating Energy Modeling in the Design Process by AIA (AIA, 2012), and the Architect Magazine website. [31] For example, Architect magazine identifies Revit Plugins such as Green Building Studio, Sefaira, Open Studio, and IES-VE as digital tools for architects to test building performance of their designs. The AIA survey indicates that architects in high performance firms are moving towards using in-house simulation tools for receiving fast feedback on design decisions, instead of relying only on outside consultants.

AIA survey indicates that Sefaira is the most popular tool, which has been used widely by 80% of architects in 2015. This tool is a cloud-based program, which was introduced in 2009, to evaluate carbon, daylight, energy, water, thermal comfort, and renewables. The AIA survey identifies Sefaira, Climate Consultant, DIVA, Ecotect, Vasari, Radiance, and COMFEN-Energy Plus as the most popular building simulation tools for architects. Today, some of these tools are no longer supported by their producers or have been replaced with more powerful performance analysis tools introduced by their producers. Therefore, in a new survey these tools should be replaced with their successor

---

[31] For further information, please see https://www.architectmagazine.com/technology/five-digital-tools-for-architects-to-test-building-performance_ o

tools. One example is Vasari as a plugin for Revit, which is replaced today by the Autodesk Flow Plugin for Revit or the more powerful computational fluid dynamic program/package of Autodesk CFD.

The Architect's Guide to Integrating Energy Modeling in the Design Process by AIA (2012) lists COMFEN, DesignBuilder, eQuEst, Green Building Studio/Vasari, HAP, IES-VE, OpenStudio, Sefaira Concept, Simergy, Energy Pro, Energy 10, EMIT 1.2, TAS, TRACE, and TRNSYS as the available simulation tools at the time. These tools mostly use EnergyPlus or DOE-2 as their simulation engines, but some of them utilize other simulation engines including TRNSYS, TAS, and TRACE. Some of these tools do not use any of these engines and may only use a simple calculation method or a spreadsheet. Examples include the Hourly Analysis Program (HAP) tool, which uses a transfer function method to design HVAC systems.[32]

The result of the author's investigations about the mostly used tool for building performance analysis resulted in the following list of simulation tools in an alphabetic order:

- Ansys Flow
- Autodesk CFD

---

[32] Today, the Hourly Analysis Program (HAP) assists engineers in designing HVAC systems for commercial buildings and is, in fact, two tools in one. First, it estimates loads and designs systems, and second, it simulates building energy use and calculates energy costs for buildings.

- Autodesk Flow
- BeOpt
- Climate Consultant
- COMFEN
- Daysim
- DesignBuilder
- Diva for Rhino
- Energy Plus
- eQuest/DOE2
- F-Chart
- HAP
- HEED
- IES VE
- Ladybug/Honeybee plugins for Rhino
- Manual tables, charts, and protractors
- OpenStudio
- Personal or In-house Software
- PHPP (Passive House Planning Package)
- Radiance
- Revit Tools/Plugins
- Sefaira

- Solidwork Flow Plugins
- Spreadsheets
- TAS
- Therm
- TRNSYS
- WUFI

Table 2.31 Building envelope, daylighting, and solar analysis capabilities of twenty simulation tools by Crawley et al. (2008)

Features / **Tools**	**BLAST**	**BSIM**	**DeST**	**DOE 2.1E**	**ECOTECT**	**Ener-Win**	**Energy Express**	**Energy 10**	**EnergyPlus**	**eQUEST**	**ESP-r**	**IDA ICE**	**IES-VE**	**HAP**	**HEED**	**Power Domus**	**SUNREL**	**TAS**	**TRACE**	**TRNSYS**
Outside surface convection algorithm:																				
-BLAST/TARP	X								X										X	
-DOE-2				X					X	X									X	
-MoWiTT									X		X								X	
-ASHRAE simple	X					X		X	X				X		X			X	X	
-Ito, Kimura, and Oka correlation											X	X								
-User-selectable			X						X		X	X	X			X		X	X	X
Inside radiation view factors		X	X						X		X	X	X				P	X		
Radiation-to-air component separate from detailed convection (exterior)		X	X						X	X	X	X	X				X	X	P	X
Solar gain and daylighting calculation account for inter-reflections from external building component and other buildings		P			X				X		X		X			P				X
Note that X means available feature; P means partially available; O means optional feature; R means research feature; E means expert-needed feature; I means feature with difficulty to obtain input																				

Table 2.31 Continued

Tools Features	BLAST	BSIM	DeST	DOE 2.1E	ECOTECT	Ener-Win	Energy Express	Energy 10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES-VE	HAP	HEED	Power Domus	SUNREL	TAS	TRACE	TRNSYS
Single zone infiltration	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Automatic calculation of wind pressure coefficient		X	P						P				X				X	X		
Natural ventilation (pressure buoyancy driven)		X	P						X	P	X	X	X			X	X	X		O
Multi-zone airflow (pressure network model)		X	P						X		X	X	X				X	X		O
Hybrid natural and mechanical ventilation		X	P			X					I	X	X			X		X		O
Control window opening based on zone or external conditions		X				X			X		X		X			P	X			O
Displacement ventilation									X		X	X	X					X		O
Mix of flow networks and CFD domains			X								E									
Contaminants, mycotoxins (mold growth)		P									R					P				

Note that X means available feature; P means partially available; O means optional feature; R means research feature; E means expert-needed feature; I means feature with difficulty to obtain input

2.4.4 Construction Cost and Construction Complexity

Any technological or design intervention, which is different from the business-as-usual practices, will be seen by clients as an additional cost for a project. This difference even during building occupancy might be perceived by the occupants as a new challenge because of their unfamiliarity with the required training for operating the building. These issues of construction cost and operation/implementation complexity represent two typical obstacles that may prevent realization of any design idea, including passive systems, in practice.

Between the 1980s and the beginning of the current century green designs and constructions had a tendency to incorporate a variety of overly complex technological components to a building. Examples include different forms of solar chimneys, bermed walls, tombe walls, water walls, heat storage bedrocks, wind turbines, PV panels, or geothermal heat pumps design (Cook, 1984; Galloway, 2004; Strong and Burrows, 2017). In many cases these components would not contribute to energy saving, which was caused by a variety of reasons, such as maintenance problems, incomplete implementation of a complex passive system, unintegrated functions of mechanical and passive systems, or occupants' lack of training in running these systems.

A benefit associated with the application of sustainable design strategies in buildings, such as passive systems, is the perception of an added property value. For example, data show buildings that are certified with green rating systems, such as LEED, will have a higher property value. In 2014, the DOE reported in its Energy Efficiency & Financial Performance study that customers pay 10%-31% more for LEED-certified properties (Weinschenk, 2015). Therefore, the perceived benefits of a sustainable design strategy or green certification process can convince designers to invest more for the design and construction of a building.

These benefits are not limited to monetary savings, such as energy saving, and can expand to include environmental benefits and occupants' well-being. The impact of using natural/passive systems in buildings goes beyond energy saving since it affects the health and productivity of building occupants. Many of modern society's chronic health issues correlate with the poor indoor environmental qualities since we spend almost 90 percent of our time inside buildings. Decoupling buildings from nature and its seasonal variations can result in poor daylighting and air qualities (Bessoudo, 2017). Researches have linked improved ventilation with up to 11% gains in employees' productivity because of increased outside air rates and delivery of fresh air. Similarly, improved daylighting shows an increase of 10% to 25% in occupants' productivity and wellbeing in work environments (Grange, 2016).

Likewise, the cost of investment is not limited to capital costs and may include other long-term costs. These costs are usually identified through a process of life cycle assessment (LCA). LCA includes four evaluation aspects (Edwards and Naboni, 2013):

- manufacturer's environmental impacts and transportation costs for construction materials and products

-lifetime maintenance of a building

-building operation costs such as energy consumption and other impacts

-end of building life (usually 50 years) and its construction products

For example, to achieve the Passive House Standard of 15 kWh/m2-yr large amounts of insulation, highly engineered construction products, and sophisticated details should be used, which considerably increase the construction cost as well as the environmental impact of demolishing the building.

To minimize these costs, therefore, an approach should be taken in design that can reduce the complexity of implementing a passive/natural system. Simplifying the technological aspects of the design/construction of a passive system will not only reduce the construction/demolition costs and operation/maintenance costs, but also will increase the potential health benefits for occupants due to easier understanding in running the passive.

2.4.5. Design Team and Client Collaboration

"Ask any architect who has produced a building to be proud of, and he or she will tell you that the client contributed significantly to nurturing its conception and ensuring the quality of its implementation. Conversely, the same architect probably could talk about aesthetically disappointing projects compromised by clients short on design aspiration or unwilling to go the distance financially" (Lewsi, 1998). This quote from an article on Washington Post can best summarize the types of relationship between architects and clients and their results. The same types of relationship can happen if we focus on the use and implementation of passive systems in buildings.

Most of the times a client's complaint about an architectural design idea or a client's refusal in implementing an idea is resulting from the client's lack of information about that idea's potential benefits. Economically baseless ideas that are insensitive to budget limitations or ideas that are complex for implementation will render any design proposal unacceptable for a client (Lewsi, 1998). Therefore, to convince a client for the inclusion of passive design strategies in the construction budget, it is necessary for the design team to be able to prove the return of investment on the implementation of any passive design strategy.

Demonstrating the economic feasibility of a design idea, including a passive design idea, should be through a method that is both transparent and understandable for the client. Most clients accept what has been tried before and is also predictable, particularly predictable in terms of the construction costs (Lewsi, 1998). That would be easier for a client to understand how much can be saved annually through the use of passive systems if the design team predicts the energy savings in dollars than in words. That will most probably convince the client, for example, to collaborate with the architect to include a Trombe' wall with a shading device on the south façade. That being said, other design factors such as maintenance or aesthetics of using a passive system should be also considered by the design team such that the client understand the benefits of their implementation. Therefore, a holistic integrated design approach is required, which can consider many factors such as capital/operative costs, design aesthetics, and construction budget of the design and implementation of passive design strategies.

The collaboration between architect and engineer is also of high importance for a successful implementation of a passive design strategy. Kjell Anderson in the book *Design Energy Simulation for Architects* by interviewing 20 architectural firms showed they face challenges connecting their design simulation program with each project team at the optimum time. “Project schedules are tight, the right people are not available when needed, and some individuals are leery of an energy-based critique of their designs” (Anderson, 2014, p .563). The interview has shown most firms voiced frustration with their lack of interaction with mechanical engineers. In most cases, clients do not allow their hiring until most of the geometric decisions have been made. In other cases, the engineers do not have the fee or interest in performing quick, iterative studies, running models without detailed inputs, or looking at non-standard options.

Anderson’s other findings showed that only three of the interviewed firms with in-house mechanical engineers also had a group that specializes in early analysis and acts as translators between architects and engineers. The individuals who make up this group include architects who have learned simulation, daylighting specialists, and others who are skillful enough to deal with the unknowns of early design. Four of the architect-only firms employed at least one individual to do Whole Building Energy Simulation (WBES) in-house. This individual does not design mechanical systems, but can set up and run the rigorous shoebox and compliance energy models that later design stages and LEED submittals will require. Beyond those four, some other firms had an individual with eQuest experience who could perform quick, specific shoebox energy models on projects (Anderson, 2014).

That would be helpful to compare also the organization of the traditional design teams and the integrated design teams in relation to their clients. The organization of traditional design teams is usually linear and treelike with the client at the top rank who is communicating with the architect. The architect, in turn, will collaborate/communicate with the branches of the contractor and the design/engineering specialists, such as the landscape architect and the mechanical engineer. Therefore, a specialist, who communicates with the architect as the leader of the design team, rarely communicates directly with the client or other specialists to inform them about his expert views and thoughts.

In contrast, the organization of an integrated design team is such that the clients and all design/engineering specialties are communicating/collaborating through the contribution of a facilitator, who could be one of the specialists as well. The facilitator is someone who is able to play the role of a team leader in the direction of sustainability (Busby

Perkins+Will and Stantec Consulting, 2007, p.17). The facilitator manages the integrated design Process and is responsible
for keeping the team on time and on target. He/she will link and coordinate the thoughts and wants of the project's core team members including the architect, engineer, project manager, contractor, client, and primary consultant team members such as the mechanical engineer. The core team, as needed, will be linked closely with other experts such as energy analysts and daylighting simulators. An expert may join the core team for a short period during the design/construction process, but makes valuable insights about the project.

Therefore, integrating the design team and the delivery team is a key component of a whole-system design approach (Strong and Burrows, 2017). Traditional methods of building design and procurement usually lead to a divergence between the design and construction team in implementation. These traditional methods also cause a collaboration/communication gap between clients and design team members due to clients' lack of direct connection with the specialists as well as lack of familiarity with designers' specialties. Therefore, major savings can be achieved by bringing together not only the clients and designers at an early stage of design, but also to add to this cohort of clients and designers the experts who are in charge of construction as well as building maintenance and operation (Strong and Burrows, 2017). Accordingly, collaboration between the client and the design team members, including the architect, is as important as the collaboration between the architect and the engineer experts. Such a collaboration is the foundation of any successful design that can respond to the needs of all the stakeholders.

2.4.6 Knowledge and Experience for Simulating and Integrating Passive Systems

As discussed in section 2.4.3, not only it is required to have simulation tools with capabilities in simulating passive design strategies, but also it is required to have the knowledge for analyzing the performance of these passive strategies through simulations. In most cases, passive strategies' simulations are complicated due to difficulty in controlling a variety of factors that change in reality and are difficult to control in simulations. Therefore, existing tools for passive design simulation or calculation, such as Passive House Planning Package (PHPP) developed by PHIUS, in fact simplify the building physics to a steady-state energy balance condition as a useful strategy to be able to predict the passive performance of usual buildings.

However, to reach acceptable simulation results that can match the actual energy consumption of innovative buildings, a more detailed analysis of the thermal processes should be conducted. Such analysis can include, for example, buildings with large glazing areas, special wall-structures, extremely large or small storage capacities, special indoor condition requirements, and heating loads that fluctuate greatly over time. Therefore, for passive building simulations there is a need for simulation tools with dynamic simulation capabilities and a high temporal resolution. These capabilities can help in predicting the time-based varying temperatures in space as well as the integration of spatial temperature variation with the impact of other environmental factors such as moisture, wind, and humidity for thermal comfort.[33]

Therefore, for a designer who wants to simulate the performance of a passive building it is required to have the knowledge of different energy use models that are applied by simulation tools. This knowledge can help the designer to choose the proper simulation tool and be able to analyze or predict the final outcomes with respect to the shortages of a simulation tool.

In this regard, ASHRAE Handbook of Fundamentals (2013) defines two general simulation modeling approaches for estimating energy usage: modeling for building and HVAC system design and associated design optimization (forward modeling), and modeling energy use of existing buildings for establishing baselines, calculating retrofit savings, and implementing model predictive control (data-driven modeling) (ASHRAE Handbook of Fundamentals 2013, 19.4). Table 2.32 and Table 2.33 show classification of the modeling/analysis methods as steady-state and dynamic methods. It seems that the second part of the table including dynamic methods are more appropriate for passive

---

[33] More recently tools such as Dynbil has been developed by the German Passive House Institute (PHI) which claims can run dynamic building simulations and predictions for passive designs. This tool seems to be stronger than other known passive simulation tools due to considering a dynamic method of simulation. However, the author could not find any validation/verification study by recognized energy institutes for this simulation tool. For further information about the tool please see https://passivehouse.com/01_passivehouseinstitute/02_expertise/02_simulations/01_buildingsimulations/01_buildingsimulations.html, last accessed February 2019.

simulation tools. TRNSYS is one of these tools which uses a transient simulation method.

Passive strategies perform based on natural phenomena, and because in the real world everything is always changing tools supported by dynamic simulation methods are more appropriate for the simulation of passive buildings. In comparison, steady-state simulation tools provide faster feedback and are more convenient for work because they do not require the knowledge of complex and different input variables of dynamic simulations. With the improvement of computer processor speeds, it is expected that in the near future dynamic simulation methods which take more time for simulation replace the steady methods applied in simulation tools (Da Silva, 2015). However, such a change also needs promotion of the users' knowledge in a large scale about these simulation tools and their energy modeling methods.

The simulation knowledge of passive design strategies per se is insufficient to design a successful passive building, because these buildings need auxiliary systems for heating and cooling to provide comfort conditions all year around. This knowledge of integrating passive and active systems is one of the key issues in designing passive buildings that do not suffer from cold in winter or overheating in summer.

Table 2.32 Classification of analysis methods for building energy use: steady state methods. Reprinted with permission from ASHRAE ©ASHRAE www.ashrae.org (ASHRAE Handbook of Fundamentals, 2013)

Method	**Forward**	**Data Driven**			**Comments**
		Empirical or Black-Box	**Calibrated Simulation**	**Physical or Gray-Box**	
Steady State Methods					
Simple linear regression (Kissock et al. 1998; Ruch and Claridge 1991)	-	X	-	-	One dependent parameter, one independent parameter. May have slope and y-intercept.
Multiple linear regression (Ali et al. 2011 Dhar 1995; Dhar et al. 1998, 1999a, 1999b; Katipamula et al. 1998; Sonderegger 1998)	-	X	-	-	One dependent parameter, multiple independent parameters.
Modified degree-day method	X	-	-	-	Based on fixed reference temperature of
Variable-base degree-day method, or 3-1) change point models (Fels 1986; Reddy et al. 1997; Sonderegger 1998)	X	X	-	X	Variable base reference temperatures.
Change-point models: 4-1), 5-1) (Fels 1986; Kissock el al. 1998)	-	X	-	X	Uses daily or monthly Utility billing data and average period temperatures.
ASHRAE bin method and data-driven bin method (Thamilseran and Haberl 1995)	X	X	-	-	(Hours in temperature bin) x (Load for thal bin).
ASHRAE TC 4.7 modified bin method (Knebel 1983)	X	-	-	-	Modified bin method with cooling load factors.
Multistep parameter identification (Reddy et al. 1999)	-	-	-	X	Uses daily data to determine overall heat loss and ventilation of large buildings.

Table 2.33 Classification of analysis methods for building energy use: dynamic methods. Reprinted with permission from ASHRAE ©ASHRAE www.ashrae.org (ASHRAE Handbook of Fundamentals, 2013)

Method	**Forward**	**Data Driven**			**Comments**
		Empirical or Black-Box	**Calibrated Simulation**	**Physical or Gray-Box**	
Dynamic Methods					
Thermal network (Rabi 1988; Reddy 1989; Sonderegger 1977)	x	-	-	x	Uses equivalent thermal parameters (data-driven mode).
Response factors (Kusuda 1969; Mitalas 1968; Mitalas and Stephenson 1967; Stephenson and Mitalas 1967)	x	-	-	-	Tabulated or as used in simulation programs.
Frequency-domain analysis (Shurcliff 1984; Subbarao 1988)	X	-	X	X	Frequency domain analysis convertible to time domain.
ARMA model (Armstrong et al. 2006b; Rabl 1988; Reddy 1989; Seem and Hancock 1985; Subbarao 1986)	-	-	-	X	Autoregressive moving average (ARMA) model.
PSTAR (Subbarao 1988)	X	-	X	X	Combination of ARMA and
Modal analysis (Bacot et al. 1984; Rabi 1988)	X	-	-	X	Fourier series; includes loads in time domain.
Differential equation (Rabi 1988)	-	-	-	X	Building described by diagonalized differential equation using nodes.
Computer simulation: DOE-2, EnergyPlus, ESP-r (Crawley et al. 2001; ESRU 2012; Haberl and BouSaada 1998; Manke et al. 1996; Norford et al. 1994)	X	-	X	-	Analytical linear differential equation.
Transient simulation: TRNSYS, HVACSIM+ (Clark 1985; Klein et al. 1994; TRNSYS 2012)	X	-	-	-	Hourly and sub-hourly simulation programs with system models. Sub-hourly simulation programs.
Artificial neural networks (Kreider and Haberl 1994; Kreider and wang 1991)	-	X	-	-	Connectionist models.
Equation based (Wetter et al. 2011)	X	-	-	X	-

The major objective of passive design is the reduction of auxiliary heating/cooling. Heating systems can be defined in two main categories: convective heating systems that mainly heat the room air and radiant or panel heating systems with the source of heat integrated to the building envelope components. To reduce the auxiliary load several points should be considered (Athienitis and Santamouris, 2013). First, for sizing the heating system, a sequence of cloudy days should be considered with the thermal mass being utilized to minimize the peak loads. Second, the cooling system should be sized based on a sunny hot day in which natural ventilation and shading devices are applied. Third, to reduce the peak loads the set point temperature should be considered variable. And fourth, in the case of using a convective heating/cooling system, the design of the air distribution system becomes important to provide the acceptable thermal comfort condition.

In most cases sizing the heating/cooling system becomes an issue in an integrated design process of passive buildings. The main reason is underestimating or overestimating the passive or active system sizing by either the architect or the engineer. Architects, for example, may consider a high percentage of glazing in their designs or may consider insufficient spaces for the installation of mechanical systems' components. On the other hand, mechanical engineers usually apply their long-term normal workflow for sizing the active systems in buildings without considering the incorporation of passive design strategies by the architect. The result of such a design could be lack of thermal comfort due to underestimating or overestimating the contribution of passive/active systems. For example, cooling load temperature difference (CLTD) as a method for calculating heating systems uses a steady-state peak heat loss calculation technique which may result in an oversized system (ASHRAE, 1997).

In passive solar systems that use radiant heating systems the thermal storage of the building envelope and its integration with the heating system, which is embedded in the wall or floor, becomes important. In other words, the floor or the wall becomes both a matter of design for storing the direct solar gain while hosting, for example, the hot water pipes of the heating system. The only difference is that the solar gain is absorbed at the top surface while the auxiliary heat is supplied at the bottom of the slab. Therefore, there is a thermal lag difference for each heating system (i.e. passive solar gains and active heating system) to be released to the space, which needs a delicate design and integration of the heating system and the thermal storage mass of the floor/walls. This design integration should focus on the required maximum auxiliary heating, thickness and material properties of the thermal mass hosting the heating system, and appropriate control strategies to prevent overheating of the floor surface above 84.2 °F (29 °C) (Athienitis and Santamouris, 2013).

In addition to the integration of passive and active systems, the knowledge of integrating different passive design strategies is important to realize a successful project. For example, overly large glazing areas for the increase of direct solar gain may cause glare and visual discomfort for the occupants. Gorndzik and Kwok (2015) suggest ten steps to be considered for the integration of passive design strategies. It should be kept in mind that these steps are not considered linearly in a passive design process. Findings from one of these design steps may influence the design considerations of the another step. These steps for the integration of passive systems include:

- Daylighting Design: to employ sidelights and skylights on the building envelope. Daylighting Factor, Spatial Daylighting Autonomy (SDA), and Annual Solar Exposure (ASE) are example of the items that need to be reviewed to ensure the appropriate level of illumination inside the building.
- Overall Heat Loss: in a passive solar building by calculating the total U × A of the south façade without including the glazing area the overall heat loss can be estimated in Btu/DD ft2 and be added with the effects of required ventilation (ACH). Comparing the results with reference tables will determine if the existing design can promote energy conservation of the building.
- Approximate Solar Savings Fraction (SSF): to determine if the glass area/floor area ratio is appropriate.
- Approximate Heat Gain: which finds the approximate heat gains from people, lighting, building envelope, and ventilation.
- Cross-Ventilation Guidelines: to find the appropriate inlet areas for cross-ventilation
- Night Ventilation of Thermal Mass Guidelines: to find out if potentials for night ventilation of thermal mass exist.

- January Balance Point Temperature
- Annual SSF Based upon the Load Collector Ratio (LCR): which determines through reference tables which of the direct or indirect solar gain systems are appropriate.
- Clear January Day Indoor Temperature Swing, and
- Detailed Night-Cooling of Mass Calculation

The purpose of the discussion in the above paragraphs on integrating passive systems or passive and active systems was to elaborate the importance of the knowledge for integrating these systems. It should be now perceptible why, for example, a passive solar building due to overheating might actually use more energy to reach thermal comfort. Therefore, the knowledge of passive design is a combined knowledge of calculation, simulation, collaboration, and other design considerations for spatial, thermal, visual, and even acoustic comfort.

This knowledge of design integration is followed by the knowhow for implementing passive and active systems. Certainly, experience in building your passive designs and evaluating their energy and comfort performance after occupancy can promote the design of the next passive building project. That is the undeniable role of experience in any type of design including passive buildings for both architects and engineers.

2.4.7. Architectural Curriculum and Natural/Passive systems

The NCARB Education Standard is the approximation of the requirements of a professional degree from a degree program which is accredited by NAAB (National Architectural Accrediting Board). It includes a minimum of 150 semester credit hours in six subject areas of General Education; History and Theory and Human Behavior; Building Practices; Design; Professional Practice; and Optional Studies. Table 2.34 shows these required subject areas in detail.

Among these subjects, courses in Environmental Control Systems with a minimum of 6 credit hours and Building Service and Building Enclosure Systems with a minimum of 3 credit hours are part of the requirements for a NAAB-accredited program.

Environmental Control Systems are defined as “the study of building elements that pertain to the modification of the microclimate for purposes of human use and comfort.” Acceptable topics based on NCARB (2018) include “acoustics, air conditioning, building core systems, energy, energy efficiency, energy transmission, environmental systems, active and passive heating and cooling systems, lighting (natural and artificial), solar geometry, natural ventilation, indoor air quality, solar energy utilization, and sustainability.” NCARB also defines Building Service and Building Enclosure Systems as “the study of the appropriate selection and application of building service systems including lighting mechanical, plumbing, electrical, communication, vertical transportation, security, fire protection, non-thermal mechanical, control, circulation, and signal systems and application of building enclosure systems relative to fundamental performance, aesthetics, moisture transfer, durability, and energy. Acceptable topics include curtain wall systems, sustainability, construction methods, facades, plumbing, electrical, vertical transportation, security, control, communication, and fire protection and life safety systems" (NCARB, 2018).

These two course subjects (ie. Environmental Control Systems and Building Service and Building Enclosure Systems) comprise about 6% of the total 150 credit hours. Since these course subjects are the only courses that can be related to passive systems and with respect to the variety of the topics that need to be covered in environmental systems, it seems that educators have a very limited opportunity to teach about the concept, calculation, and simulation of passive system design to students. In response to this shortage, design studios can provide more opportunities for students to learn about the use of passive systems and their integration with other design features including active systems. However, such a learning process is usually a matter of the instructors' interests in choosing an appropriate design studio topic or a matter of the specialty areas supported by architecture schools. Integrated design studios may fulfil this requirement to some extent. However, these studios may not necessarily go beyond daylighting and simple passive building envelope strategies to embrace add-on passive systems and their integration with active systems.

With recent moves towards defining architecture as a STEM field (Science, Technology, Engineering, and Mathematics), an in-depth inclusion of courses on design, calculation, and simulation of passive systems and their integration with active systems in architectural curriculums needs to be considered. In particular, such an inclusion is more in line with architecture students' interests and educational background, who compared with engineering students are learning more about the design of passive building components/systems rather than active building components/systems. While education and knowledge about active systems in buildings is essential for architecture students, this education needs to have a deeper focus on the integration of active systems with passive systems. Architecture students will be more dealing with this design integration and the design of passive building components in their future profession, and therefore, including a specific course in their curriculums addressing passive design seems not inappropriate.

A quick search for the existing course catalogues in architecture schools in the US suggests that passive design is not being taught beyond conceptual levels. Therefore, learning about calculation/simulation of passive systems' performance as well as implementation of passive systems remains to be experienced after graduation. This experience will not happen for all architecture graduates and will be for architects who are interested in passive design. Due to lack of knowledge about passive systems, many of architecture graduates may avoid design opportunities for the inclusion of passive systems in their design, thereby losing an important chance of design for reducing carbon emissions. However, a systematic survey is required to reveal the level of teaching in passive design in architecture schools with respect to conceptual perception, calculation approaches, and simulation skills focused on passive design.

Table 2.34 Academic credit grouped into six subject areas required to become a NAAB accredited program in the US (NCARB, 2018)

Subject Area and Category	**Semester Credit Hour Requirement**
General Education	**45 Hours**
A. Communication Skills in English Composition	3 Hours Min.
B. Humanities and Arts	N/A
C. Quantitative Reasoning	N/A
D. Natural Sciences	N/A
E. Social Sciences	N/A
History and Theory, and Human Behavior	**12 Hours**
A. History and Theory	6 Hours Min.
B. Human Behavior	3 Hours Min.
Building Practices	**27 Hours**
A. Structural Systems	6 Hours Min.
B. Environmental Control Systems	6 Hours Min.
C. Construction Materials and Assemblies	6 Hours Min.
D. Building Service and Building Enclosure Systems	3 Hours Min.
E. Technical Documentation	3 Hours Min.
F. Financial Considerations	3 Hours Min
Design	**42 Hours**
A. Fundamental Design	8 Hours Min.
B. Programming and Site Design	8 Hours Min.
C. Research and Investigative Based Design	8 Hours Min.
D. Integrated Design	8 Hours Min.
Professional Practice	**12 Hours**
A. Stakeholder Roles in Architecture	3 Hours Max.
B. Project Management	3 Hours Max.
C. Business Management	3 Hours Max.
D. Laws and Regulations	3 Hours Min.
E. Ethics and Professional Conduct	3 Hours Min.
Optional Studies	12 Hours
Total	**150 Hours**

2.5. Case Studies: Practitioners' Application of Passive Systems

In this section, first, a description of the professionals' general approach for choosing/or not choosing natural systems in their projects is provided. Then three case studies will illustrate this description to understand better the practitioners' design approaches for using passive systems. This section then will be expanded to an overview of the best sustainable design practices in the US. For this purpose, twenty projects selected from the AIA COTE TOP 10 awards will be studied in the form of tables and charts to find out about the practitioners' extent of the application of passive/natural systems in the US in the contemporary practice.

Considering the categories/questions of the AIA TOP 10 Award selection criteria, which have a focus on sustainability factors such as energy, water, well-being, ecology, and design integration, a review of its award-receiving projects can reveal if passive/natural systems are used in the US in best sustainable practices, and if yes, which strategies are used more regularly. The AIA categories and selection criteria for case study analysis will be further discussed in the section on research methodology.

2.5.1. Practitioners' Approach Toward the Use of Passive Systems

Although, each architect or engineer may have a personal approach towards design and each project could have its exclusive design path, it is possible to find a general design process among specific types of design projects. The design of high performance buildings with passive systems is no exception to this rule. Hayter et al. (2001) defines nine steps for the design of low-energy buildings including the decision making process on the use of natural systems. On this basis, generally location/climate, type of the building load (i.e. skin-dominated or internal-load dominated), and simulation tools provide the basis for professionals to decide for using/not using natural systems in a design process (Atkins, 2017).

For example, for a small, skin-load dominated building in cold and temperate climates, natural system design often involves using solar energy to provide space heating. For other types of structures, such as internal-load dominated buildings in warm climates, responsible passive solar design is more likely to emphasize cooling avoidance using shading devices, high performance glazing, and daylighting. In these internal-load dominated buildings, for cooling the building, high efficiency mechanical systems will be utilized rather than natural systems (WBDG, 2017).

Therefore, for skin-load dominated buildings professionals draw in very first steps on climatic analysis for the inclusion of natural systems. They start with the use of climate analysis tools such as climate consultant, weather tools, building bioclimatic and psychometric charts, or tables in standards such as ASHRAE standards (e.g. ASHRAE 90.1-2016, ASHRAE 169-2013, and ASHRAE Standard 55-2013) for determining the appropriate climate zone based on weather data and the possible natural system strategies.

The climate provides a basis for receiving design feedback about the feasibility of utilizing natural/passive system strategies in that climate zone through software programs with interactive psychometric charts or manual tabulated charts. These charts can show the hours and zones of thermal comfort with/without utilizing natural systems (e.g. natural ventilation or solar gain) and the hours/zones of discomfort where mechanical systems are required, because passive strategies are not effective. A good example of a software program including these charts is Climate Consultant as a tool for feedback on climatic data, passive design strategies, and the hours that active systems should operate to reach thermal comfort. The tool is connected to the Architecture Challenge Palette 2030. The Palette 2030 proposes mostly passive design strategies for the design of zero-net-carbon and resilient built environments from a building scale to a regional scale.

To calculate the effectiveness of the received design feedback/strategies in more details, the designers draw on building simulation tools or spreadsheets by making a baseline model and incorporating those strategies to find about the possible energy savings or adverse effects of the strategies (e.g. glare or increased energy consumption) through parametric simulation runs.

In the next step, practitioners integrate the possible passive strategies with other systems of the building (i.e. active systems) in a whole-building simulation to find out about their interrelation/interaction in terms of reducing/increasing energy consumption and indoor thermal, visual, spatial, and in some cases acoustic comfort. This step can help practitioners to prioritize the natural/passive system strategies, found in previous steps, based on the functional requirements of the building, its energy consumption, cost, and thermal/visual comfort priorities.

Table 2.35 The three-tier design approach with the highlighted tier of passive design for achieving a high performance sustainable building, based on (Lechner, 2015)

Tier/Step	Type of Strategy	Possible examples to consider in design
1	Climate Responsiveness: Heat avoidance, rejection, retention	• Building: location; site design; landscaping; form; orientation; color; insulation; exterior shading; construction materials; air tightness • Windows: orientation; size; glazing type; insulation; shading
2	**Passive systems**	• Heating with direct gain, Trombe' wall, or sunspace • Cooling with comfort ventilation, night flush cooling, earth coupling, and cooling tower system • Daylighting with light shelves or clerestories
3	Active Systems: Heating& cooling equipment, renewable energy, lighting equipment	• Efficient lighting and appliances: Task ambient lighting fixtures, LEDS, and fluorescent • Renewables: photovoltaics, wind turbines, solar domestic hot water, active solar swimming pool water • Heat pump, furnace, boiler, spot electric heating, active solar space heating, heat pump, air conditioners, evaporative coolers, fans (whole house, ceiling, spot)

Probably, a brief description of where or when practitioners draw on the use of passive systems is the three-tier approach proposed by Lechner (2009). Table 2.35 shows the possible considerations in each tier/step which also include passive systems. To illustrate this process with examples I draw briefly on three case studies including HKS design for Dadeng Island Convention Center in Xiamen, China (HKS, 2013), National Renewable Energy Lab Research Support Facility (NREL RSF) in Golden, Colorado (Athienitis and O'Brien, 2015), and Zion National Park Visitor Center in Utah (Hayter et al., 2001).

2.5.2. Three Case Studies on The Approach of Using Passive Systems

The first case study is HKS designs for Dadeng Island Convention Center in Xiamen, China. The design process of the convention center included early design analysis using the Ecotect software and its Weather tool for finding climatic classification, optimum orientation of the building, shading design, and insolation on the building's envelope. In addition, using the psychometric charts in the Weather tool HKS recommended active cooling along with possible passive strategies including thermal mass effect, passive solar heating, and natural ventilation for this building and climate.

In the second step, using eQuest for the whole-building energy simulation, a baseline model has been developed and the individual effect of skylight, improved glass type, and building orientation for energy saving were analyzed. In a final step the useful energy efficiency measures, which were compared individually with the baseline, were collected together and simulated resulting in 20% energy savings compared to the basecase energy model. This project has received awards, though in the category of unbuilt projects. In sum, we can say the design of the convention center began with a study about the individual impact of the passive strategies found through Climate Consultant. These strategies then were input to eQuest for a whole-building simulation study to compare the savings with the basecase model.

National Renewable Energy Lab Research Support Facility (NREL RSF), in Golden, Colorado, is the second case study. This facility's plan and its thermal zones are realized through three rectangular shapes: two unparalleled and one crossing these two rectangles. Some of the applied natural system energy saving strategies in this facility center included high performance building envelope, daylighting, thermal storage labyrinth, natural ventilation, and thermal mass. In NREL RSF computer modeling has played an important role throughout the design process and in ensuring that the energy goals would be met within the scope of the specified budget. eQuest, a whole-building energy simulation program, has been used as the main simulation tool in the design process.

Other programs have been used in this project to provide more detailed information or to complement the whole-building simulation tool. Hirsch et al. (2011) has described the models used in the design process in details as well as how the models informed important design decisions on the path from preliminary design to the completed building. Specialized simulation tools have been used independently for the project to design the major innovative components of the building, which were later integrated into the whole-building simulation program.

A brief summary of the major tools and design approaches applied include (Hirsch et al., 2011):

- RADIANCE for daylighting analysis such as light redirection and shading analysis as well as electric light control analysis
- IES VE for natural ventilation analysis and its thermal effects
- Separate modeling of the data center for its cooling and heat recovery design, including the electric consumption of information technology (IT), fan energy, cooling energy, and heat recovery. The resulting information defined the input for the thermal labyrinth model and the eQuest software.
- eQuest for the whole-building energy simulation and the integration of various components of the energy model
- Numerical models for further investigation/validation of the advantage of including or not including natural systems. Examples include a numerical thermal network model with explicit finite differencing approach, which was created using Mathcad for a typical section of the office area. Additionally, for heat flow between thermal zones and its surroundings convective and radiant heat transfer modeling were coupled, but modeled within two enclosures: physical and radiosity. Solar heat gains and daylighting due to transmitted solar radiation were calculated in the radiosity model with the radiosity approach.

In sum, we can say what distinguishes the design of the NREL RSF from other similar projects is the integration of different simulation tools and the use of numerical models. Particularly, the numerical models were developed to validate the findings from computer simulations or for the time that computer simulation tools are not sufficient to reach a correct design solution.

The third case, Zion National Park (ZNP) Visitor Center in Southwest Utah, USA, draws vastly on natural/passive systems. For this reason, this project has been further discussed here compared with the two other case studies.
The key steps in the design process for choosing/or not choosing the natural systems in this project included:

This project began with a series of design charrettes to brainstorm about the project's goals including energy issues and natural systems in design. During the charrettes, the energy consultant through observing the natural cooling and heating effects of the National Park's canyon was inspired for a similarly climatically adaptable design. In this region, daily high summer temperatures easily exceed 38°C (100°F). The Virgin River in the region has cut a deep narrow slot (about 2000 ft. deep) through many rock layers. Water seeping through the rocks wet the canyon walls. Hot air rising from the wider canyon below passes through the narrow passage of the slot canyon. In many parts of the slot canyon, direct sunlight on the lower walls and canyon floor lasts less than an hour per day.

The combination of the evaporating water from the walls of the canyon due to hot air and the high-mass walls in the canyon provides comfortable temperatures. In other words, a cool microclimate is provided in this harsh climate through integrated natural strategies such as solar load avoidance, evaporative cooling, thermal mass, and natural ventilation. Additionally, inside the slot canyon, the predominantly diffuse daylighting makes a building feel cooler since it avoids the solar gain usually caused by direct sunlight.

The wider areas of the canyon have an opposite effect. The east canyon walls are heated due to evening sun, which stays warm into the night despite the average temperature drop to 15°C (60°F) at summer nights. The heat absorbed by the massive stone materials will be slowly released during the evening and night times. Therefore, the stored heat is reradiated from these rocks to keep the temperature at comfort range.

These observations resulted from understanding the features of the natural environment in which the building was to be designed and analyzing the programmatic needs of the building. On this basis, the integrated design of the building established natural systems including natural ventilation, evaporative cooling, daylighting, solar gain avoidance with building shape/envelope features in summer, passive solar heating in winter with direct and indirect solar gains, massive building materials to stabilize indoor temperatures, and location in relation to the shade of trees and newly constructed outdoor structures.

Before incorporating all of these natural systems, hourly base-case simulations of the building were conducted to determine building energy loads and to calculate the energy performance of a code-compliant building (LBNL, 1994; Palmiter, 1984). After realizing the code compliance of the ZNP Visitor Center base-case (ASHRAE 90.1, 1989), parametric analysis was performed. This analysis used the base-case building simulations to find out the impact of the changes of certain building envelope components. Examples include the U-value of the wall, floor, roof, and windows which were minimized to reach zero heat transfer across these components. The resulting building energy simulations of these parameters could show that daylighting, shading, natural ventilation, evaporative cooling, and passive solar heating more than other strategies reduced total building energy consumptions. By combining the parametric analysis results with elements used to keep the canyon comfortable, the design team of the ZNP analyzed strategies to address primary energy loads.

Therefore, computer simulations were conducted to assess the usefulness of these strategies quantitatively. In this case, architectural requirements and energy-efficient strategies were merged. For example, the team chose downdraft cool towers as the primary cooling system, which is covered in a material in harmony with the stone material of the canyon. For cooling the building no mechanical fan is required. The location of the building's windows, including clerestory windows, promote daylighting by reducing the depth of the building for lighting and improve natural ventilation by moving the cool air inside.

Cost analysis were used in this project to show the usefulness of the selected natural system strategies. The energy cost savings, excluding the savings from the PV system, were approximately 80% based on the simulation results. The integration of the energy features into the envelope increased the cost of the building, however, due to the reduction of infrastructure and mechanical systems cost the total cost was reduced. A post occupancy evaluation (POE) also helped the designers to decide about the usefulness of the applied natural systems for their future designs. The POE showed that the downdraft cooling towers and the natural ventilation work best in open floor plans. Since the occupants of the office rooms in ZNP building preferred to keep the doors/windows closed for privacy and security reasons, it was impossible for natural ventilation/cooling to take place in these areas.

In sum, what distinguished ZNP from the other two case study projects is its application of a variety of natural/passive systems which has been followed by cost evaluation and post occupancy evaluation to inform the future application of these systems.

2.5.3. Best Practices: AIA COTE Top 10 Awards

This section evaluates exemplary buildings in the US, which are claimed to be highly sustainable and high performance. For this purpose, the buildings that are awarded each year by the AIA Committee of The Environment were selected. As mentioned earlier, these buildings should achieve high scores in terms of design integration and their impacts on other factors such as community, ecology, water use, economy, energy saving, wellness, and material resources. An analysis of these buildings' use of passive systems can determine to some extent if passive systems are being used in best sustainable designs in the US, and, if yes, which systems are being use more regularly.

For the ease of analysis, the passive strategies used in these buildings were analyzed through twenty tables and charts. Table 1-passive to Table 20-passive include columns for the location/climate of the projects and their design strategies for building envelope, natural heating, natural cooling, daylighting, natural ventilation, active systems, and water conservation. One column also outlines the milestones of each project. The case study selection included the buildings from the year 2010 and the year 2017. The cases from the year 2017 represent the latest at the time of analyzing the AIA COTE TOP 10 awards. Additionally, analyzing buildings from the year 2010 for the AIA Award, will show if passive systems were being used more in the earlier awarded projects compared to the present time. Among these AIA awarded projects, two buildings are located outside the US, though they have taken part in the AIA Award program. These two buildings include the Green Mark Platinum-certified Ng Teng Fong General Hospital (NTFGH) in Singapore, and Manitoba Hydro Place in Canada.

Ten radar charts in Appendix D summarizes an analysis of the mainly passive performance of these buildings. For this purpose, the performance data available for each building, such as the percentage of the floor area achieving adequate light without artificial lighting (PWF/O), was considered. This analysis was limited to the projects awarded in the year 2017, since compared to the 2010 projects they provided more quantitative data as well as qualitative descriptions for building performance evaluation. This increase in building performance data availability could be a result of higher code compliance requirements and AIA's demand for providing more measurable sustainability metrics in daylighting, water, and energy design.

Review of the charts and tables for the passive performance of the selected buildings reveals that in passive cooling and heating the building performance rarely goes beyond 5 score on a scale of 10. While in daylighting and establishment of the Domestic Hot Water (DHW) through solar thermal collectors most of the buildings achieve an acceptable range of score from five to ten, with few exceptions that have not passive strategies for providing the domestic hot water at all.

The passive survival of the buildings more than passive design strategies depends highly on the production of energy through renewable energy sources such as wind and solar energy. Therefore, those buildings with higher solar power capacity, such as the Stanford University Plant Facility, will have a higher chance of continual building performance without interruption in the case of power outage.

All in all, the case study analyses of AIA COTE TOP 10 Awards show that there is more opportunities in the application of passive heating and cooling in sustainable buildings. This is perceptible from the low score of passive heating and cooling and also very rare application of passive design strategies. The Tables Passive 1-20 show that almost none of the add-on passive systems are applied in the awarded buildings and their passive design strategies mainly include building envelope design such as superinsulation or natural ventilation/cooling such as through strategically located windows. A few buildings have expanded their use of passive design such as NOAA center, which had applied downdraft cooling strategies or the Stanford University Facility center, which had applied phase change materials.

3. RESEARCH METHODS

3.1. Introduction

The literature review in the previous section revealed some of the issues of passive design in the US, which led to the construction of several themes that have ushered the current research investigation. This section will explain the methodologies that were applied in this dissertation research to investigate and measure qualitatively and quantitatively these themes through four main constructs including:

- The factors influencing the increase/reduction of the use of passive/natural systems in buildings
- The design tools being used for the education/application of passive design
- The most and least recurring types of passive/natural system strategies, and
- The importance of incorporating passive/natural system strategies in a practical design process with respect to their integration with mechanical systems

Due to the qualitative and quantitative nature of these themes/constructs a mixed-method research methodology will be adopted which included both qualitative and quantitative research methodologies. These research methodologies include: case study, survey questionnaire, and content analysis. While each of these methods has been discussed in their own exclusive sections tied to the findings of that method, the following sections will explain further about the logic and philosophy of adopting these research methodologies.

The logic of integrating the three methods in this research is using their results for comparison to find out if they are converging or diverging. In the proposed research, survey and case study results support the content analysis as in a mixed method research. Content analyses are not necessarily stand-alone methods and might be an integral part of the data analysis in other types of studies (Wennick et. al, 2009). This may result in a mixed method research, with both qualitative and quantitative elements, which also reduces research biases (Leedy and Ormrod, 2013). Therefore, in this dissertation research, case study and content analysis respond to the qualitative investigation of the research, while the survey methodology contributes to the quantitative findings of the research.

3.2. Qualitative Methods Applied

3.2.1. Case Study

A case study approach was applied as one of the two qualitative approaches in the research. Case studies included buildings selected by the American Institute of Architects Committee of the Built Environment to be awarded as the Top Ten high performance sustainable buildings in the US. AIA COTE TOP 10 is the American Institute of Architects' Committee of the Environment award which is given every year to the best ten new green projects in the US, that are sustainably high performance. The author neither confirms nor rejects the AIA TOP 10 Awards as the best sustainable practices in the US. However, these buildings were selected because they are selected by

AIA as a nationally recognized institution in architecture in the US. Launched in 1997, the AIA annual awards are the longest running recognition program for sustainable design excellence by AIA.

Another reason for the selection of the AIA TOP 10 Award as best building practices was four criteria that were pursued by this research for case study selection and analysis. First, the buildings to be selected for case study analysis should be mainly nonresidential or commercial buildings that have received sustainable design certifications such as LEED, NZEB, Living Building Challenge, and Passive House Certification. Second, the buildings' Energy Use Intensity (EUI) should be less than the national median EUI. Third, buildings should have been built in the last ten years to reflect a recent snapshot of the sustainable design practice. And fourth, preference will be given to buildings that have post-occupancy evaluation with measured data along with predicted data. The majority of AIA TOP Ten Awards, particularly those buildings which received awards in recent years, have post occupancy evaluation information as an optional requirement to take part in the AIA TOP 10 Award Competition, while they also fulfil the other four selection criteria.

As such, the AIA COTE TOP 10 Toolkit (AIA, 2018) evaluates built projects in ten categories including:

- Design for integration: what is the big idea behind this project—and how did the approach toward sustainability inform the design concept?

- Design for community: how do community members, inside and outside the building, benefit from the project? The focus is on walkability, human scale, alternative transportation, community engagement and buy-in, and social equity.
- Design for ecology: In what ways does the design respond to the ecology of this place?
- Design for water: how does the project use water wisely and handle rainfall responsibly?
- Design for economy: how does the project provide “more with less”?
- Design for energy: how much energy does the project use? Is any of that energy generated on-site from renewable sources, and what is the net carbon impact?
- Design for wellness: how does the design promote the health of the occupants? The answer should describe strategies for optimizing daylight, indoor air quality, connections to the outdoors, and thermal, visual, and acoustical comfort inside and outside the building.
- Design for resources: what are the efforts to optimize the amount of material used on the project to reduce product-cycle environmental impacts while enhancing building performance?
- Design for change: how the project is designed to facilitate adaptation for other uses and/or how an existing building was repurposed?

- Design for discovery: is there post-occupancy evaluation of the building in terms of its actual performance? What lessons have learned from design to the occupancy phase and post-occupancy evaluation, and how have these been incorporated in subsequent project?

The cases selected from the top ten awards included buildings from the year 2010 and 2017. Year 2017 was the latest year with available top ten awards by AIA and the year 2010 compared with the first years of launching the award competition had a stronger database and more information to evaluate any selected case study. A tabular format was used to analyze the selected case studies in Table 1-passive to Table 2-passive in the appendix. The analysis of the buildings included information in nine main columns about the project completion year, the project team members, location and climate of the project, passive building envelope strategies, natural heating, natural cooling, daylighting, natural ventilation, active systems, and milestones of the project.

Passive design concepts and technical/performance metrics were used to analyze the buildings and to score their passive building performance. Selected buildings' data were collected online through the AIA website (AIA, 2018). Efforts were made to collect performance data as much as possible, beyond the available data on the AIA website, by searching for building performance information in other sources for the awarded projects. One example of these efforts is searching for the websites of the firms who contributed to an award-winning project.

The metrics used to analyze the case studies were based on the metrics provided by the majority of the case study projects for energy, daylighting, visual comfort, water, carbon emission, and resiliency. For example, these metrics for daylighting and visual comfort analysis included PFVO, PFW/O, SDA, and the percentage of area which is daylit with more than 300 lux at 3pm on March 21(equinox). Other applied building technical/performance metrics include the followings: Site EUI, SDA (Spatial Daylighting Autonomy), annual carbon emission reduction, heating /cooling loads reduction, renewable energy, active systems' energy consumption, passive survivability, and natural systems energy savings. While there are other building performance metrics for evaluating a building's performance, the case study focused on the metrics that had a corresponding data available in the AIA TOP Ten Projects.

Description of some of the applied metrics for the case study analyses is as follows (Sterner, 2015; AIA, 2018):

- PFVO is the percentage of floor area or percentage of occupant work stations with direct views of the outdoors.
- PWF/O is the percentage of floor area or percentage of occupant work stations achieving adequate light without the use of artificial lighting.
- PFW30 is the percentage of floor area or percentage of occupant work stations within 30 feet of operable windows.

- EUI or Energy Use Intensity is a building's annual energy use per unit area. It is typically measured in thousands of BTU per square foot per year (kBTU/ft2/yr) or kWh/m2/yr. EUI can measure "site" energy use (what the building consumes) or "source" energy use (the amount of fuel the power plant burns to produce that much energy). Unless otherwise specified, EUI typically refers to "site" energy use.
- Annual carbon emissions measure the carbon emissions associated with a building's energy consumption. To calculate carbon, we have to follow the energy back to where it was produced. This means that the carbon intensity of electricity depends on the mix of power sources in a region. Other (non-carbon) greenhouse gasses (e.g., methane) are assigned a standard carbon equivalency. Therefore, the final result is in terms of carbon.
- SDA or Spatial Daylight Autonomy describes how much of a space receives sufficient daylight. Specially, it describes the percentage of floor area that receives a minimum illumination level for a minimum percentage of annual occupied hours — for instance, the area that receives at least 300 lux for at least 50% of occupied hours (which would be notated as sDA300/50%). It is a climate-based daylighting metric, meaning that it is simulated using a location-specific weather file.
- A heating or cooling load is the amount of heat that needs to be added/removed from a space to maintain the desired temperature. The "peak load" is the worst hour over the span of a year. Therefore, a

building's "peak heating load" is the largest amount of heat that needs to be added to a space in a single hour.

- Energy saving is the percentage of energy savings compared to the base case model through active or passive systems
- Passive survivability is the number of days that a building can function normally without access to electricity, such as in the case of power outage.

As for the passive design concepts which were considered for the evaluating the passive performance of case studies, factors such as the percentage of operable windows for natural ventilation, or passive design concepts such as solar chimney, downdraft cooling, or proper application of phase change materials were considered in scoring the passive performance of the buildings on a scale of 1 to 10. Therefore, a combination of objective weighting scores (i.e. scores based on technical building performance metrics) and subjective weighting scores (i.e. scores based on passive design concepts) was used to analyze/score the passive performance of the selected buildings. analysis The findings of the case study beyond tables, were also presented through radar charts for the ease of analysis.

The radar charts scored the passive performance of the buildings in terms of heating, cooling, ventilation, domestic hot water, renewables, lighting, and passive survival. These charts were only provided for the Top 10 Awards of the year 2017, due to the limited building performance data that were provided for the Top 10 Awards of the year 2010.

Because usually there is a difference between theory and actual practice, the findings of the case study of the TOP 10 COTE AIA Awards can show to what extent passive systems are being used in practice. The case study findings in fact can support the findings of the survey/interview by showing if natural system strategies proposed in the books/guidelines reflect the way sustainable designers are using them their actual practice, and if yes to what extent.

Therefore, the case study of exemplary sustainable buildings representative of best practices will provide a snapshot of the actually applied strategies for the incorporation of natural systems to buildings. This snapshot will provide a ground to compare the case study results with the results of the survey questionnaire to seek any commonality/discrepancy between these methods' findings in using tools and strategies for natural/passive system designs in the US. This ground will be reinforced with the findings of the content analysis in which practitioners may reflect on their attitude about passive design strategies and tools as well as their relevant issues.

However, case study cannot alone reveal information about the passive design tools applied by practitioners or the challenges that practitioners have dealt with for the incorporation or implementation of these systems in buildings. Therefore, other methodologies including survey questionnaire and content analysis will be utilized to reveal such information.

3.2.2. Content Analysis

A content analysis is a detailed and systematic examination of the contents of a particular body of material for the purpose of identifying patterns, themes, or biases (Leedy and Ormrod, 2013). Content analyses are typically performed on forms of human communication such as books, journals, written text, and internet blogs. Therefore, content analysis determines the presence of certain words, themes, or concepts within a set of collected qualitative data (i.e. text). Although it may count the number of times a pattern appears in a context, here content analysis will be used as a qualitative approach to categorized the patterns in the context of the written responses to a text question in the survey questionnaire.

According to Columbia University description of content analysis (2018) it can be used to identify the intentions, focus, or communication trends of an individual, group, or institution; to describe behavioral responses to communications; to determine psychological or emotional state of persons or groups; to reveal international differences in communication content; to reveal patterns in communication content; or to analyze focus group interviews and open-ended questions to complement quantitative data.

On this basis, content analysis in the current research was adopted as a methodology to analyze part of the findings of the survey questionnaire and to supplement the survey findings. In other words, content analysis will be used to analyze the findings of an open-ended text question in the survey questionnaire. The open-ended text question in the survey questionnaire will ask participants if there is any comment or point that was not included in the survey questions, which they want to share. This question, in fact, plays the role of a face-to-face interview question. This strategy was adopted to overcome the time/budget constraints for face-to-face interviews or issues such as participants' hesitation in revealing sensitive information in a face-to-face interview. Although a face-to-face interview can establish rapport between the interviewer and the interviewee to gain more information, this type of interview may bias the findings if the interviewer is not skilled enough to avoid influencing the conversation with personal opinions.

The intent of the applied content analysis method was to make replicable and valid inferences by interpreting and coding textual material (Columbia University, 2018). Using the format proposed by Leedy and Ormrod (2013) for content analysis, this research follows these steps:

First, the specific body of the materials for content analysis needs to be identified, which in the case of the current research include the responses to the last text question in the survey.

Second, the characteristics or qualities of strategies to be examined in precise, concrete terms will be defined. To connect the findings of the content analysis to the constructs of the survey (e.g. challenges in the use of passive design or tools applied by practitioners) and based on the responses that will be collected several themes/categories will be defined to assign relevant responses or part of the responses to each category/theme. To facilitate the analysis process, a color-coding approach will be adopted in which each category has a certain color and all the responses that share the same theme/category will be highlighted in the text responses with the same color.

Third, the color-coded text materials will be extracted to find the shared patterns between the responses and if needed change their category/theme in the previous step. Since the judgments are entirely objective for the studies that involve looking for the appearance of certain words/concepts (e.g. simulation tools) in a text, only one judge/rater (here the researcher) is enough.

3.3. Quantitative Methods Applied

This research uses a survey methodology for its quantitative approach to measure/evaluate the constructs mentioned in the introduction section of this section. Qualtircs software will be used to design the survey questionnaire and to distribute it online among the participants. The use of Qualtircs software also facilities the analysis of the collected data in the next step through its possibilities for exporting the collected data in an excel file format.

3.3.1. Survey Questionnaire Design Principles

One principle which was used to design the survey questionnaire was developing questions with respect to the types of expected responses from the survey. These responses with respect to their measurement tools can be divided into four sets: one set with ordinal scales (e.g. ranking as first, second, third, etc.), one set with nominal scales (e.g. male/female or educational region), and one set with ratio scale (e.g. percentage of residential projects). These measurement scales then were developed to the form questions with respect to types of expected responses from the questionnaire. These questions should shed light on the four constructs of the survey: the tools being used for passive design; the most and least recurring types of natural system strategies including cooling strategies (if any), heating strategies, and daylighting strategies; the challenges and opportunities which will increase/reduce the use of natural systems in design; and the importance of natural system strategies in a practical design process with respect to the use of mechanical systems.

More importantly, the main principle which was maintained in designing the survey questionnaire was to reduce the survey errors/biases. In this case questions were designed with respect to reducing the four typical types of survey errors as explained in the following sections. Conducting surveys that produce accurate information to reflect the views and experiences of a given population requires developing procedures to minimize all four types of survey error. These types of error include coverage, sampling, nonresponse, and measurement errors (Dillman, 2014). Therefore, the logic of the questionnaire design in this research is to reduce these errors to the feasible extent with respect to time and cost. This logic is briefly explained here by discussing these types of survey errors and the strategies which will be adopted to reduce their effects on the survey findings. In addition, before launching the survey, a pilot study can reveal any issue in the content of the survey questionnaire. This strategy will be used to correct any potential issue/error with respect to the potential four types of survey errors discussed in the following sections.

3.3.2. Reducing Survey Measurement Errors

Reducing measurement error: this error is often the result of poor question wording or that the questions are not unidirectional in measuring one construct/concept (Dillman, 2014). There are methods such as factor analysis or focus group to ensure the questions are measuring the desired construct. Conducting focus group with a group of professional experts across the states does not seem feasible. Instead of focus group, the research will use an approach similar to Delphi communication method to ask experts about their feedback on a set of questions that are intended to be used in the survey questionnaire. In Delphi method the process begins by sending a survey questionnaire to the experts in the panel and receiving their response/feedback about that. The survey will continue by a facilitator (the author) in a second run to ask about the shortages/issues in the questions that need to be addressed. This process continues until the responses received from the expert panels are convergent to confirm the appropriateness of the questions (Linstone & Turoff, 1975). This process was tailored to the needs of the current research survey from practitioners/educators and will be further discussed in the survey procedure in section four.

For choosing the proper wording of the questionnaire, the readability of the questions will be checked using Word software readability statistics. A readability level between 9 and 5 for Flesch-Kincaid Grade Level is used. This level of readability makes the meaning of the questions understandable for a wider group of respondents to avoid interpreting the questions by respondents in ways other than intended.

3.3.3. Reducing Nonresponse Error

The nonresponse error occurs when the individuals selected for the survey who do not respond are different from those who do respond in a way that is important to the study (e.g., expertise, experience, etc.) (Dillman, 2014). Minimizing nonresponse error involves motivating most of the individuals sampled to respond. To reduce the nonresponse error, the survey will be short and concise not to take more than 9 minutes to answer. Additionally, the visual appearance of the survey is important such that it looks simple and attractive. Therefore, constructing survey questions involves both choosing words to form the questions and deciding how to visually present the questions, including each of the component parts, to respondents. Besides the use of readability index in word software, avoiding open-ended questions, using multiple choice answers, and Likert scale (if appropriate) can help the survey to be simply understandable.

Meanwhile having one open-ended question at the end, as was explained in the content analysis methodology, will reduce the nonresponse error if there was an answer not covered in the questionnaire. The survey avoids expanding an open-ended question theme to all the questions because codifying/classifying the answers will be difficult later. The order of questions will be from simple questions to questions that are more detailed such that answering each question helps answering the next question.

In the case of measuring sub-constructs of one larger construct, the questions will be grouped together. In grouping multiple questions, the logic is to select questions that are related. For instance, the survey can be structured into four parts including the background, tools, strategies, and influential factors with their related questions to survey the degree of adopting natural/passive systems and factors influential in their design process. Additionally, the survey questionnaire design is after conducting a well-informed literature review to use the findings for designing the survey.

3.3.4. Reducing Survey Sampling and Survey Coverage Errors

Sampling and survey coverage errors can bias the research findings in addition to the two types of survey errors discussed above (i.e. nonresponse error and measurement error). Based on the Design intelligence survey in 2012, the number of architectural firms established in the US equals 20,836 design firms (Design Intelligence, 2017). If Np=population, B = acceptable margin of error (for example, .03 = ± 3% of the true population value), C = Z score associated with the confidence level (1.96 corresponds to the 95% level) and p= the proportion of the population expected to choose one of the two response categories (SurveyMonkey, 2017), the required sample number (Ns) in a rough estimate based on the equation below will be 1000:

$$\boldsymbol{Ns} = \frac{(Np)\ (p)\ (1\text{-}p)}{(Np\text{-}1)\ (B/C)^2 + (p)\ (1\text{-}p)}$$

$$1015=20836\ (.25)/\ ((20836\text{-}1)\ (.03/1.96)^2 + .25)$$

Distributing survey questionnaires to collect about 1000 responses is not reasonable with respect to cost and time. Therefore, to reduce the sampling error through a feasible approach, a purposeful sampling process can be applied in which a fair mix of architects and engineers, who have contributed to both business-as-usual and best building practices, will be included in the survey. Through this approach different lists of architects and engineers' professional organizations as well as top design firms in the US can be surveyed as needed to expand the range of the sample group with a variety of professional backgrounds to increase the external validity of the research. Examples include the AIA Chapters, ASHRAE Chapters, and top sustainable design firms in the US ranked by Architect 50 Magazine, or top design firms ranked by Architectural Record. Meanwhile, for increasing the internal validity of the research the focus can be on the design strategies and architects/engineers inside the country for sampling. The survey will also focus only on passive design strategies, instead of both passive and active systems, to increase the internal validity of the findings.

To implement the explained sampling logic, a survey link will be distributed among architecture and engineering practitioners in the US through each state's AIA and ASHRAE Chapters. Online accessibility to these organizations' chapter information for a preliminary contact as well as their high level of impact on the design and construction of buildings in the US are two main reasons for their inclusion in the survey sample. Each chapter will be contacted to ask for the possibility of distributing the survey among their members for participation.

To manage the survey distribution process among architects and engineers through each state's AIA and ASHRAE Chapters, an excel spreadsheet will be prepared. The spreadsheet will include the name of the executive/vice president of each chapter or the director of communication to be contacted to distribute the survey among their chapters' members. Table 3.1 shows the list of the AIA Chapters and their region, which will be contacted to participate in the survey. Table 3.2 shows the list of the ASHRAE Chapters who will be contacted for participation in the survey. This sample of AIA and ASHRAE members will be supplemented by distributing the survey directly to the lists of top designers and engineers in the US. These lists include top ten sustainable design firms in the US recognized by Architecture 50 magazine[34] (Table 3.3), top ten architecture and

---

[34] For further information please see https://www.architectmagazine.com/practice/architect-50/2017-architect-50-top-50-firms-in-sustainability_o

design firms in the US recognized by Architectural Record [35](Table 3.4), and professionals who contributed to preparing the high performance building standard ASHRAE 189.1.

The target groups of the survey will include educators in addition to practitioners in the in the areas related to passive building design. However, a separate survey will be sent to educators to measure the same four constructs discussed in the introduction of the current chapter. In this case, the focus of the survey will be more on class projects related to passive/natural systems rather than professional projects. Using a separate survey for educators will increase the validity of the findings. The selection of educators in architecture schools will be based on the list of top 50 architecture colleges and schools in the US according to the NICHE 2019 ranking.[36] Table 3.5 shows the list of these schools. Since there is a possibility that not all of these school have educators in the area of passive design, therefore the actual list of universities receiving the survey could be less than fifty schools. The top graduate architecture schools, not included in this list, were also added to the list of survey recipients including: Harvard, MIT, Columbia University, Yale University, SCI-Arc, and the University of Michigan.

---

[35] For further information, please see TOP 300 Architecture Firms in the US rank by Architectural Record at https://www.architecturalrecord.com/Top300/2017-Top-300-Architecture-Firms-1

[36] The 2019 Best Colleges for Architecture ranking by NICHE is based on key statistics and student reviews using data from the U.S. Department of Education. The ranking compares the top architecture programs in the U.S. For further information and the list of schools please see https://www.niche.com/colleges/search/best-colleges-for-architecture/

Table 3.1 List and region of the AIA Chapters who were contacted to participate in the survey

Row Number	Region	AIA Organization
1	Pacific	Washington Seattle
2	Pacific	California Council
3	Pacific	San Francisco
4	Pacific	Oregon
5	Pacific	Portland
6	Southwest	Arizona
7	Southwest	New Mexico
8	Southwest	Texas
9	Southwest	Oklahoma (Central)
10	Southwest	Oklahoma (Eastern)
11	West/Rocky Mountains	Nevada
12	West/Rocky Mountains	Colorado
13	West/Rocky Mountains	Montana
14	West/Rocky Mountains	Idaho
15	West/Rocky Mountains	Wyoming
16	Midwest	Chicago
17	Midwest	Iowa
18	Midwest	Wisconsin
19	Midwest	Nebraska
20	Midwest	Central States (Iowa, Kansas, Missouri, Nebraska and Oklahoma)
21	Midwest	Indiana
22	Midwest	Illinois
23	Midwest	Ohio
24	Midwest	Michigan/Detroit
25	Midwest	Michigan
26	Midwest	Missouri
27	Midwest	Minnesota
28	Midwest	South Dakota
29	Midwest	North Dakota

Table 3.1 Continued

Row Number	Region	AIA Organization
30	Midwest	Kansas
31	Southeast	Tennessee
32	Southeast	Arkansas
33	Southeast	Louisiana
34	Southeast	Mississippi
35	Southeast	Alabama
36	Southeast	Alabama
37	Southeast	Florida
38	Southeast	Georgia
39	Southeast	Kentucky
40	Southeast	West Virginia
41	Southeast	Virginia
42	Southeast	North Carolina
43	Southeast	South Carolina
44	Southeast	Maryland
45	Southeast	Delaware
46	Northeast	New Jersey
47	Northeast	BSA Massachusetts
48	Northeast	New England
49	Northeast	Connecticut
50	Northeast	Maine
51	Northeast	Rhode Island
52	Northeast	Vermont
53	Northeast	New Hampshire
54	Northeast	New York
55	Northeast	Pennsylvania
56	Northeast	AIA DC
57	-	Alaska
58	-	AIA Honolulu (Hawaii)

Table 3.2 List and region of the ASHRAE Chapters who were contacted to participate in the survey

Row Number	Region	ASHRAE Chapter Name
1	Region I	Boston
2	Region I	Long Island
3	Region I	New York
4	Region I	New York
5	Region I	Rochester
6	Region I	Champlain Valley
7	Region I	Maine
8	Region I	Twin Tiers
9	Region I	Granite State
10	Region III	Central Pennsylvania
11	Region III	Pittsburgh
12	Region III	Hampton Roads
13	Region III	Richmond
14	Region III	Roanoke
15	Region III	Anthracite
16	Region IV	North Piedmont
17	Region IV	Atlanta
18	Region IV	Triangle
19	Region V	Columbus
20	Region V	Columbus
21	Region V	Dayton
22	Region V	Detroit
23	Region VI	Illinois
24	Region VI	Iowa
25	Region VI	Iowa

Table 3.2 Continued

Row Number	Region	ASHRAE Chapter Name
26	Region VI	St Louis
27	Region VI	Madison
28	Region VII	Louisville
29	Region VII	Memphis
30	Region VII	New Orleans
31	Region VII	Nashville
32	Region VII	East Tennessee
33	Region VII	West Virginia
34	Region VIII	Houston
35	Region VIII	Houston
36	Region VIII	Alamo
37	Region VIII	Austin
38	Region VIII	Austin
39	Region VIII	Dallas
40	Region VIII	Dallas
41	Region VIII	Dallas
42	Region VIII	Central Oklahoma
43	Region VIII	Northeastern Oklahoma
44	Region VIII	Fort Worth
45	Region IX	Kansas City
46	Region IX	Rocky Mountain
47	Region IX	Utah
48	Region IX	Utah
49	Region IX	Nebraska
50	Region IX	Nebraska
51	Region IX	South Dakota

Table 3.2 Continued

Row Number	Region	ASHRAE Chapter Name
52	Region IX	Black Hills
53	Region IX	Big Sky
54	Region IX	Pikes Peak
55	Region X	San Joaquin
56	Region X	Southern California
57	Region X	San Diego
58	Region X	Central Arizona
59	Region X	Central Arizona
60	Region X	Tucson
61	Region X	Tucson
62	Region X	Northern Nevada
63	Region XI	Oregon
64	Region XII	Miami
65	Region XII	Miami

Table 3.3 List of the top ten sustainable design firms in the US ranked by Architect 50 in Architect Magazine (Architect 50, 2017)

Rank	Organization	Architect 50 Magazine Score
1	ZGF Architects	100
2	ZeroEnergy Design	94
3	EYP Architecture & Engineering	84.8
4	Perkins+Will	84
5	Skidmore, Owings & Merrill	83.6
6	Lake|Flato Architects	82.1
7	Leddy Maytum Stacy Architects	80.1
8	The Miller Hull Partnership	79.9
9	Touloukian Touloukian Inc.	79.8
10	Mithun	79.3

Table 3.4 List of top ten design firms in the US ranked by Architectural Record (2017)

Rank 2017/ 2016	Company	U.S. Headquarters	Type of Firm	Total Architectural Revenue	Domestic Architectural Revenue	International Architectural Revenue	% Design Revenue from Architecture	Total Design Revenue in Millions of Dollars
1/1	Gensler	San Francisco	A	$1,192.37	$981.02	$211.35	100%	$1,192.37
2/2	AECOM	Los Angeles, Calif.	EAC	$595.50	$245.80	$349.70	8%	$7,429.97
3/3	Perkins + Will	Chicago, Ill.	A	$562.33	$423.43	$138.90	100%	$562.33
4/4	Jacobs	Dallas, Texas	EAC	$426.07	$243.24	$182.83	7%	$6,387.25
5/6	HOK	St. Louis, Mo.	AE	$384.74	$288.31	$96.43	89%	$430.00
6/7	HKS	Dallas, Texas	A	$376.68	$338.13	$38.55	100%	$376.68
7/8	CH2M	Englewood, Colo.	E	$357.63	$197.56	$160.07	10%	$3,551.16
8/9	HDR	Omaha, Neb.	EA	$354.30	$238.20	$116.10	18%	$1,927.60
9/13	IBI Group	Westerville, Ohio	AE	$318.89	$106.39	$212.50	89%	$358.30
10/12	Stantec Inc.	Irvine, Calif.	EAL	$258.53	$258.53	$-	16%	$1,621.93

(A = Architect; AE = Architect-Engineer; AP = Architect Planner; EAL = Engineer Architect Landscape; AEC = Architect-Engineer-Contractor)

Table 3.5 List of top 50 Architecture Schools in the US ranked by Niche (2019)

Ranking	School of Architecture
1	Washington University in St. Louis, Saint Louis, MO
2	Rice University, Houston, TX
3	Cornell University, Ithaca, NY
4	University of Southern California, Los Angeles, CA
5	University of Notre Dame, Notre Dame, IN
6	University of California – Berkeley, Berkeley, CA
7	The Cooper Union for the Advancement of Science and Art, New York, NY
8	Tulane University, New Orleans, LA
9	University of Virginia, Charlottesville, VA
10	Virginia Tech, Blacksburg, VA
11	Northeastern University, Boston, MA
12	Carnegie Mellon University, Pittsburgh, PA
13	California Polytechnic State University - San Luis Obispo, San Luis Obispo, CA

Table 3.5 Continued

Ranking	School of Architecture
14	University of Texas – Austin, Austin, TX
15	Syracuse University, Syracuse, NY
16	Rhode Island School of Design, Providence, RI
17	Pratt Institute, Brooklyn, NY
18	Rensselaer Polytechnic Institute, Troy, NY
19	Illinois Institute of Technology, Chicago, IL
20	Georgia Institute of Technology, Atlanta, GA
21	University of Michigan - Ann Arbor, Ann Arbor, MI
22	University of Miami, Coral Gables, FL
23	University of Minnesota - Twin Cities, Minneapolis, MN
24	University of Washington, Seattle, WA
25	University of California - Los Angeles, Los Angeles, CA
26	University of Cincinnati, Cincinnati, OH
27	Texas A&M University, College Station, TX
28	University of Illinois at Urbana-Champaign, Champaign, IL
29	Clemson University, Clemson, SC
30	The Ohio State University, Columbus, OH
31	Penn State, University Park, PA
32	University of Maryland - College Park, College Park, MD
33	University of Massachusetts – Amherst, Amherst, MA
34	Iowa State University, Ames, IA
35	University of Wisconsin, Milwaukee, WI
36	Woodbury University, Burbank, CA
37	University of Georgia, Athens, GA
38	Miami University, Oxford, OH
39	Hobart and William Smith Colleges, Geneva, NY
40	Judson University, Elgin, IL
41	Catholic University of America, Washington, DC
42	University of Florida, Gainesville, FL
43	Jefferson (Philadelphia University + Thomas Jefferson University), Philadelphia, PA
44	Auburn University, Auburn, AL
45	Lawrence Technological University, Southfield, MI
46	SUNY College of Environmental Science & Forestry, Syracuse, NY
47	University of Oregon, Eugene, OR
48	North Carolina State University, Raleigh, NC
49	Kent State University, Kent, OH
49	California State Polytechnic University – Pomona, Pomona, CA
50	University of Kansas, Lawrence, KS

3.4. Research with Human Subject

The U.S. Department of Health and Human Services (2011) regulations (45 CFR 46) requires that all studies related to human subjects receive approval from an Institutional Review Board (IRB). An application for this study was submitted to the Texas A&M University IRB office since it included a survey targeting the practitioners and educators in the US. The IRB reviewed the application with the required materials including the survey questionnaire and determined that the proposed activity is not a research involving human subjects as defined by DHHS and FDA regulations. The IRB protocol number for this approval was IRB2018-0262, which is included in Appendix A.

3.5. Summary of the Applied Research Methodologies and Strategies

In summary, this research started with a broad review of the literature on passive systems and the potential issues for their application in the US. This review informed the content of the required research methodologies including case study and survey/content analysis. The case study and content analysis will respond to the qualitative nature of the research while survey questionnaire will respond to the quantitative nature of the research constructs. Therefore, the use of both quantitative and qualitative approaches paves the ground for applying a triangulation approach to reveal more accurate information on the practice and education of passive design in the US and their challenges.

As explained in this section the following approaches and research methodologies will be adopted to avoid/reduce research bias and errors in the research:

- Use of a mixed method research: content analysis, case study, and survey methods can form a mixed method research to reduce biases through comparing the findings of the three methods.
- Use of Delphi communication method with a panel of experts: receiving feedback from experts in several rounds of review will reduce the bias from the content of the questions based on the Delphi method explained earlier.
- Use of a pilot study: conducting a pilot study may reveal some of the biases in the survey questionnaire, such as measurement errors, which can be corrected before the actual survey. Time and cost are crucial factors in using/or not using this strategy.
- Minimizing the number of constructs/concepts: minimizing the number of constructs to be measured in the survey will increase the homogeneity of the survey and its internal validity.
- Reducing the coverage bias: this error/bias occurs when not all members of the population have a known, nonzero chance of being included in the sample for the survey and when those who are excluded are different from those who are included (Dillman, 2014). Because the link of the survey will be sent directly through email to the sample group members, all of the members will have an equal chance to respond which will reduce the coverage bias/error.

4. PRACTITIONERS SURVEY: RESULTS AND DATA ANALYSIS

4.1. Introduction

This section will present and analyze the results of the data that was collected through two online survey questionnaires. The purpose of the surveys was to obtain a more accurate perception of the education and practice of passive system design across different disciplines in academia and the building industry in the US. The two survey questionnaires were designed to find answers in response to the issues found in the literature on the application of passive design in buildings. Additionally, each question was designed to address these issues, which are summarized through the following constructs:

- The factors influencing the increase/reduction of the use of passive/natural systems in buildings
- The design tools being used for the education/application of passive design
- The most and least recurring types of passive/natural system strategies
- The importance of incorporating passive/natural system strategies in a practical design process with respect to their integration with mechanical systems

To begin the survey, its first draft was sent to academics and professionals in the field to ask for their feedback on the content of the survey. In some cases, phone conversations with professionals about the content of the survey replaced correspondence through email. Using this process, the content of the survey was revised based on the feedback received from academics and professionals. In addition, some pilot tests were conducted to adjust the content of the survey as well as the required time for answering its questions. To increase the rate of response to the survey, the questionnaire began with 12 questions and, through several revisions, reached 22 questions at the end of the pilot tests. Final survey used 22 questions for professionals and 26 questions for educators to keep an optimum balance between the required time to answer the questions and the comprehensiveness of the survey in measuring the desired constructs.

4.2. Procedure

In the overall process it was determined that one survey would target building practitioners while the other survey would focus on academics in the field of sustainable design and building performance in architecture schools. The survey link was distributed to architect and engineering practitioners in the US through each state's AIA and ASHRAE Chapters. Prior to the distribution each chapter was contacted to determine the possibility of distributing the survey among their members for their participation. Before the survey started, it was difficult to determine how many survey participants there would be. However, based on the author's communication with number of members in each chapter is not known, but based on the author's communication with chapters it was estimated that 100 to 3,000 members per chapter were partially available to take the survey depending on the location and size of the chapters.

To increase external validity and generalizability of the survey findings within the US, the sample of AIA and ASHRAE members was supplemented by distributing the survey directly to the lists of top architectural designers and engineers in the US. These lists include the top ten sustainable design firms in the US recognized by Architecture 50 magazine[37], top ten architecture and design firms in the US by Architectural Record[38], and ASHRAE professionals influential in preparing high performance building standards 189.1. The selection of the survey recipients in the top firms was based on a purposeful sampling process. In this process design and/or engineering members/directors of each firm practicing in the field of sustainability and green building design were selected to respond to the survey. The selection of educators in architecture schools was from the top 50 architecture colleges and schools in the US based on the NICHE 2019 ranking.[39]

Over the course of two and a half months a total of 168 responses were collected from practitioners in the building industry from which 138 responses were usable. In addition, a total of 39 responses were collected from educators, with 37 responses out of the 39 responses considered for the analysis. The remaining two responses were not used

---

[37] For further information please see https://www.architectmagazine.com/practice/architect-50/2017-architect-50-top-50-firms-in-sustainability_o

[38] For further information, please see TOP 300 Architecture Firms in the US rank by Architectural Record at https://www.architecturalrecord.com/Top300/2017-Top-300-Architecture-Firms-1

[39] The 2019 Best Colleges for Architecture ranking by NICHE is based on key statistics and student reviews using data from the U.S. Department of Education. The ranking compares the top architecture programs in the U.S. For further information and the list of schools please see https://www.niche.com/colleges/search/best-colleges-for-architecture/

because they were incomplete. The selection of the building educators was through a purposeful sampling of the top 50 architecture schools with the selected instructors and/or professors who indicated on their websites' profiles they used passive systems in their studio or course syllabi.

The survey contained in Appendix B shows the invitation that was sent to participants either directly or through the AIA and ASHRAE chapters in the US. In some cases, the content of this email along with the survey link was posted by the chapters' director on the local chapters monthly/weekly digital newsletter. The content of the email was meant to explain the goals and target groups of the research. In all cases the survey was anonymous and did not reveal the identity of the respondents through its collected information. In the first month after the invitations were sent, only 35 complete responses were received from practitioners. Therefore, multiple attempts were made to encourage the AIA and ASHRAE Chapters to participate in the survey. This process increased the number of usable collected responses to 163. After a review of the responses, 138 responses were determined to be appropriate for use in the analysis, yielding a 138/168 or 82.1% response rate.

In the final analysis only finished surveys with a 100% survey completion were considered. The reported time spent by the participation answering the survey for those participants with a 100% survey completion was in a range from a minimum of 3 minutes and 50 seconds to a maximum of 86 minutes (Figure 4.1). Ignoring the outliers in this time spent for analysis, the average response time was 8 minutes and 47 seconds.

The average time spent by educators to respond to the survey questionnaire (26 questions) was about 21 minutes and 20 seconds. From these 26 questions five questions were contingent upon the respondents' answers to other questions giving a range of 21 to 26 questions overall. Compared with professionals' response time, the response time of educators was longer. This longer time was due to having more questions for educators and the inclusion of cross table questions for educators where several questions were asked for the same topic.

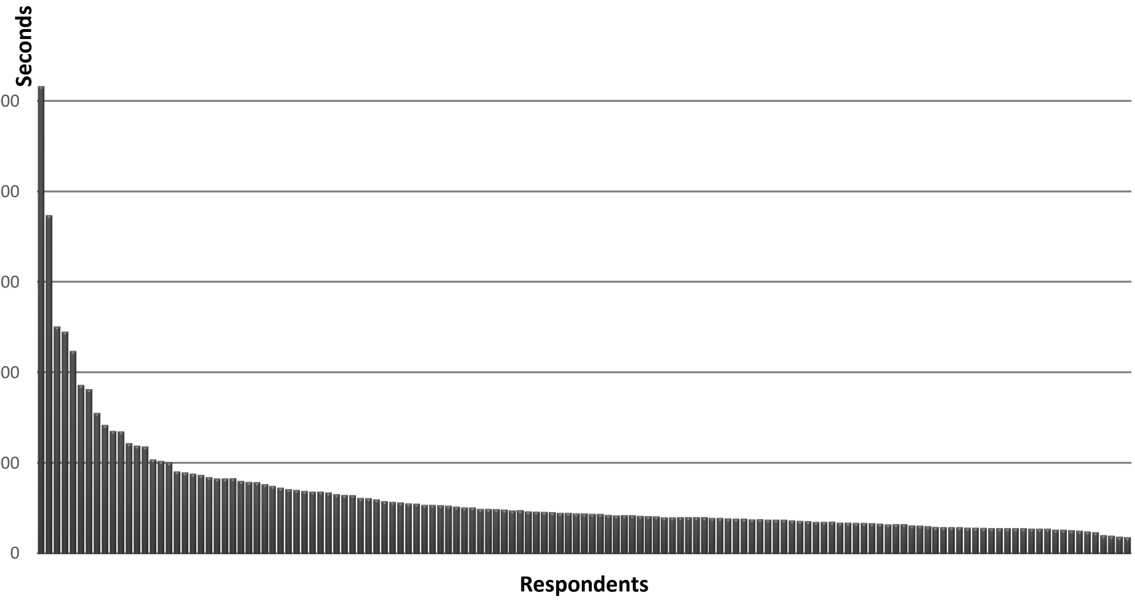


Figure 4.1 Survey Duration for Practitioners (Amount of Time respondents Spent Completing the Survey)

4.3. Survey Tools and Analysis Procedure

The survey consisted of 22 items for practitioners, including 18 short answer questions, 1 image question, and 1 narrative question. In addition, the display of two of the questions was contingent upon the respondents' answers. These two questions inquired about their primary professions and professional registrations in the US. The short-answer questions used a multiple choice format or a percent slider format. A dropdown answer format was selected for questions that allowed only one applicable answer from the possible choices. This strategy reduced the time and length of the survey visually and made it easier to read.

Demographic information was determined primarily through multiple-choice questions, including: the individual's primary professional role, location of their education, years of work experience, geographic location of their licensure if applicable, and their affiliations. The survey also included a visual question through which respondents would click on the ASHRAE climate map to determine the location of their projects with passive design strategies in the last 10 years.[40] The slider question included different project categories such as residential, office, and commercial projects with a slider for each category to be used by the respondents for determining the percentage of their projects in the last 10 years in that category.

---

[40] This question was designed by redrawing and overlaying the associated polygon area for each climate zone on the map of the ASHRAE climate zones.

The multiple choice questions, which focused on the respondents' last 10 years of professional experience, included:

- Applied passive/natural heating strategies
- Applied passive/natural cooling strategies
- Applied renewable energy systems
- Applied daylighting strategies
- Applied passive building envelope strategies

The reason for focusing on the last 10 years of professional experience was to define a time span large enough to include a variety of passive/natural system strategies, but not too much retrospective to be hard for the respondents to remember. The observed decline in the application of passive/natural systems in buildings at the beginning of the 21st century was another reason for such a time span definition in the survey.

- The multiple choice questions regarding the practitioners' performance analysis tools and approaches for the design of passive/natural systems included:
- The simulation or calculation tools for the design/analysis of passive/natural systems
- The design to construction phase used to analyze the application of passive/natural systems
- The phase used to calculate savings from the passive/natural systems with respect to the inclusion of the mechanical systems in an analysis

In difference to the questions used for the practitioners' survey, the questions for educators instead of professional projects focused on their class projects in terms of applied strategies, tools, and approaches. For the passive/natural system strategies, questions were reformatted in a multiple choice cross table where answer to each question would include three levels of teaching: level of concept, level of calculation, and level of simulation. Meanwhile the survey asked educators if they have been involved in a design or construction of a passive building project including the location of their projects and percentage of their professional work in each category.

Finally, a multiple choice question asked all respondents to select the top three factors from a list of eleven items which can increase the use of passive/natural systems in buildings. This list of items was developed based on the issues found through the literature review and its analysis. These issues include:

- Building codes and rating systems
- Simulation tools with capabilities for analyzing passive systems
- Knowledge of the modeling and simulation of passive system strategies
- Avoiding complexity and simplifying the implementation of passive system strategies
- Occupants' training for the use and maintenance of the passive systems
- Architect-engineer collaboration
- Client's desire and collaboration to include passive systems
- Cost of material and construction of passive systems

- Climate of the location where a passive system should be designed
- Knowledge integrating mechanical and passive systems performance
- Experience of the project team in the design, implementation, and integration of passive systems

In addition, in the survey to educators, three questions were added to the content of the survey:

- one additional question in the survey asked about their degrees and the universities they earned the degrees,
- one question asked about their current and previous professional role in addition to their academic role, and
- one question asked about the courses they teach.

In all of the survey questions, wherever appropriate, the answer choice “other” was included with an inquiry about “specifying” in a following text question or embedded text box. These responses, which increased the time for data classification during the survey response analysis, ensured the inclusiveness of all possible responses for the survey. In analyzing the collected data, the Pareto chart format was used to display the data from largest to smallest in each category for easier and faster perception of the results for analysis. In the analysis, the mean, count, and percentage of the collected data were used wherever appropriate. In the following paragraphs the focus would be on the survey from practitioners. The results of the survey from educators will be analyzed in an individual section.

4.4. Demographic Information (Practitioners)

4.4.1. Primary Professional Role (Practitioners)

The respondents practiced mainly as architect (77 counts), engineer (29), energy consultants (6), mechanical equipment consultants (5), architect interns (4), architectural engineers (4), engineers in training (3), green building consultants (2), and daylighting consultants (1). In the category of "other" there was 1 person for each of the following professions: manager/HVAC manufacturer; business development for architecture and energy consulting firm; sustainable design consultant, architectural consultant; architectural researcher in human comfort; government policy maker; and interior designer (Figure 4.2)

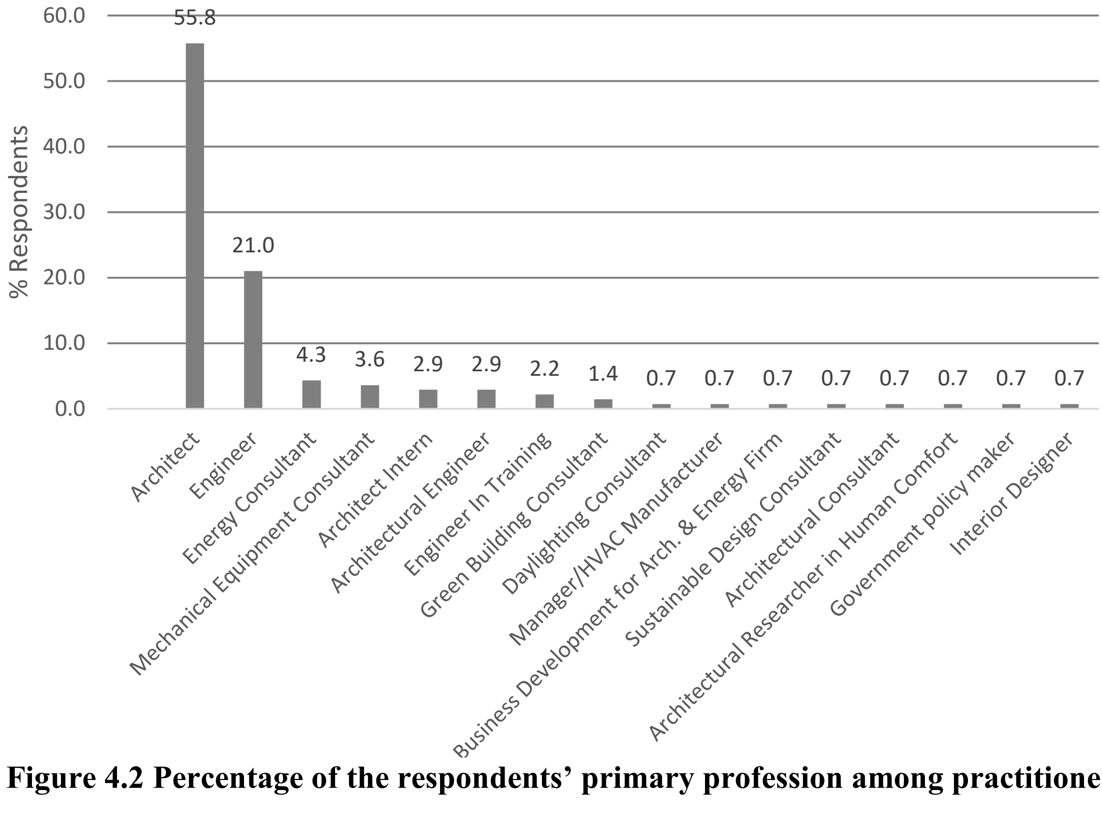


Figure 4.2 Percentage of the respondents' primary profession among practitioners

Table 4.1 Percentage of the respondents' primary profession among practitioners

Respondents' Primary Profession	**Percent %**	**Number of Participants**
Architect	55.8	77
Engineer	21.0	29
Energy Consultant	4.3	6
Mechanical Equipment Consultant	3.6	5
Architect Intern	2.9	4
Architectural Engineer	2.9	4
Engineer In Training	2.2	3
Green Building Consultant	1.4	2
Daylighting Consultant	0.7	1
Manager/HVAC Manufacturer	0.7	1
Business Development for Architecture & Energy Consulting firm	0.7	1
Sustainable Design Consultant	0.7	1
Architectural Consultant	0.7	1
Architectural Researcher in Human Comfort	0.7	1
Government policy maker	0.7	1
Interior Designer	0.7	1
Total	100.0	138

Among the respondents, 7 people were also certified as passive house consultants (CPHC) which is about 5% of the total number of the participants.

4.4.2. Affiliations (Practitioners)

AIA, LEED AP, and ASHRAE were the first three choices of the participants' affiliations. 84 respondents (61% of the total respondents) were AIA, 64 respondents (46%) were LEED AP, and 45 respondents (33%) were ASHRAE members (Figure 4.3).

The ratio between AIA and ASHRAE members' affiliations is about 2 to 1, which reflects higher number of architects compared to engineers in the actual building industry. Skipping the "other" category, the next most selected affiliation was the PHIUS with 3.6%. About 2.9% of the participants were also members of the Society of Building Science Educators (SBSE). From respondents 2.9% were also ASHRAE Building Energy Modeling Professionals (BEMP). About 2.2% were High Performance Building Design Professionals (HPBDP) and 1.4% were Well AP.[41]

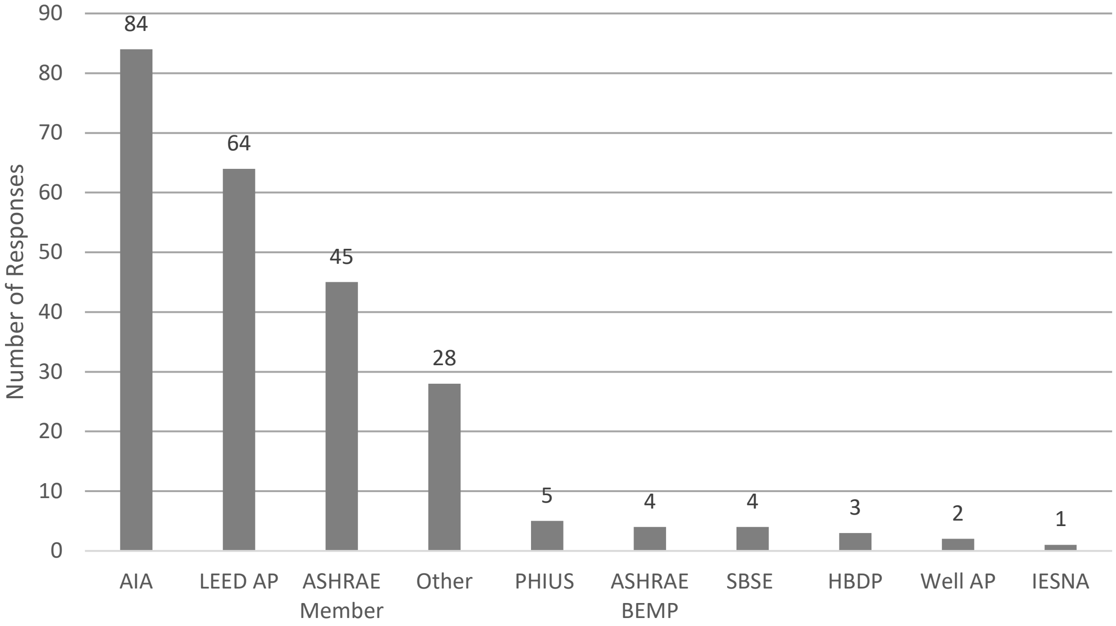


Figure 4.3 Respondents' affiliations among practitioners

---

[41] The WELL Building Standard is a performance-based system for measuring, certifying, and monitoring features of the built environment that impact human health and wellbeing, through air, water, nourishment, light, fitness, comfort, and mind. For further information please see https://www.usgbc.org/articles/what-well

Table 4.2 Respondents' affiliations among practitioners

Affiliation	**Count**	**%From Total Affiliations**	**% From Respondents**
AIA	84	35.0%	61%
LEED AP	64	26.7%	46%
ASHRAE Member	45	18.8%	33%
Other (please specify)	28	11.7%	20%
PHIUS (Passive House Institute US)	5	2.1%	4%
ASHRAE BEMP	4	1.7%	3%
SBSE (Society of Building Science Educators)	4	1.7%	3%
HBDP (High Performance Building Design Professional)	3	1.3%	2%
Well AP	2	0.8%	1%
IESNA (Illumination Engineering Society of North America)	1	0.4%	1%
Total number of affiliations	240	100%	NA

Affiliations specified in the "other" category by the respondents were in a wide range, which was analyzed and redefined as shown in Figure 4.4. In this case, 1.5% of the respondents had affiliations with IBPSA, NCARB, and CSI, which were extracted from the "other" category as the most mentioned affiliations.

Participants' other affiliations included the followings: Connecticut Green Building Council (CTGBC), Certified Building Commissioning Professional (CBCP), ASHRAE Building Energy Assessment Professional (BEAP), Energy Management Professional

(EMP), USGBC Member, International Interior Design Association (IIDA), International Living Building Institute (ILBI), Envision Sustainability Professional (ENV SP), Building Enclosure Commissioning (BECx), Architectural Engineering Institute (AEI), Association of Energy Engineers (AEE), Architectural Lighting Alliance (ALA), Design-Build Institute of America (DBIA), American Society of Civil Engineers (ASCE), American Council of Engineering Companies (ACEC), American Society of Landscape Architects(ASLA), Construction Document Technology (CDT), Association for Preservation Technology International (APT), Illumination Engineering Society of North America (IESNA).

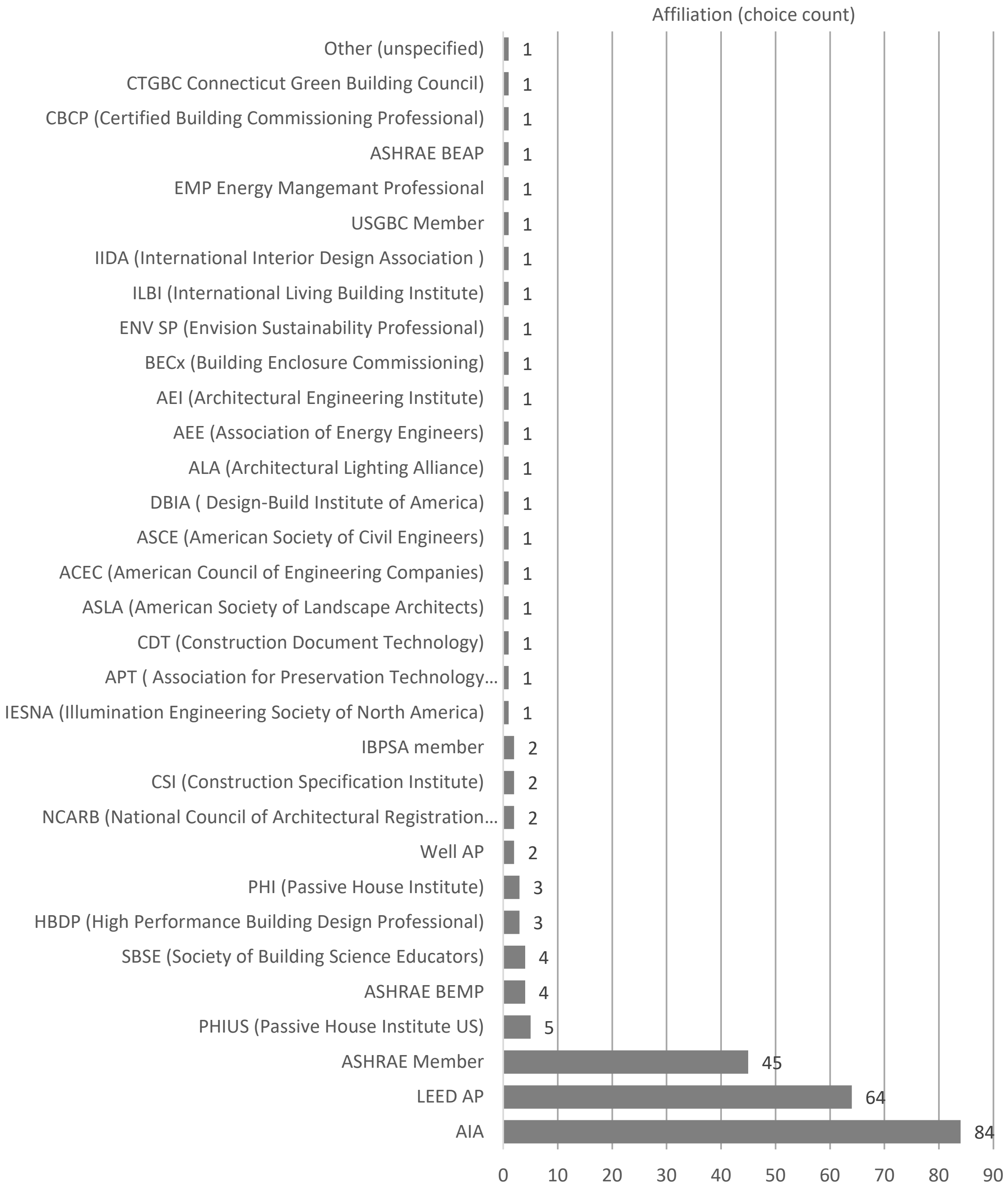


Figure 4.4 Respondents' affiliations among practitioners with the expansion of the "other" category

4.4.3. Professional Work Experience (Practitioners)

The majority of the participants had 34 or more years of work experience (23.9%). After that 18.1% of the participants had 10 to 14 years, 12.3% with 20 to 24 years, 10.9% with 5 to 9 years, 10.1% with 30 to 34 years, 8.7% under 5 years, 8.7% with 25 to 29 years, and 7.3% with 15 to 19 years of work experience (Figure 4.5 and Table 4.3). One finding could be that passive/natural systems appeal to all age ranges in terms of work experience from young to old professionals. Meanwhile, older professionals and professionals who are in the middle of their career with 10-14 years of work experience might have a greater passion for passive designs. This outcome might be the result of the trends of these generations education and practice when passive/natural systems were of greater interest and focus in universities and design firms in the 1970s and the 1980s and the beginning of the 21st century.

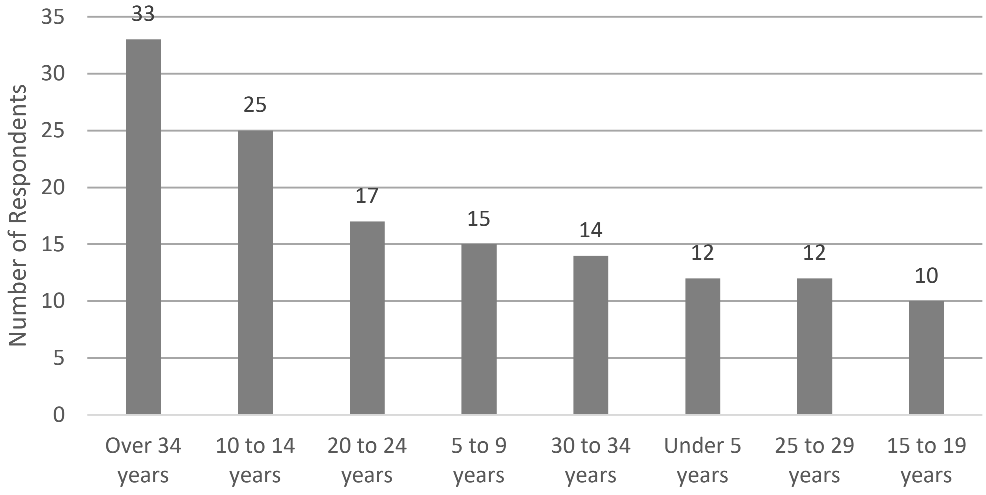


Figure 4.5 Respondents' years of professional experience

Table 4.3 Respondents' years of professional experience

Work experience	**Percentage**	**Count**
30 to 34 years	10.1%	14
25 to 29 years	8.7%	12
20 to 24 years	12.3%	17
15 to 19 years	7.3%	10
10 to 14 years	18.1%	25
5 to 9 years	10.9%	15
Under 5 years	8.7%	12
Over 34 years	23.9%	33
Total	100%	138

4.4.4. Age Group (Practitioners)

The majority of the responding practitioners were 59 years old (25.5%). The smallest age groups were professionals who were 40-44 years old (5.1%) or under 25 years old age (1.5%). From largest to smallest, 18.3% of the participants were 35-39 years old, 11% of participants were 45-49 years old, 11% of participant were 55-59 years old, 10.2% of participants were 30-34, 9.5% of participants were 25-29, and 8% were 50-54 years old. Therefore, for age groups other than 40-44 years old, over 59, and under 25, the collected data show almost a uniform distribution (Figure 4.6 and Table 4.4).

Table 4.4 Practitioners' age group

Age group	Percentage	Count
Under 25	1.5%	2
25-29	9.5%	13
30-34	10.2%	14
35-39	18.3%	25
40-44	5.1%	7
45-49	11.0%	15
50-54	8.0%	11
55-59	11.0%	15
Over 59	25.5%	35
Total	100%	137

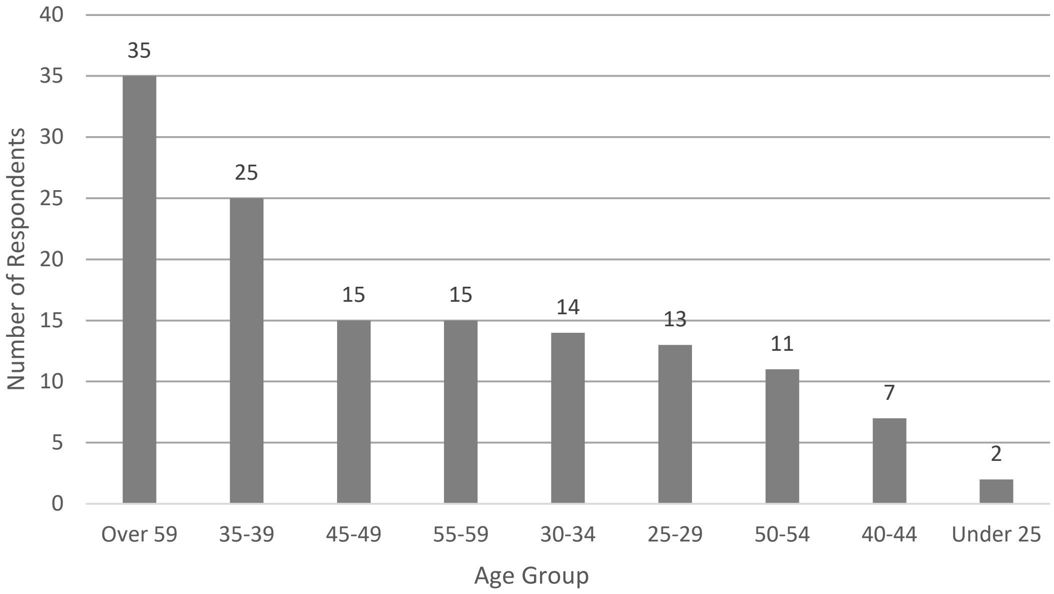


Figure 4.6 Practitioners' age group

Having a large percentage of the participants in the age group of 55 or more (36%) could be indicative of their educational background in the heyday of passive system design/education in the 1980s.

4.4.5. Location (Practitioners)

Figure 4.7 shows the locations of the respondents in the US. Accordingly, there are no participants from Wyoming, New Mexico, North Dakota, South Dakota, Montana, Minnesota, Nevada, Colorado, and Kansas states. This lack of participation from the mentioned states is compensated to some extent by the participants who, although not located in these states at the time of survey, were also certified as either professional architects or engineers to practice in these states. As it is visible from the map, a majority of the participants either live or were located in the North East area at the time of responding to the survey.

4.4.6. Professional Registration (Practitioners)

Figure 4.8 shows that the majority of respondents were licensed architects. Seventy-five of the 138 respondents (54.4%) were licensed architects while 26.8% of the participants were Professional Engineers (P.E.). Therefore 81.2% of the total respondents have professional registration in the US either as an architect or engineer. Among the respondents 18.8% did not have either an architectural licensure or a P.E. As shown in Figure 4.9, most of the registered professionals (65%) have Architectural Licensure or

P.E. in only one state, with very few having professional registration in more than 6 up to 15 states.

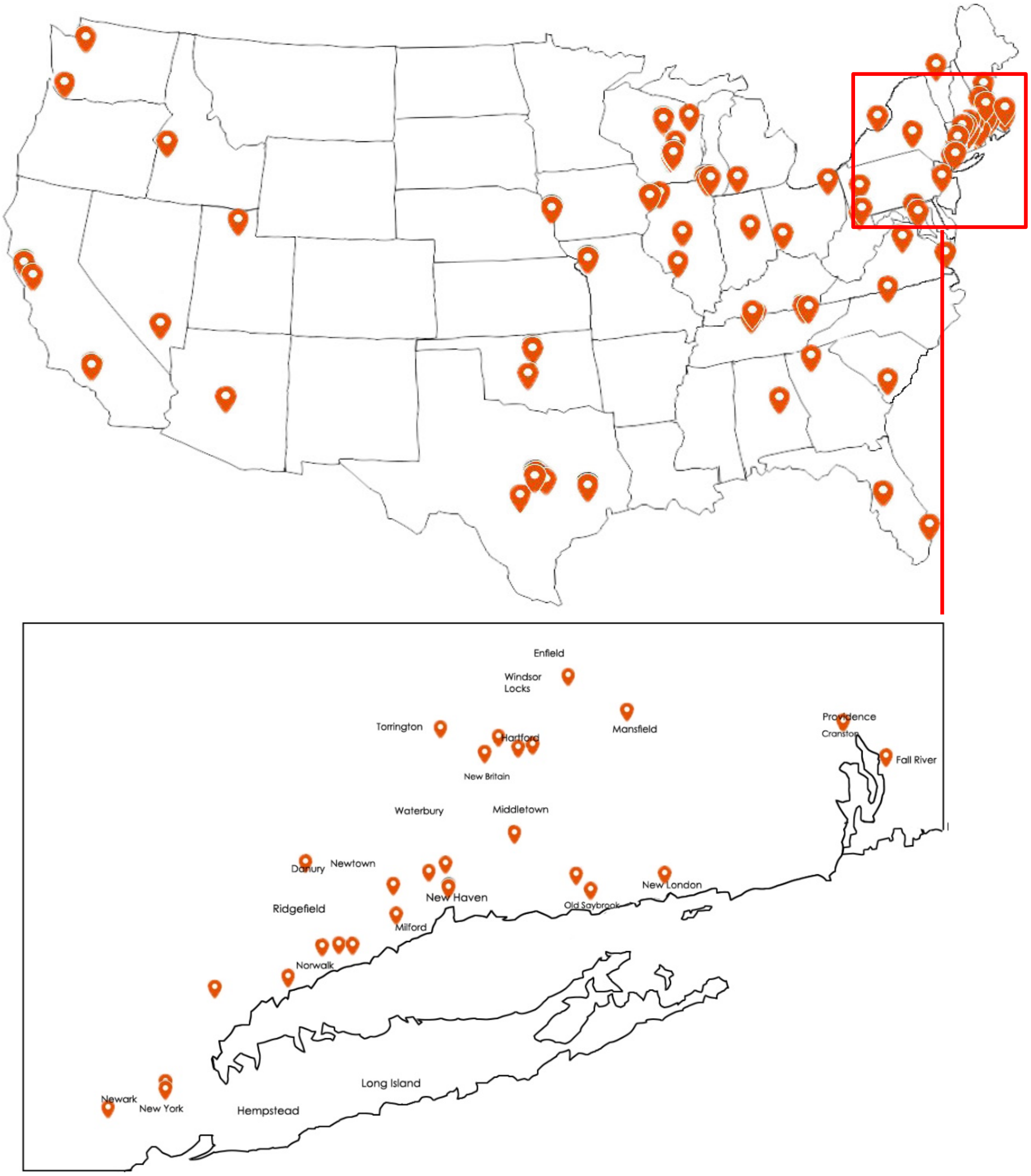


Figure 4.7 Locations of the survey respondents on the US map

Note that a pin only stands for the city, but not the exact location or the number of the participants in that city

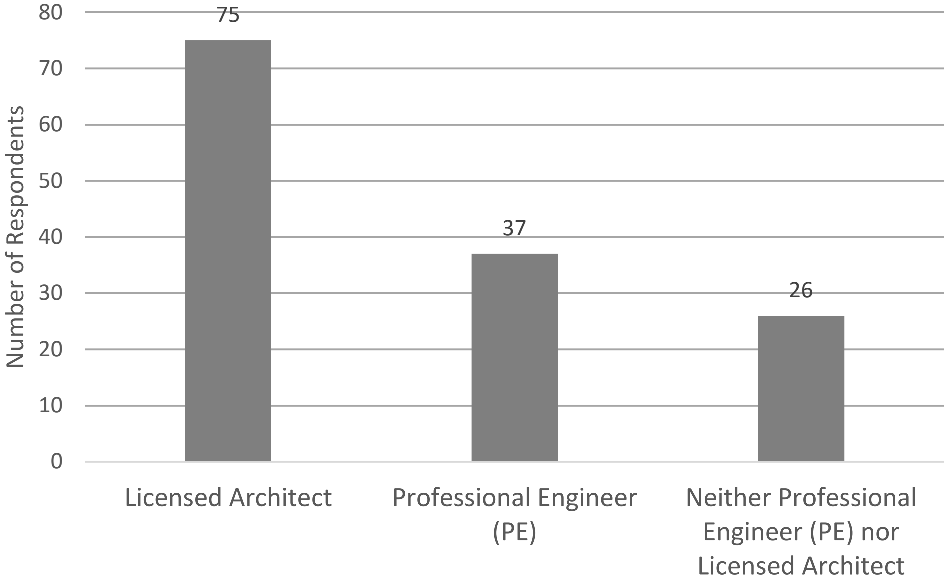


Figure 4.8 Distribution of professional registration among the participants

Table 4.5 Distribution of professional registration among the participants

Licensure/PE	**%of Total Participants**	**Count**
Licensed Architect	54.4%	75
Professional Engineer (PE)	26.8%	37
Neither Professional Engineer (PE) nor Licensed Architect	18.8%	26
Both Professional Engineer (PE) and Licensed Architect	0.0%	0
Total	100%	138

As shown by Figure 4.10 states that were selected by practitioners for P.E. registration was 42.6% (72/169) of the times that states were selected for Architectural Licensure. In this case Connecticut (27 architectural licensure counts), New York (16), Illinois (12), Massachusetts (9), and Texas (9) had the highest number of selection for architectural licensure. Texas (12), Illinois (5), Wisconsin (5), and California (5) were the states with highest number of selections for PE registration.

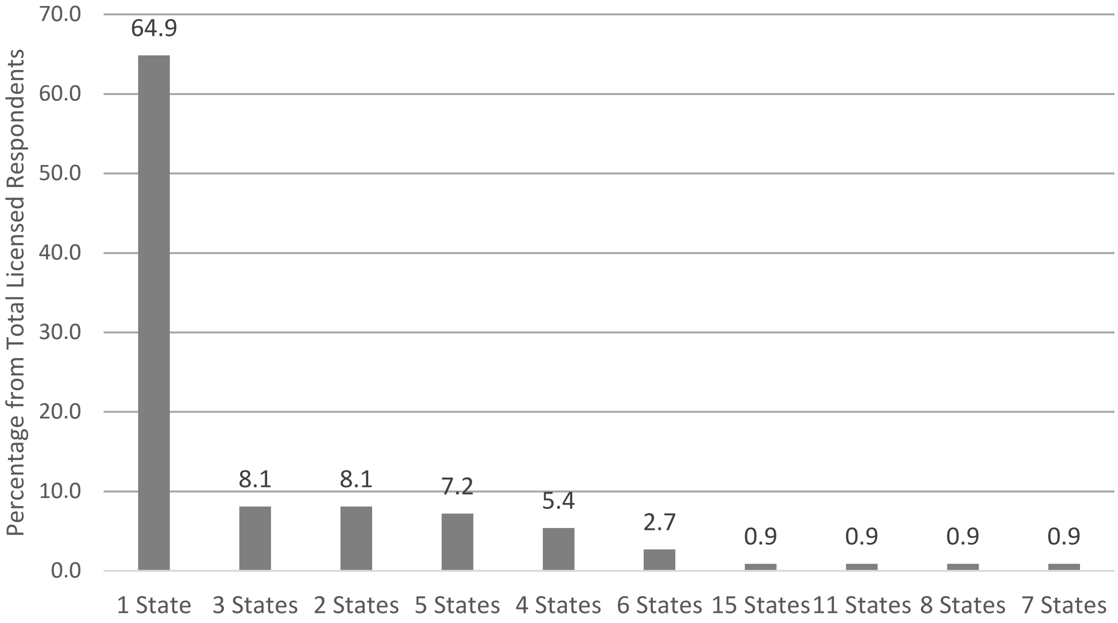
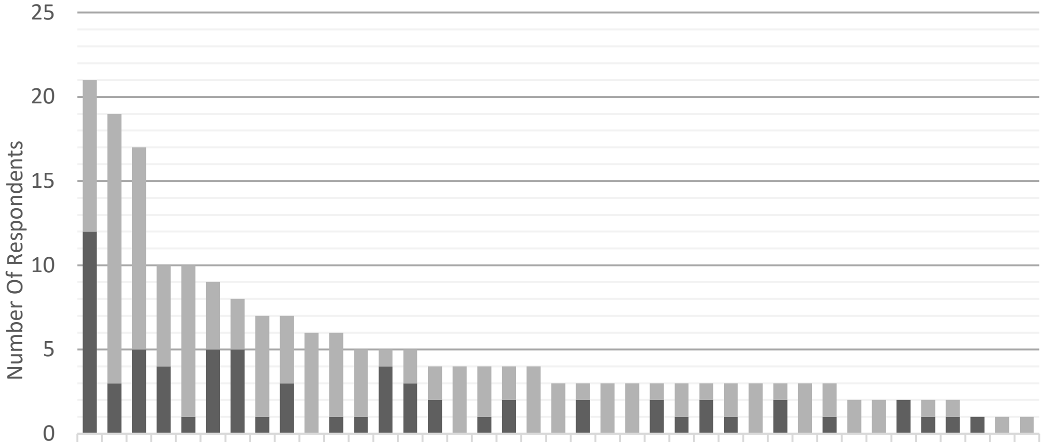


Figure 4.9 Number of states where a respondent is professionally registered as an architect or engineer



	TX	NY	IL	PA	MA	WI	CA	RI	MI	ME	FL	VT	TN	OK	WV	NH	MD	IN	GA	WA	VA	UT	SC	NC	MO	KY	IA	HI	DC	CO	AZ	OR	NJ	NE	MN	KS	NM	ID	DE
▨ Licensed Architect	9	16	12	6	9	4	3	6	4	6	5	4	1	2	2	4	3	2	4	3	1	3	3	1	2	1	2	3	1	3	2	2	2	0	1	1	0	1	1
■ PE	12	3	5	4	1	5	5	1	3	0	1	1	4	3	2	0	1	2	0	0	2	0	0	2	1	2	1	0	2	0	1	0	0	2	1	1	1	0	0

Figure 4.10 Respondents' Architectural Licensure or PE with their distribution in each state

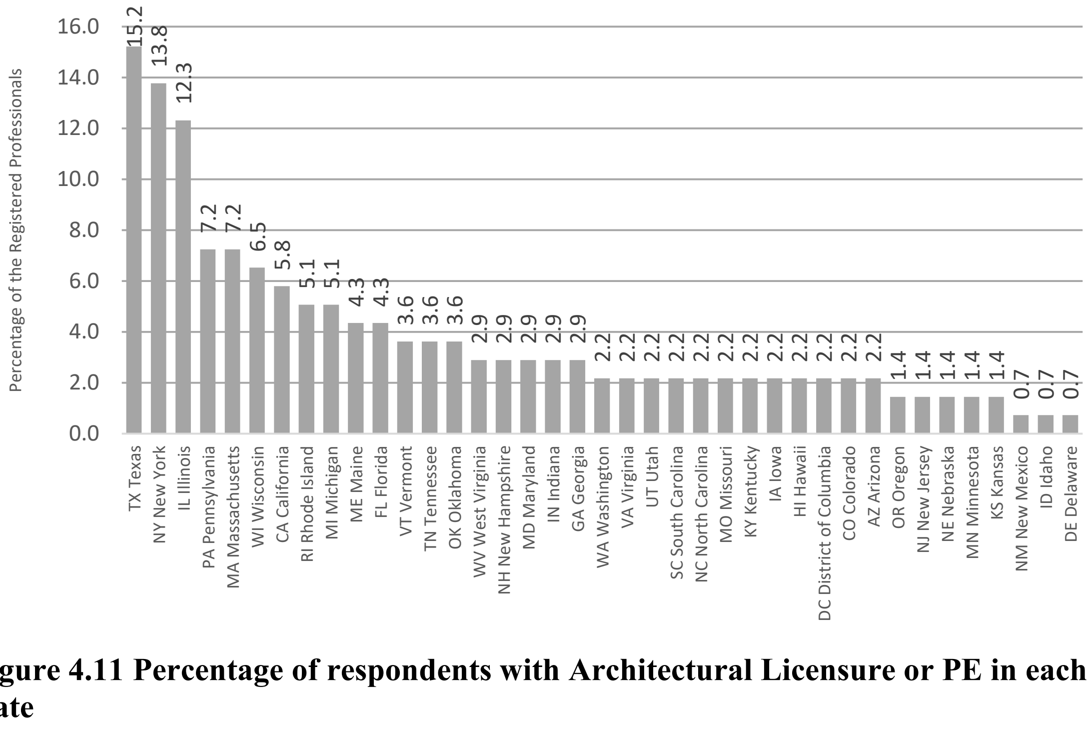


Figure 4.11 Percentage of respondents with Architectural Licensure or PE in each state

4.4.7. Location of Education (Practitioners)

The largest percentage of the participants who have earned the degree(s) most related to their current profession were from the New England Area. Texas and the Great Lakes regions come next in this regard. Figure 4.12 and 4.13 show all the locations selected by respondents with respect to the map shown to them within the survey. Three of respondents who are practicing in the US earned their degrees abroad in France, Belgium, and the UK. None of the respondents selected the Gulf Coast as the location of their education.

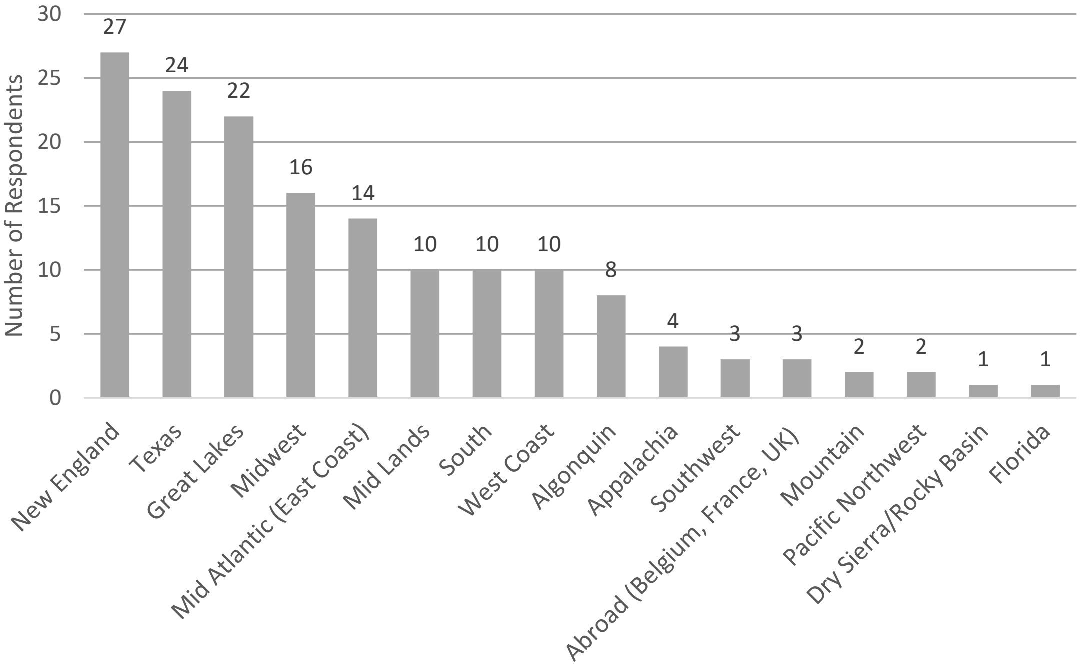


Figure 4.12 Location of education that the respondents earned their degree(s) most related to their current profession

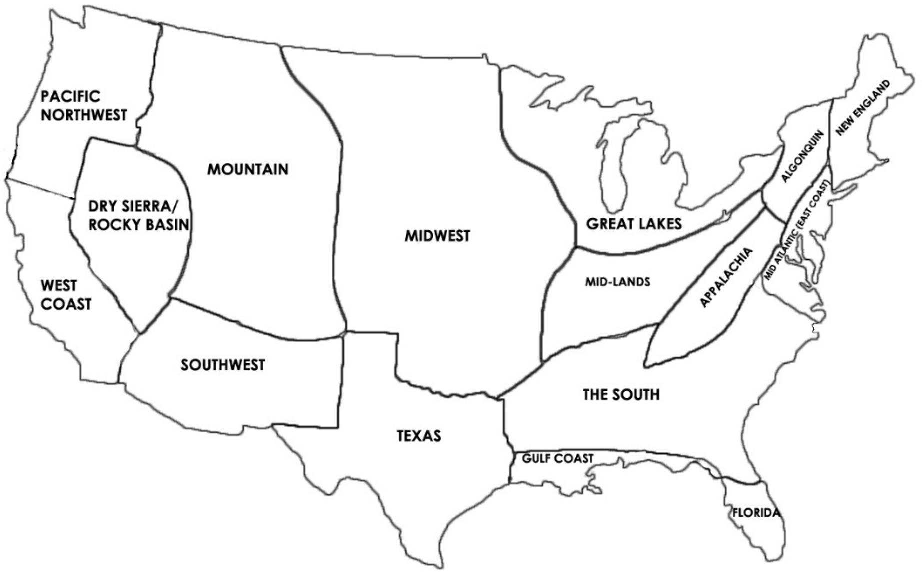


Figure 4.13 Areas for which respondents were asked about their earned degree(s) most related to their current profession

4.5. Professionals Projects

4.5.1. Projects Typologies (Practitioners)

The highest average percentage of the professionals' projects in the last ten years was for educational projects with 27.6% of the total projects. Office projects (21.8%), Single family residential projects (14%), and Multi-family residential projects (8%) were the next types of projects with the highest mean percentage as shown in Figure 4.14.

Among the "other" types of projects which were specified by professionals, healthcare (26.2%) and civic/governmental (16.3%) projects composed the highest percentage of the other projects (Figure 4.15 and Table 4.6). Healthcare projects, with 4.7%, and civic/governmental projects, with 4.7%, define the fifth and sixth types of projects among all the project types in the survey. About 12.4% of the projects selected by professionals in the “other” category were not specified, which is equal to 3.5% of the total projects. Other types of practitioners projects included lab and data centers (2.1%), public, library, and religious (2.1%), cultural, recreational, and mixed-use (1.9%), industrial (1.7%), institutional (1.2%), hospitality and restaurant (1%), water treatment, breweries, and warehouse (0.9%), historic preservation (0.7%), and sports (0.5%).

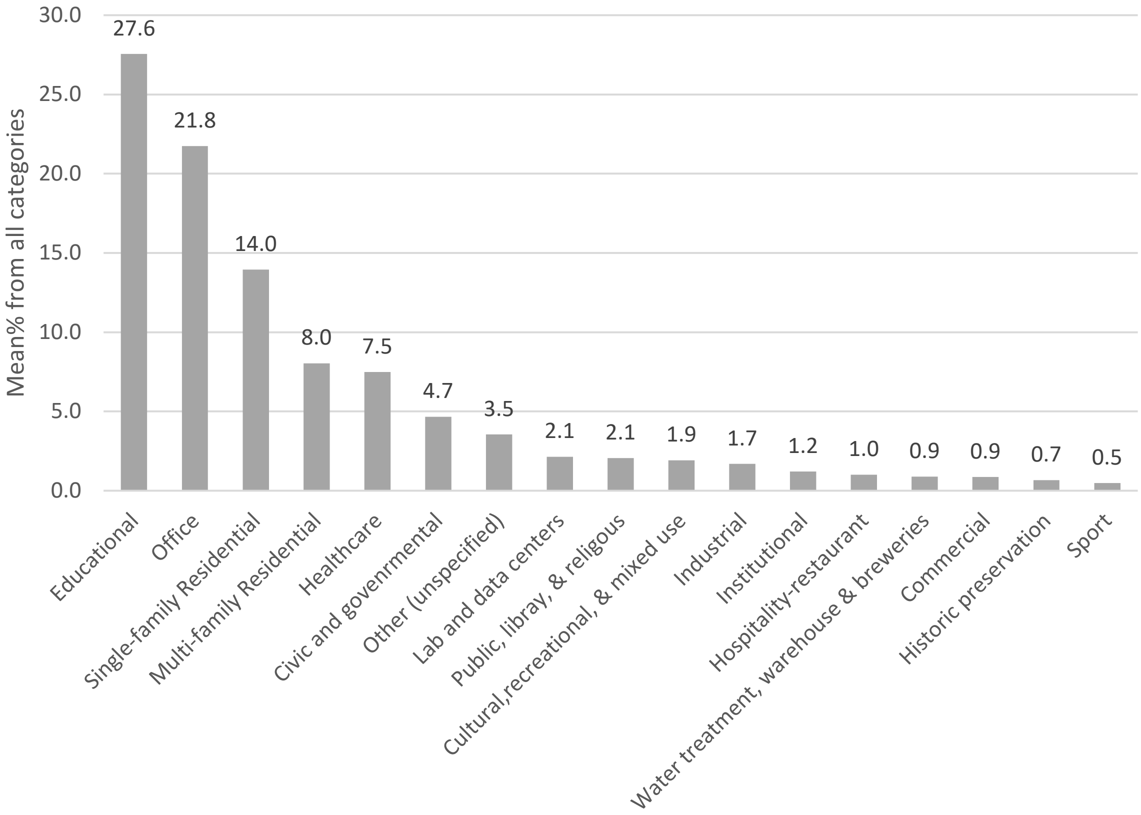


Figure 4.14 Mean percentage of professionals projects in different categories for the last 10 years

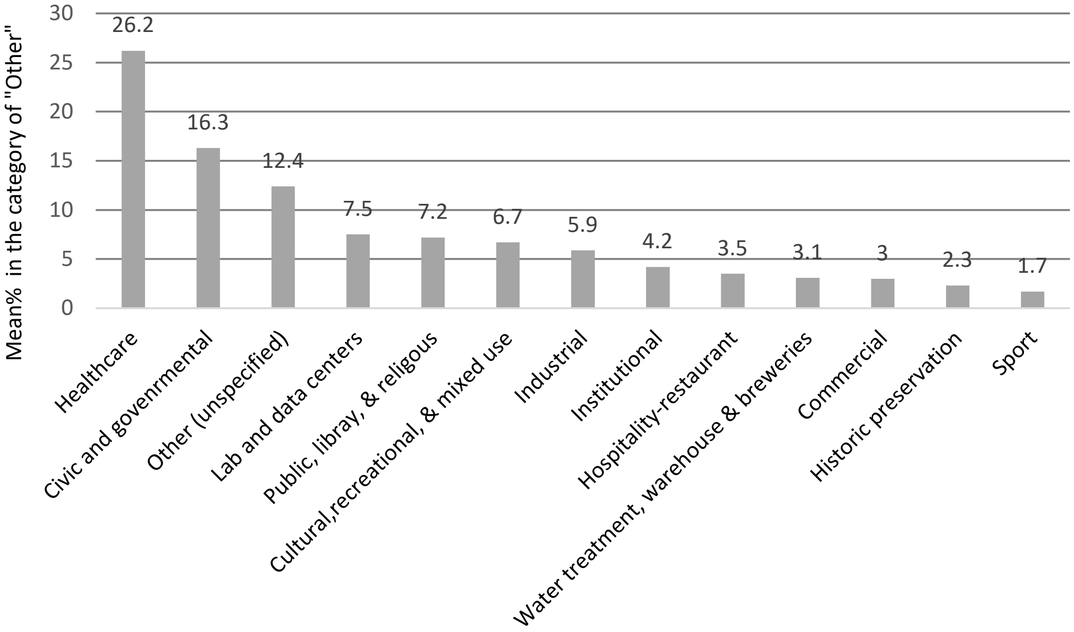


Figure 4.15 Mean percentage of the projects in only the “other” project category for the last 10 years

Table 4.6 Mean percentage of the projects in only the “other” project category for the last 10 years

Project Category	**Mean% in the "Other" category**	**Mean% from all categories**
Educational	NA	27.6
Office	NA	21.8
Single-family Residential	NA	14.0
Multi-family Residential	NA	8.0
Healthcare	26.2	7.5
Civic and governmental	16.3	4.7
Unspecified	12.4	3.5
Lab and data centers	7.5	2.1
Public, civic, library, & religious	7.2	2.1
Cultural, recreational, & mixed use	6.7	1.9
Industrial	5.9	1.7
Institutional	4.2	1.2
Hospitality-restaurant	3.5	1.0
Water treatment, warehouse & breweries	3.1	0.9
Commercial	3	0.9
Historic preservation	2.3	0.7
Sports	1.7	0.5
Total	**100**	**100**

The data collected suggests that among respondents there is a good mix of professionals with expertise in the design of a variety of project types from commercial to residential. Based on the data collected, there is a greater potential for energy saving through the incorporation of passive/natural systems, not only in residential buildings, but also in educational and office buildings among other types of commercial buildings. Educational and office buildings with daytime occupancy schedules provide opportunities for the utilization of passive system strategies during the night time to prepare the building for daytime use. Such strategies could be particularly applicable in hot climates with high diurnal temperature variations.

4.5.2. Climates of the Practitioners' Passive Projects

Figure 4.16 is the map shown in the survey to the participants to click for the locations of their projects in the last 10 years. Ten boundary areas were defined to encircle and automatically assigned to the respondents' clicks (project locations) on the US climate map. Figure 4.17 shows the number of selections/click inside the defined areas.

According to the collected data the majority of the practitioners' passive projects in the last ten years is located in the east central part of the US, including in the East-Center 5-6 zone embracing the climate 5A and small areas of climate 6A (35.9%). The second most selected area is the southern part of the US including the states of Texas and Florida (14.7%) with climate zone 2A. Attached to the top of this area is the southern part of the US with climate zone 3A, which was the fourth area selected (12%) by practitioners. This area includes parts of Texas, Louisiana, Mississippi, Georgia, Alabama, Oklahoma, and South Carolina. Climate zone 4A, which includes states such as Virginia, Kentucky, Missouri, and Kansas was the third selected area (13.4%) for the application of passive design strategies based on the survey results.

The word of caution about the survey results is that since the survey participation was higher from New England and Texas (Figure 4.18) the results should not be interpreted as having a lower interest for passive design in other areas of the US. However, based on the survey results, the high percentage of passive design projects in the eastern and southern areas of the US give evidence, despite the general misbelief, of the high possibility of applying passive design strategies in harsh hot humid or cold humid US climates. Finally, it should be kept in mind that some states, such as the northern states, as mentioned earlier did not take part in the survey, which could be a reason for the low level of selection of these areas in the final results.

Table 4.7 Areas selected by practitioners as the location of their projects in the last ten years

Area	Counts of the zone selection	Selection %
East-Center 5-6	78	35.9
South-2-1	32	14.7
Center-4	29	13.4
South-3	26	12.0
Southwest-3-2-4	16	7.4
North-Center-6-7	13	6.0
West-5	8	3.7
West-4	8	3.7
Northeast-6-7	5	2.3
North-7	2	0.9
Total	**217**	**100.0**

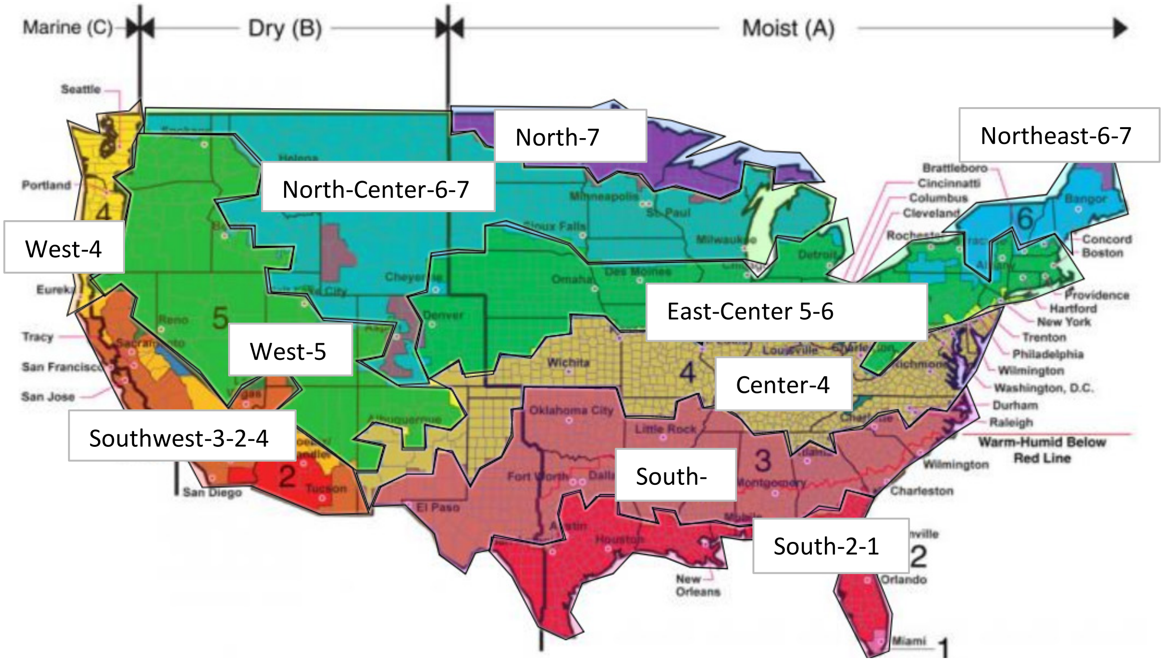


Figure 4.16 Areas defined on ASHRAE climate map to be selected by practitioners as the location of their projects in the last ten years. The climate map was reprinted with permission from ASHRAE ©ASHRAE www.ashrae.org (ASHRAE 90.1 Manual, 2016)

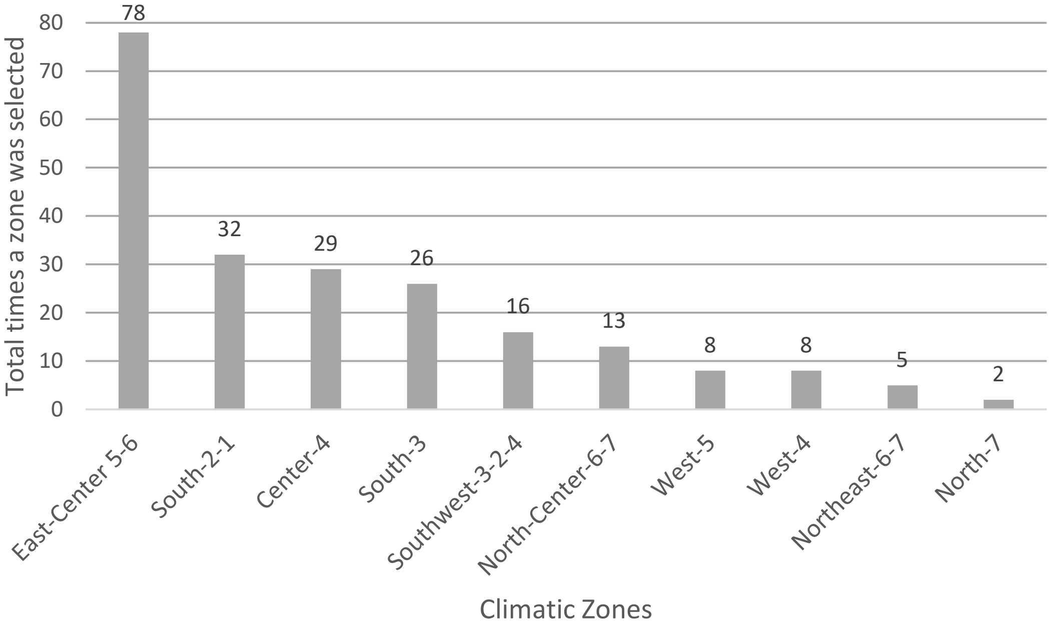


Figure 4.17 Total number of times each area on the map in Figure 4.16 was selected by practitioners

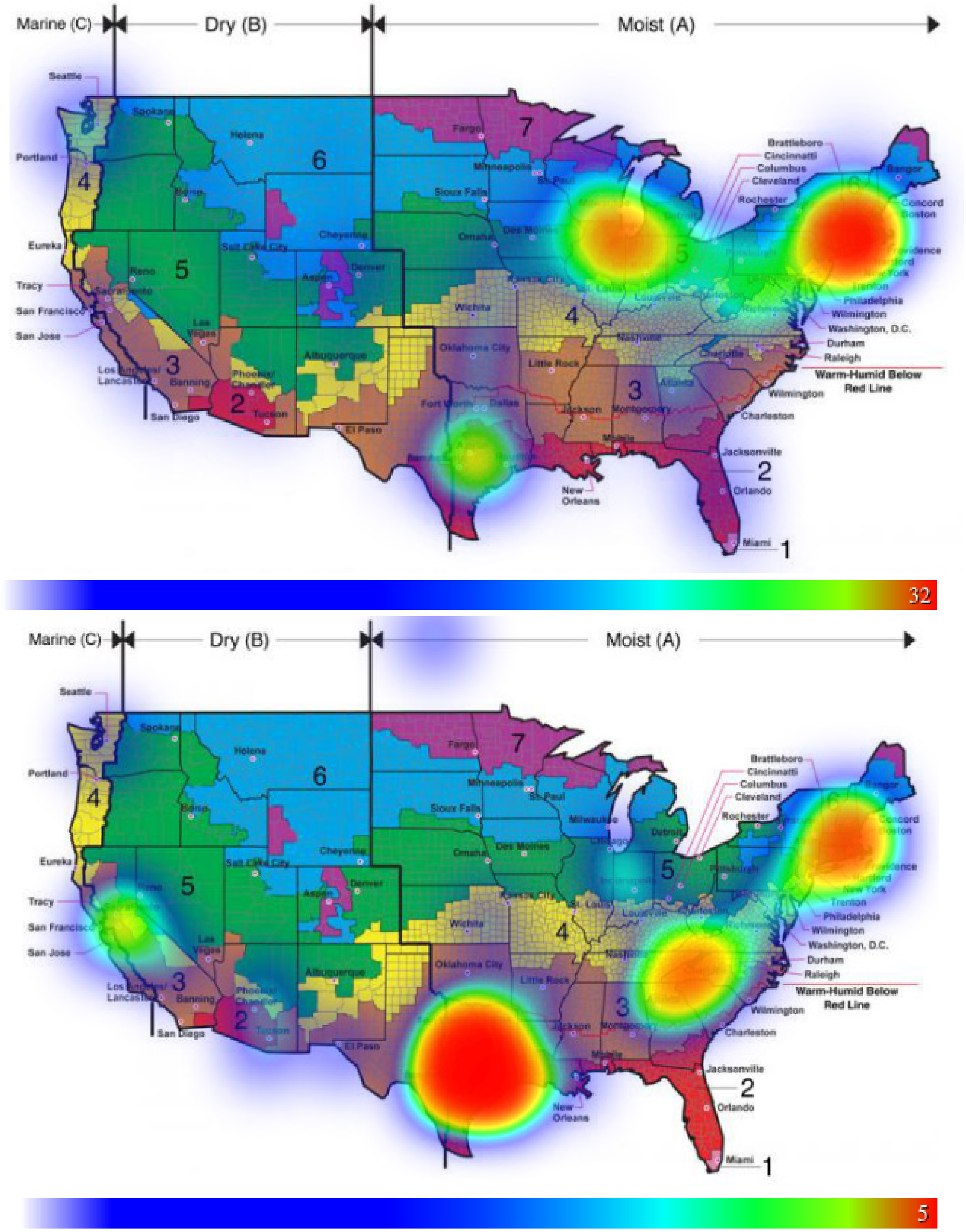


Figure 4.18 Areas selected by practitioners on the US climate map as the locations of their projects with passive design strategies in the last ten years (top, selection of a group of 120 practitioners, and bottom, selection of a group of 15 practitioners). The climate map was reprinted with permission from ASHRAE.

4.6. Passive/Natural Systems (Practitioners)

4.6.1. Renewable Energy (Practitioners)

The practitioners’ top choice for the use of renewable energy was PV panels (Photovoltaics) with 31.5% of count choices (Figure 4.19). Among practitioners 63% selected this choice as the type of renewable energy system used in their projects during the last 10 years. Geothermal (52.9%) and solar thermal collectors for domestic hot water (35.5%) were the next most selected types of renewable systems used by practitioners in their projects. Solar thermal collectors for space heating (13%) and wind turbines (9.4%) are other types of renewable energy systems used by practitioners. About 23% of the participating practitioners have not used any renewable energy system in their projects. This number seems to be high with respect to the Architecture Challenge 2030 aiming to get to net zero carbon emission by the year 2030. In other words, to reach that target there should be more incentives to encourage all practitioners to incorporate renewable energy systems to their designs. Other types of renewables applied by practitioners included hydro and biomass/biogas systems (2.2%).

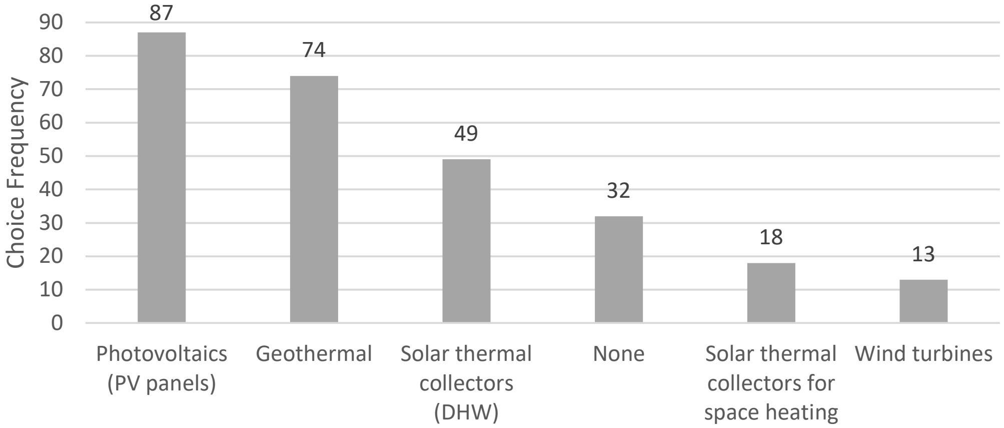
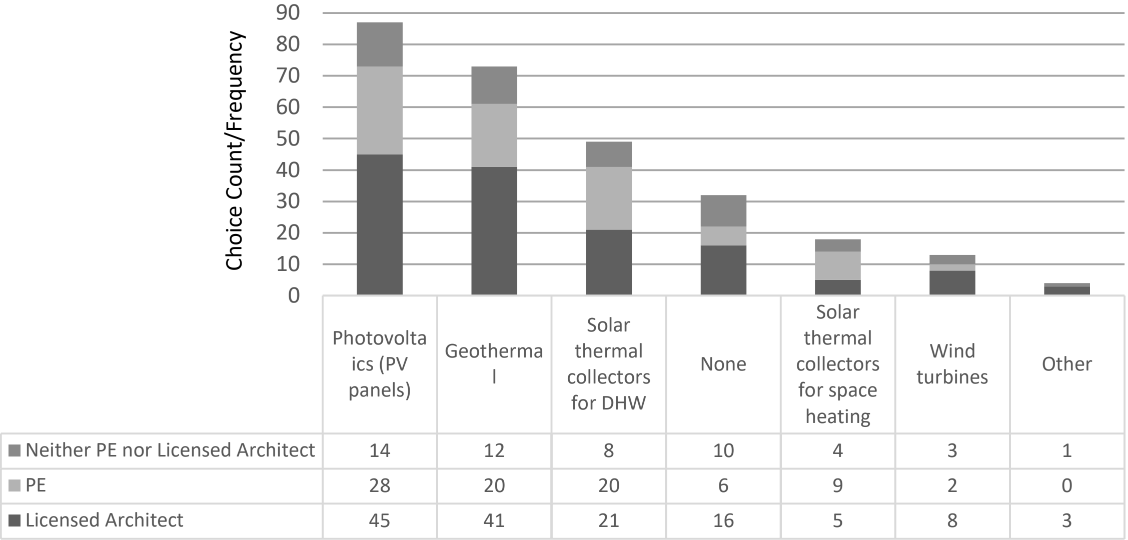


Figure 4.19 Practitioners’ use of renewable energy in the last 10 years’ projects

Figure 4.20 shows the number of professionally registered architects or engineers choosing each renewable system. A comparison shows that the ratio of engineers using solar collectors for domestic hot water (i.e. 20 choices out of 85 total choices by engineers) is higher than the ratio of licensed architects using the same system (i.e. 21 choices out of 139 choices by licensed architects). Similarly, a comparison shows a higher ratio for engineers in the use of solar collectors for space heating. One reason for such a difference could be a more detailed calculation needed for the implementation of solar collectors, which is usually more appealing to engineers rather than architects.

Table 4.8 Use of renewable energy in the last 10 years by practitioners

Renewable System	**Count**	**% Choice Count**	**%From Practitioners**
Photovoltaics (PV panels)	87	31.5%	63%
Geothermal	74	26.5%	53.6%
Solar thermal collectors for Domestic Hot Water (DHW)	49	17.8%	35.5%
None	32	11.6%	23.2%
Solar thermal collectors for space heating	18	6.5%	13%
Wind turbines	13	4.7%	9.4%
Other (Hydro, Biomass/BioGas)	3	1.5%	2.2%
Total	276	100%	



	Photovoltaics (PV panels)	Geothermal	Solar thermal collectors for DHW	None	Solar thermal collectors for space heating	Wind turbines	Other
■ Neither PE nor Licensed Architect	14	12	8	10	4	3	1
■ PE	28	20	20	6	9	2	0
■ Licensed Architect	45	41	21	16	5	8	3

Figure 4.20 Renewable energy usage in the last 10 years categorized by professional registration

4.6.2. Passive/Natural Cooling Systems (Practitioners)

External shading device (70.3%), green roof (53.6%), and cross ventilation (47.8%) are the practitioners top three choices for the incorporation of passive cooling strategies in buildings (Figure 5.21). This is followed by the use of plants/vegetation (42.8%), internal shading device (41.3%), cool roof (39.1%), courtyard (33.3%), evaporative cooling (26.8%), radiant cooling (24.6%), stack ventilation (22.5%), and dynamic shading (21%) strategies in their projects. The survey showed 14.5% of the practitioners have not used any passive cooling strategy in their designs. The last nine choices of the practitioners included night ventilation with mass (13%), earth contact (8.7%), solar chimney (8%), night ventilation without mass (6.5%), downdraft cooling (3.6%), earth tube (2.9%), double roof (2.9%), roof pond (0.7%), and super insulation (0.7%).

The results showed that the use of simple passive systems on new buildings were preferred over complex passive systems or add-on passive systems. As a result, external shading devices integrated with buildings façades, green roofs on the idle roof surfaces, and the appropriate location of building openings for cross ventilation are more likely to be applied by practitioners for the passive cooling of a building compared with strategies such as complex earth tubes or roof ponds, which are more difficult to maintain. The findings also showed that, despite the general misbelief that passive solar is more appealing to practitioners in the US, passive cooling strategies in the US are widely being applied. Table 4.11 better indicates a wide application of passive cooling by practitioners in four different humid climates including the climate of Texas.

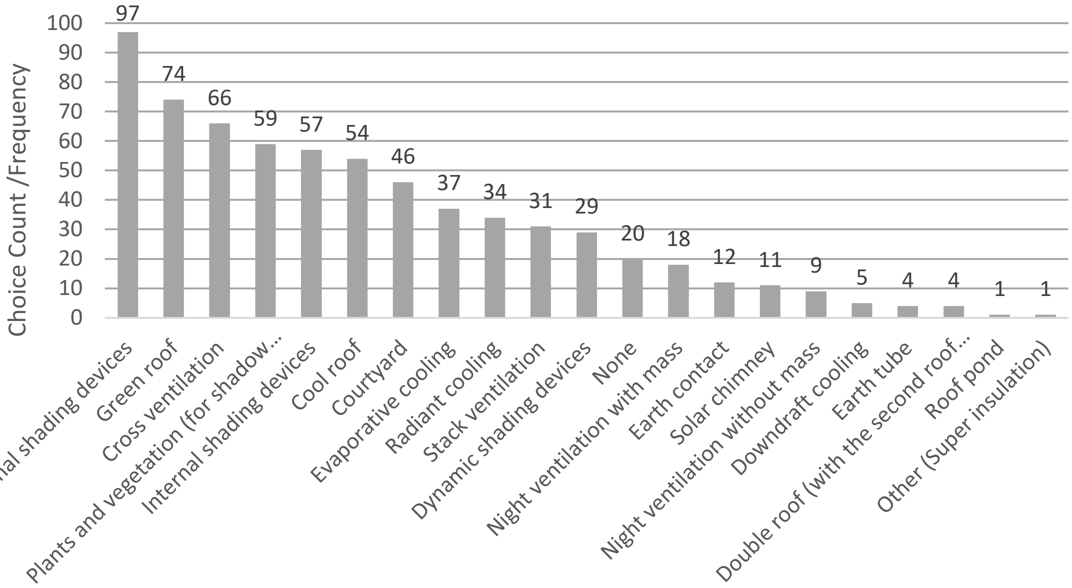


Figure 4.21 Practitioners use of passive cooling strategies in the US in the last 10 years

Table 4.9 Practitioners use of passive cooling strategies in the US in the last 10 years

Natural/Passive Cooling System	**Count**	**%Count**	**% From Number of Practitioners**
External shading devices	97	14.5%	70.3%
Green roof	74	11.1%	53.6%
Cross ventilation	66	9.9%	47.8%
Plants and vegetation (for shadow casting or evapotranspiration)	59	8.8%	42.8%
Internal shading devices	57	8.5%	41.3%
Cool roof	54	8.1%	39.1%
Courtyard	46	6.9%	33.3%
Evaporative cooling	37	5.5%	26.8%
Radiant cooling	34	5.1%	24.6%
Stack ventilation	31	4.6%	22.5%
Dynamic shading devices	29	4.3%	21.0%
None	20	3.0%	14.5%
Night ventilation with mass	18	2.7%	13.0%
Earth contact	12	1.8%	8.7%
Solar chimney	11	1.6%	8.0%
Night ventilation without mass	9	1.4%	6.5%
Downdraft cooling	5	0.8%	3.6%
Earth tube	4	0.6%	2.9%
Double roof (second roof casting shadow)	4	0.6%	2.9%
Roof pond	1	0.2%	0.7%
Other (superinsulation)	1	0.2%	0.7%
Total	669	100%	

Finally, the complexity and cost of the selected passive cooling systems, such as for earth tube, solar chimney, night ventilation with thermal mass, or downdraft cooling seemed not to hinder their selection (3% to 13%). Table 4.10 shows the total number of cooling strategies in the questionnaire selected by each practitioner. Based on this table, the median number (average number) of the strategies used by each practitioner is four (occurred 12 times). The most frequently selected cooling strategies was no passive cooling strategy (None in the questionnaire), which was selected by 20 times. In other words, the "mode" of this table is 20 which is for applying no strategy per practitioner.

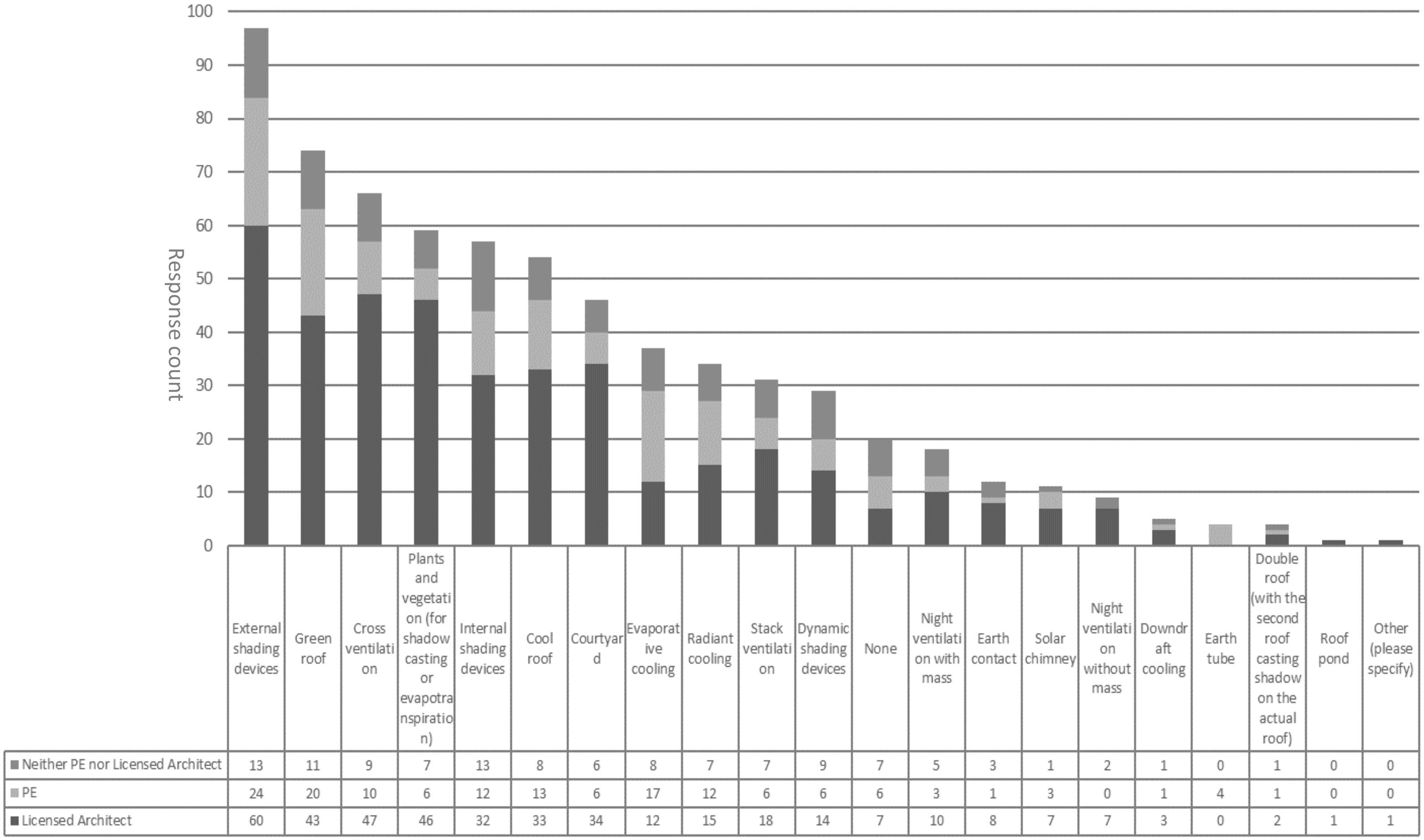
Table 4.10 The total number of cooling strategies in the questionnaire selected by each practitioner

Total number of cooling strategies applied by one practitioner	Frequency	Percentage
0	20	14.5%
3	19	13.8%
2	14	10.1%
8	13	9.4%
4	12	8.7%
7	12	8.7%
1	11	8.0%
6	10	7.2%
9	8	5.8%
5	6	4.3%
11	4	2.9%
10	3	2.2%
12	2	1.4%
15	2	1.4%
13	1	0.7%
14	1	0.7%
Total	138	100%

However, for 19 times practitioners have selected a combination of three passive cooling strategies in the questionnaires, which is very close to the “mode” of the table (i.e. 20 for no passive cooling strategy).

Table 4.11 Selection of the passive cooling strategies in four states with higher participation and four different humid climates (4A, 5A, and 2-3A)

Cooling Strategy	**Number of registered architects/engineers in each state selecting the strategy**			
	Connecticut	**Illinois**	**New York**	**Texas**
Evaporative cooling	4	3	2	7
None	3	2	2	3
Radiant cooling	6	2	4	2
Roof pond	0	0	0	0
Downdraft cooling	2	0	3	1
Cool roof	11	5	7	8
Solar chimney	2	1	3	3
Earth tube	0	1	0	0
Double roof (with the second roof casting shadow on the actual roof)	0	1	0	0
Stack ventilation	6	2	4	5
External shading devices	20	13	14	14
Night ventilation with mass	4	1	4	1
Green roof	12	10	10	7
Other (please specify)	1	0	1	0
Plants and vegetation (for shadow casting or evapotranspiration)	19	9	8	4
Dynamic shading devices	2	3	3	4
Internal shading devices	10	6	8	10
Courtyard	12	3	7	4
Night ventilation without mass	5	1	4	1
Cross ventilation	20	7	11	6
Earth contact	3	2	3	1



	External shading devices	Green roof	Cross ventilation	Plants and vegetation (for shadow casting or evapotranspiration)	Internal shading devices	Cool roof	Courtyard	Evaporative cooling	Radiant cooling	Stack ventilation	Dynamic shading devices	None	Night ventilation with mass	Earth contact	Solar chimney	Night ventilation without mass	Downdraft cooling	Earth tube	Double roof (with the second roof casting shadow on the actual roof)	Roof pond	Other (please specify)
▨ Neither PE nor Licensed Architect	13	11	9	7	13	8	6	8	7	7	9	7	5	3	1	2	1	0	1	0	0
▨ PE	24	20	10	6	12	13	6	17	12	6	6	6	3	1	3	0	1	4	1	0	0
■ Licensed Architect	60	43	47	46	32	33	34	12	15	18	14	7	10	8	7	7	3	0	2	1	1

Figure 4.22 Passive cooling strategies categorized by professional registration

4.6.3. Passive/Natural Heating Systems (Practitioners)

About half of the practitioners (45.7%) did not use any passive heating strategy in their designs. Application of direct solar gain (44.2%), deciduous plants (37%), and isolated solar gain throughout the sunspace/greenhouse space (13%) defined the practitioners top three applied passive heating strategies. Earth contact (9.4%), solar chimney (8.7%), indirect solar gain through the Trombe' wall variations without water (8.7%), transpired solar wall system (4.3%), indirect solar gain through variations of Trombe' wall with water (3.6%), and earth tube (2.9%) are other passive heating strategies used by practitioners. Strategies mentioned by the respondents in the other category included: super-insulation (1.4%), thermal mass (1.4%), roof pond (0.7%), solar screen tuned with sun angles (0.7%), and stack ventilation (0.7%). Figure 4.23 shows the frequency of the application of passive heating strategies by practitioners in the last ten years.

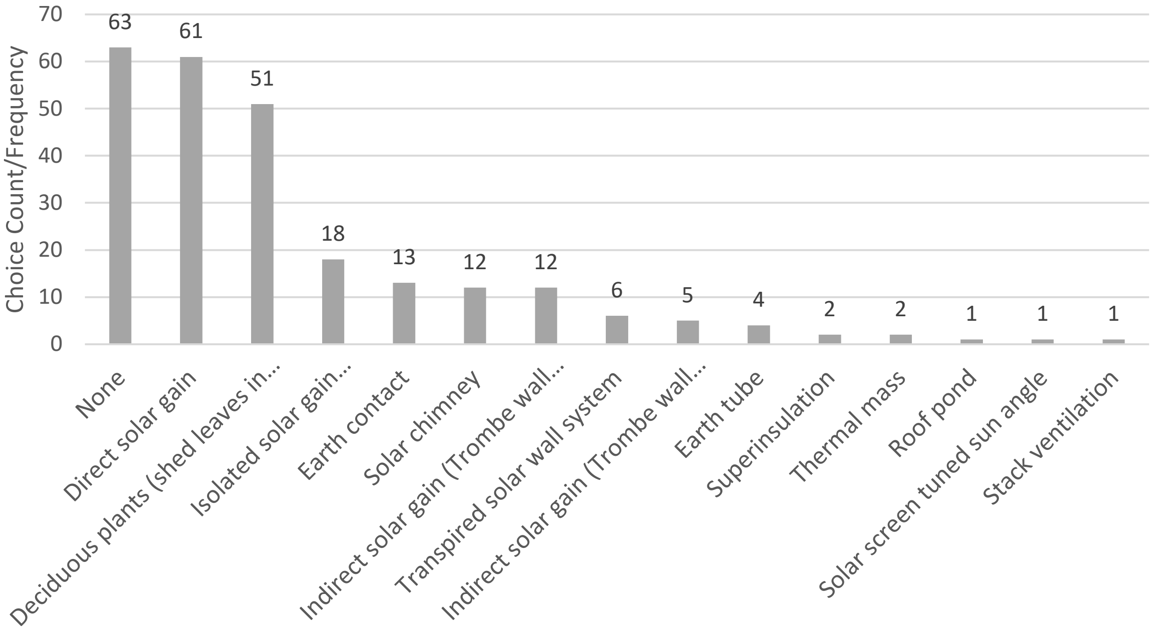
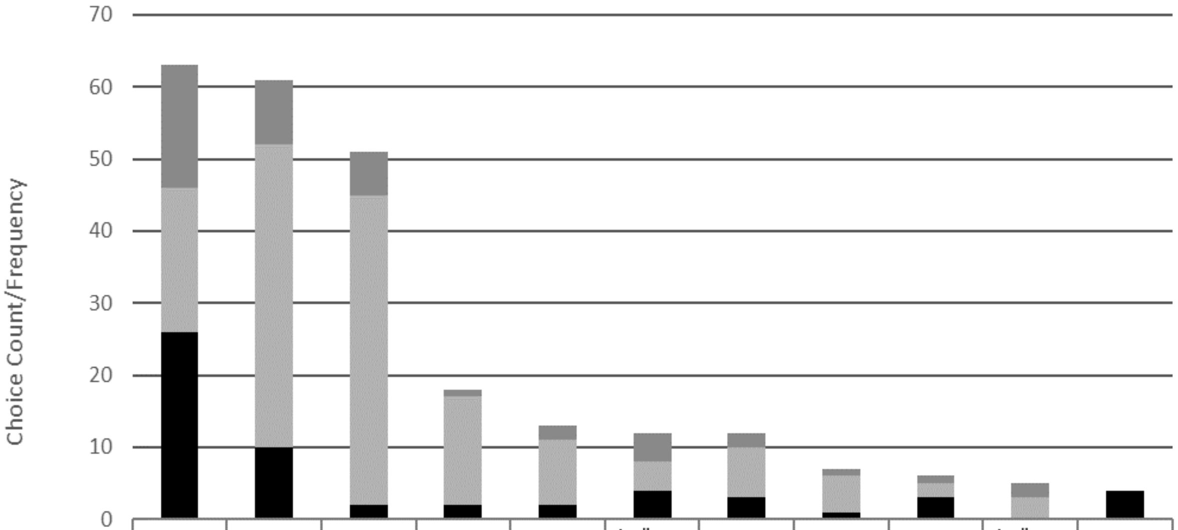


Figure 4.23 Frequency of the use of passive heating strategies by practitioners in the last 10 years

Table 4.12 Frequency of the application of passive heating strategies by practitioners

Passive heating strategy	**Count**	**%Count**	**% of practitioners**
None	63	25.0%	45.7%
Direct solar gain	61	24.2%	44.2%
Deciduous plants (shed leaves in the fall)	51	20.2%	37.0%
Isolated solar gain (sunspace/greenhouse space)	18	7.1%	13.0%
Earth contact	13	5.2%	9.4%
Solar chimney	12	4.8%	8.7%
Indirect solar gain (Trombe' wall without water and its variations)	12	4.8%	8.7%
Transpired solar wall system	6	2.4%	4.3%
Indirect solar gain (Trombe' wall including water and its variations)	5	2.0%	3.6%
Earth tube	4	1.6%	2.9%
Superinsulation	2	0.8%	1.4%
Thermal mass	2	0.8%	1.4%
Roof pond	1	0.4%	0.7%
Solar screen tuned sun angles	1	0.4%	0.7%
Stack ventilation	1	0.4%	0.7%
Total	252	100%	

The findings of the survey suggest that the majority of practitioners do not use passive heating strategies. While the climate of the US is more accommodating for the application of passive heating rather than passive cooling strategies, the percentage of practitioners who do not apply passive heating versus passive cooling in their designs is much higher (45.7% versus 14.5%). Additionally, as visible in Figure 4.24, architects are more interested in passive heating systems compared with engineers. In this case, other than direct solar gain, engineers show more interest in the use of Trombe' wall variations without water and earth tube. However, architects are more interested in the use of direct solar gain, deciduous plants, and isolated solar gain (i.e. sunspace or greenhouse).



	None	Direct solar gain	Deciduous plants (shed leaves in the fall)	Isolated solar gain (sunspace/greenhouse space)	Earth contact	Indirect solar gain (Trombe wall without water and its variations)	Solar chimney	Other	Transpired solar wall system	Indirect solar gain (Trombe wall including water and its variations)	Earth tube
Total	63	61	51	18	13	12	12	7	6	5	4
■ Neither Professional Engineer (PE) nor Licensed Architect	17	9	6	1	2	4	2	1	1	2	0
■ Licensed Architect	20	42	43	15	9	4	7	5	2	3	0
■ Professional Engineer (PE)	26	10	2	2	2	4	3	1	3	0	4

Figure 4.24 Frequency of the application of passive heating strategies categorized by practitioner' professional registration

4.6.4. Daylighting Systems (Practitioners)

The top four choices of practitioners for daylighting included: skylights (73.9%), clerestory windows (73.2%), sidelights (57.2%), and atriums (50.7%). Among practitioners 13.8% do not use any daylighting design strategies. In the case of respondents who did not apply daylighting strategies, the number of registered architects (1.4%) as shown in figure 1p is less than the number of registered engineers (5.8%). The remaining respondents were not registered architects or engineers (6.6%). Compared to add-on systems for passive heating or cooling, add-on daylighting systems were more appealing to practitioners. For instance, 39.9% use light shelves and 24.6% use light shafts. In addition, light louvers (13.8%), light pipes (12.3%), light ducts (10.1%), and external reflectors (3.6%) were the next four types of strategies that appealed to professionals.

Strategies such as light pipes and light ducts (10% of the applications) suggest that innovative and costly daylighting solutions could be more favored by practitioners, particularly by architects, compared to passive heating/cooling add-on systems. A higher percentage of the application of skylights and clerestory windows compared with sidelights might be indicative of a change in building envelope design in which the desire to bring daylight from the ceiling is replacing the desire to bring in daylight from the sidewalls. In this case, issues such as safety/security and outdoor views should be examined/considered to balance the desire for rooftop lighting with sidelight lighting.

Considering the frequency (count) of the application of skylights (19.7%) clerestory window (19.5%) light pipe (3.3%) and light duct (2.7%) together, about 60.4% of the professionals preferred daylighting from the ceiling compared with daylighting from the sidewalls (15.2%). This is without considering the choices in which atrium was considered (13.5% frequency) which may not necessarily draw light inside from only the ceiling. Issues such as glare, controllability, energy saving, and privacy could be hypothetical reasons for such a change.

Electronic light control (0.7%) was the only specified strategy in the other category. Dynamic daylighting, although very efficient for both comfort and energy saving, was rarely being applied by professionals (2.2%). The only type of dynamic daylighting strategy specified by respondents was in the form of sensors and controllers integrated into light fixtures (in NEEC required daylighting zones).

Table 4.13 Application of daylighting strategies by practitioners

Daylighting strategy	Count	%Count	% Practitioners
Skylights	102	19.7%	73.9%
Clerestory windows	101	19.5%	73.2%
Sidelights	79	15.2%	57.2%
Atrium	70	13.5%	50.7%
Light shelves	55	10.6%	39.9%
Light shaft	34	6.6%	24.6%
Light louvers	19	3.7%	13.8%
None	19	3.7%	13.8%
Light pipe	17	3.3%	12.3%
Light duct	14	2.7%	10.1%
External reflector	5	1.0%	3.6%
Dynamic daylighting (sensors integrated to light fixtures)	3	0.6%	2.2%
Other (Electronic light control)	1	0.2%	0.7%
Total	519	100%	

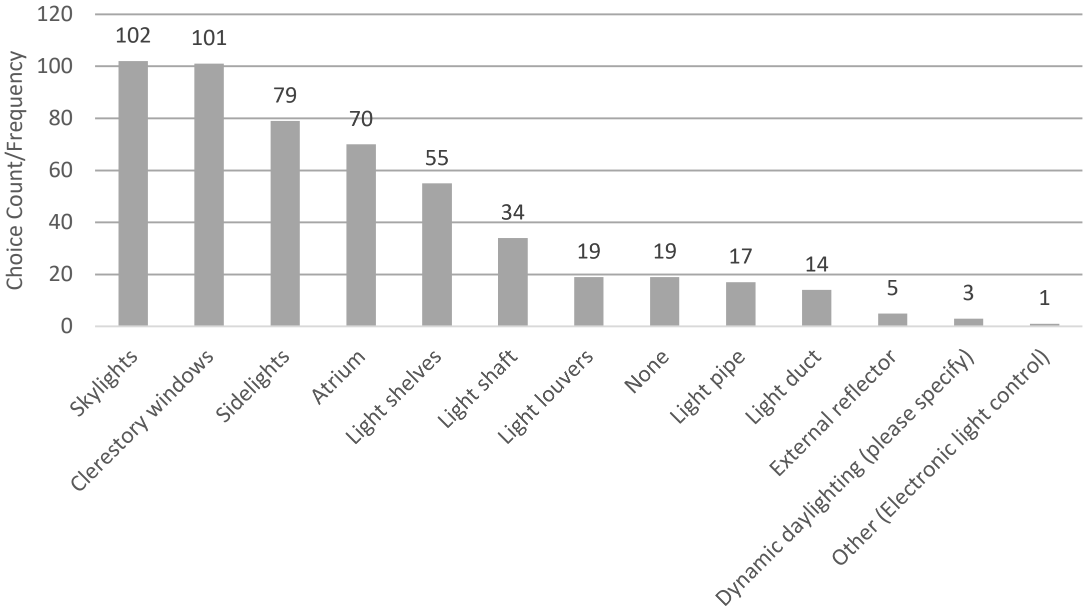
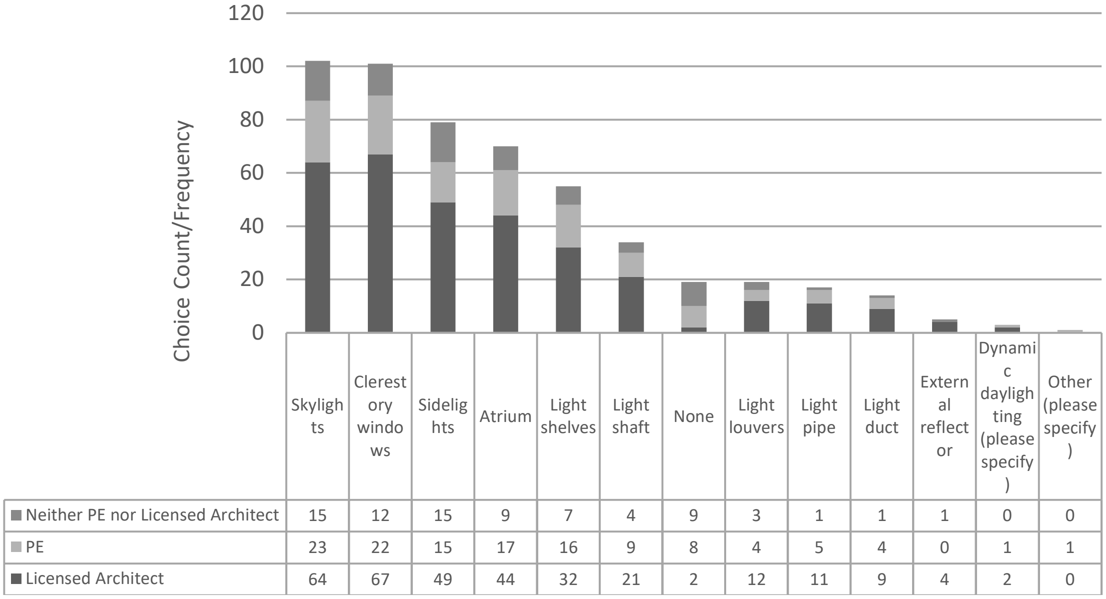


Figure 4.25 Application of daylighting strategies by practitioners



	Skylights	Clerestory windows	Sidelights	Atrium	Light shelves	Light shaft	None	Light louvers	Light pipe	Light duct	External reflector	Dynamic daylighting (please specify)	Other (please specify)
■ Neither PE nor Licensed Architect	15	12	15	9	7	4	9	3	1	1	1	0	0
■ PE	23	22	15	17	16	9	8	4	5	4	0	1	1
■ Licensed Architect	64	67	49	44	32	21	2	12	11	9	4	2	0

Figure 4.26 Application of daylighting strategies categorized by professional registration

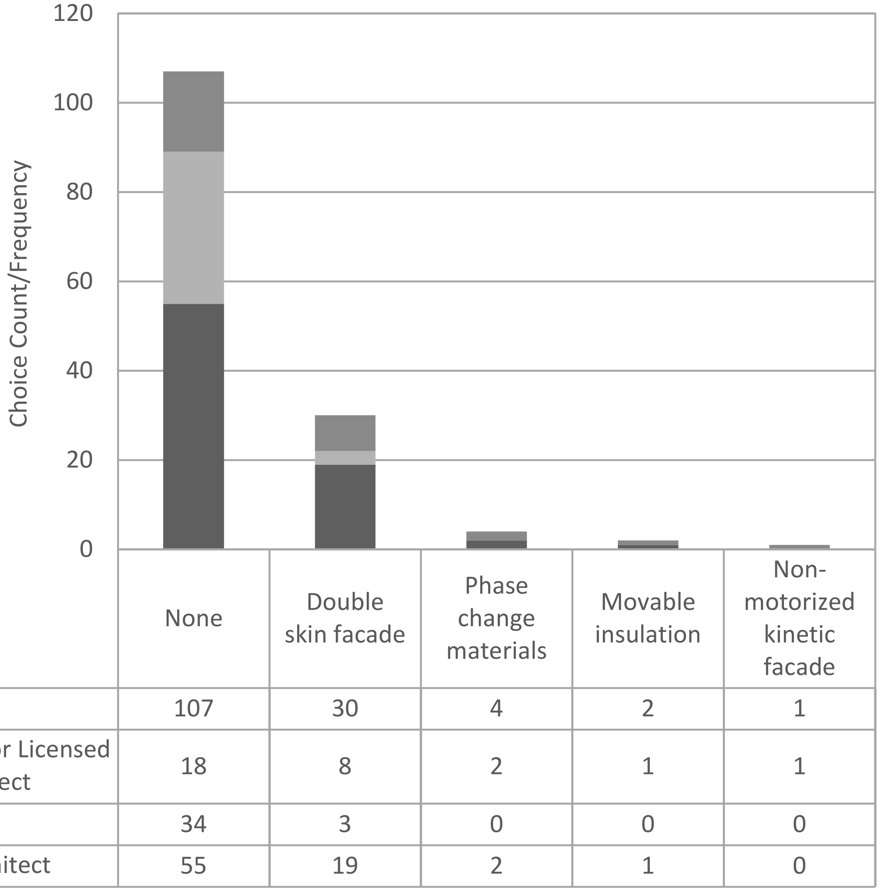
4.6.5. Passive Building Envelope Strategies (Practitioners)

This question was asked to find out at what level nontraditional or more advanced passive building envelope, design approaches have been pursued by practitioners. The survey results showed that the double-skin façade strategy with 20.83% choice count has been used by 21.7% of the practitioners in their projects during the last ten years. Other strategies including phase change materials, movable insulations, and non-motorized kinetic façades have been used by only 2.9%, 1.4%, and 0.7% of the practitioners, respectively (Figure 4.27).

Based on the survey results about 77.5% of the practitioners have not used any of these passive building envelope strategies in their projects. This low level of the application of unorthodox passive building envelope strategies might be an indicator of several issues: the lack of professionals' familiarity with the design and performance analysis of these strategies, the lack of special tools and approaches appropriate for their simulation, the lack of demand in the market for their application, and the complexity of their implementation with respect to the required cooperation between different members involved in a certain project.

Table 4.14 Application of passive building envelope strategies by professional licensure

Strategy	Count	%Count	% Practitioners
None	107	74.31%	77.5%
Double skin façade	30	20.83%	21.7%
Phase change materials	4	2.78%	2.9%
Movable insulation	2	1.39%	1.4%
Non-motorized kinetic façade	1	0.69%	0.7%
Total	144	100%	



	None	Double skin facade	Phase change materials	Movable insulation	Non-motorized kinetic facade
Total	107	30	4	2	1
■ Neither PE nor Licensed Architect	18	8	2	1	1
■ PE	34	3	0	0	0
■ Licensed Architect	55	19	2	1	0

Figure 4.27 Application of passive building envelope strategies broken out by professional licensure

4.7. Phase of Analyzing the Use of Passive Systems by Practitioners

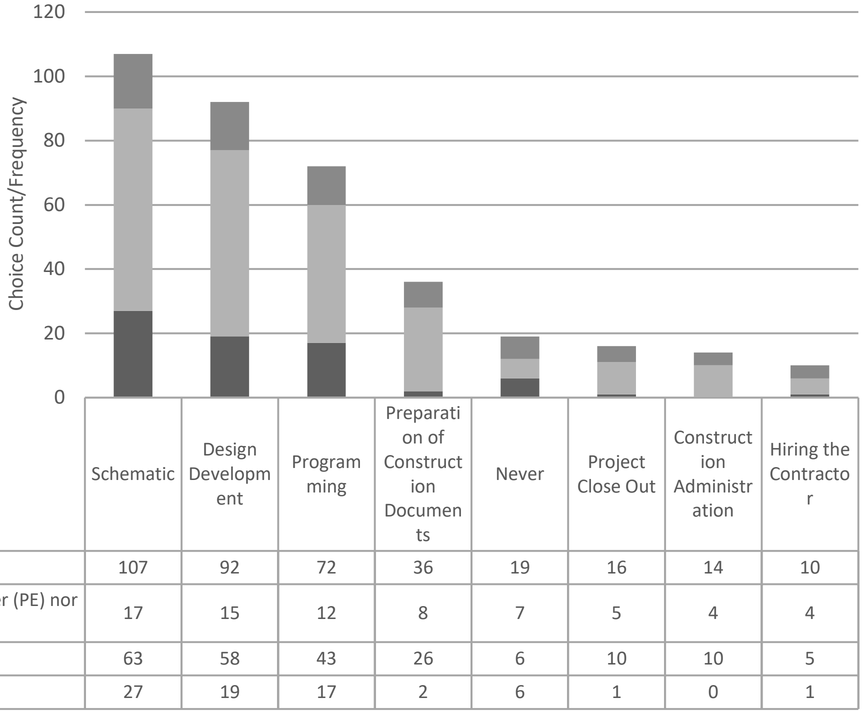
In the next question the seven phases of a project, based on AIA definitions was discussed (i.e. programming through project close-out). In this question professionals were asked to choose the phase(s) that they analyze the use of passive systems in buildings.[42] Figure 4.28 and Table 4.15 show the distribution of the analysis phase(s) among practitioners as well as their professional registrations. With the exception of 13.8% of the practitioners who never analyze the use of passive systems in a design-to-construction phase, the passive system analysis was the highest in the schematic phase (77.5% of professionals). The remaining choices reduced as we move toward the project close-out phase.

The percentage of professionals analyzing passive systems in each phase included programming (52.2%), schematic (77.5%), design development (66.7%), preparation of construction documents (26.1%), hiring the contractor (7.2%), construction administration (10.1%), and project close-out (11.6%). In the results it is important to note that there is a sharp drop in the analysis of passive systems beginning from the preparation of construction documents phase which indicates that the majority of analyses is conducted in earlier phases of programming, schematic, and design development. The fact that about 14% of professionals do not have any interest in

---

[42] These phases include programming, schematic, design development, preparation of construction documents, hiring the contractor, construction administration, and project close-out.

analyzing the use of passive systems could partially be explained by the lack of the application of these systems in general.



	Schematic	Design Development	Programming	Preparation of Construction Documents	Never	Project Close Out	Construction Administration	Hiring the Contractor
Total	107	92	72	36	19	16	14	10
■ Neither Professional Engineer (PE) nor Licensed Architect	17	15	12	8	7	5	4	4
■ Licensed Architect	63	58	43	26	6	10	10	5
■ Professional Engineer (PE)	27	19	17	2	6	1	0	1

Figure 4.28 Practitioners passive systems' analysis phase categorized by professional registration

Table 4.15 Practitioners' phase of analysis of passive systems

Analysis Phase	**Count**	**%Count**	**% Practitioners**
Schematic	107	29.2%	77.5%
Design Development	92	25.1%	66.7%
Programming	72	19.7%	52.2%
Preparation of Construction Documents	36	9.8%	26.1%
Never	19	5.2%	13.8%
Project Close Out	16	4.4%	11.6%
Construction Administration	14	3.8%	10.1%
Hiring the Contractor	10	2.7%	7.2%
Total	366	100.0%	

4.8. Practitioners' Tools

In this question practitioners were asked about 36 manual and digital tools for the analysis of passive systems in their projects. After redefining and reassigning the category of "other" and "in-house" tools, based on the survey responses, 39 different digital and manual tools were among the responses selected by practitioners (Table 4.16). The results show Revit Tools/Plugins (9.4% choice count), Climate Consultant (8.4%), and eQuest/DOE2 (8.4%) include the top three tools used by 25.4%, 22.5%, and 22.5% of practitioners respectively (Figure 4.29). The next set of tools among the top 10 tools being used by practitioners included Excel spreadsheet for 18.8% of practitioners, 15.2% EnergyPlus, 15.2% Sefaira, 13.8% Manual tables, charts, and protractors, 12.3% Radiance, 10.9% WUFI, 9.4% IES VE, and 9.4% OpenStudio.

The professionals' preference for choosing only daylighting analysis tools included Raidaince (12.3% of professionals), Daysim (5.1%), and Diva (5.1%). Interesting findings of the survey was the lack of the application of TAS by practitioners (0%) and TRNSYS (2.2%) despite the potential power of these tools for detailed analysis of passive systems in buildings. This lack of application could be the result of unfamiliarity of practitioners with these tools due to unavailability of training resources or difficulties for accessing these tools as opposed to some other tools such as eQuest or EnergyPlus.

Among the tools with exclusive packages for only CFD analysis, Autodesk CFD (8%), Autodesk Flow (2.9%), ANSYS Flow (0.7%), and Solidwork Flow Plugins (0.7%) were the most frequent tools used by practitioners respectively. The public availability of a building performance analysis tools and its training resources as well as having a platform possible to be easily shared with other design/BIM tools, such as Revit, could be a main reason for the professionals' higher interest in using Autodesk simulation tools such as Autodesk CFD.

Among the tools being used for passive solar design, HEED and F-Chart, were the least frequently applied tools selected by only 1.4% of practitioners. In the survey results 2.9% of the practitioners mentioned that they select a specialty consultant for the analysis of passive systems in their projects. In addition, 5.1% of the practitioners have developed their own in-house or personal tools for passive system analyses. Some of these tools, which have been specified by respondents, included the Weidt group tools and Chayya[43], which are used by individuals or top sustainable engineering and design firms. In the "other" category Passive House Planning Package (PHPP) was a tool that was mentioned for passive performance analysis by practitioners (2.9%). A lack of training resources available to practitioners may be the reason for this low usage. Another reason for the low level of PHPP application could be the focus of the tool on only the five criteria of the Passive House Institute in defining a passive building, which includes: air-tightness, continuous superinsulation, high performance windows for solar

---

[43] For further information about the simulation tool please see http://theweidtgroup.com.

heating, MHRV, and minimized air conditioning. These criteria were discussed in earlier sections.

About 20.3% of practitioners mentioned they do not use any tools for analyzing the feasibility of passive systems on a project. With respect to the answers to other questions, particularly the last question on the phase of analysis, the interpretation is that they are either part of a team of designers and the analysis of passive systems is delegated to other members of the team or they analyze the use of passive systems in terms of cost/savings other than energy such as in the case of construction cost. Given this assumption, the lack of a cost analysis capability in existing simulation tools or the unfamiliarity of some practitioners with the analysis capability of these tools could be a reason for not using them.

It should be also kept in mind that by categorizing the application of tools based on professional registration the result will be to some extent different as shown in Figure 4.30. In this case Revit tools/plugins, Climate Consultant, and Sefaira are the architects top three tools, while engineers' top three tools include eQuest/DOE2, Spreadsheets, and IES EV.

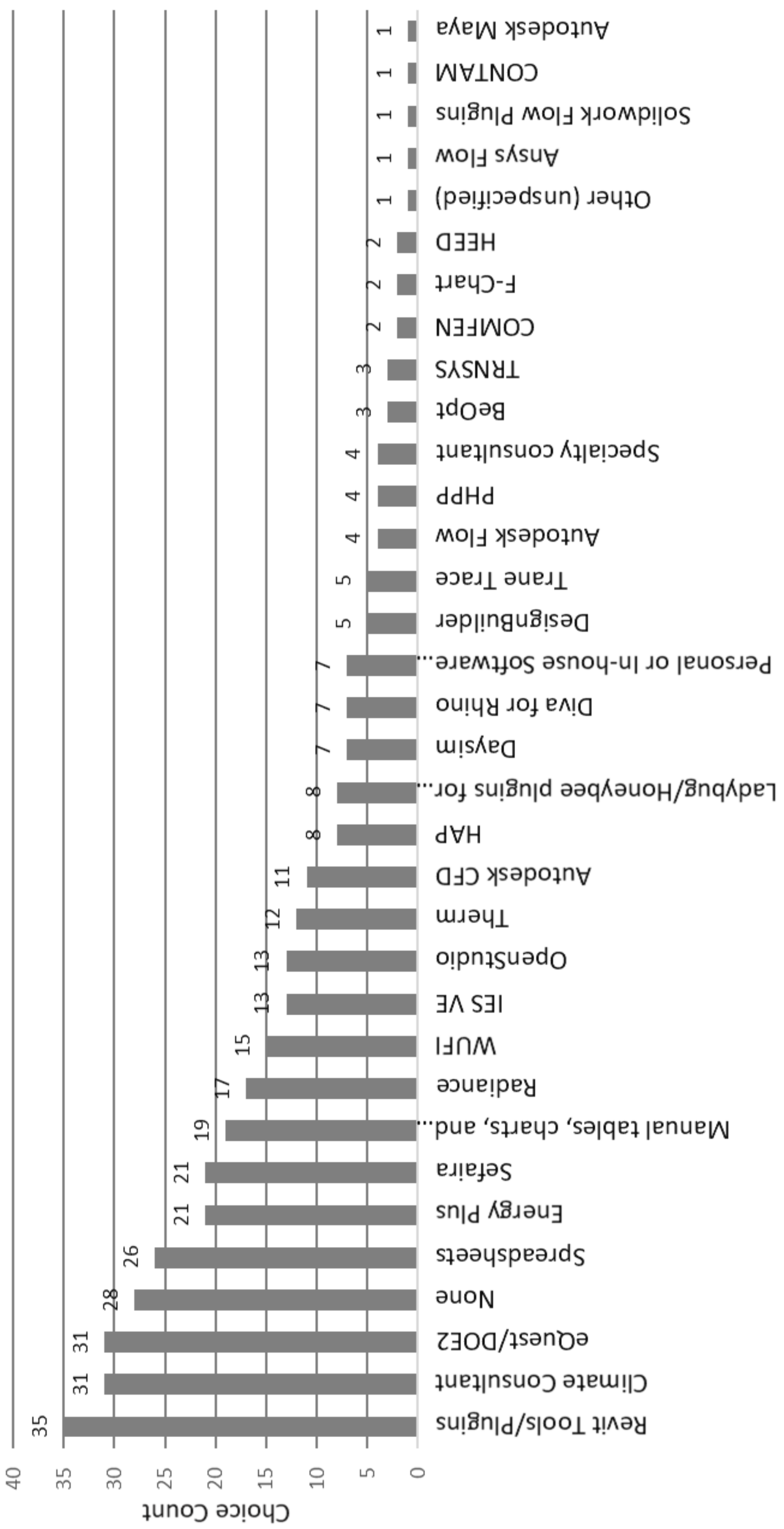


Figure 4.29 Professionals tools for analyzing the feasibility of passive systems on their projects

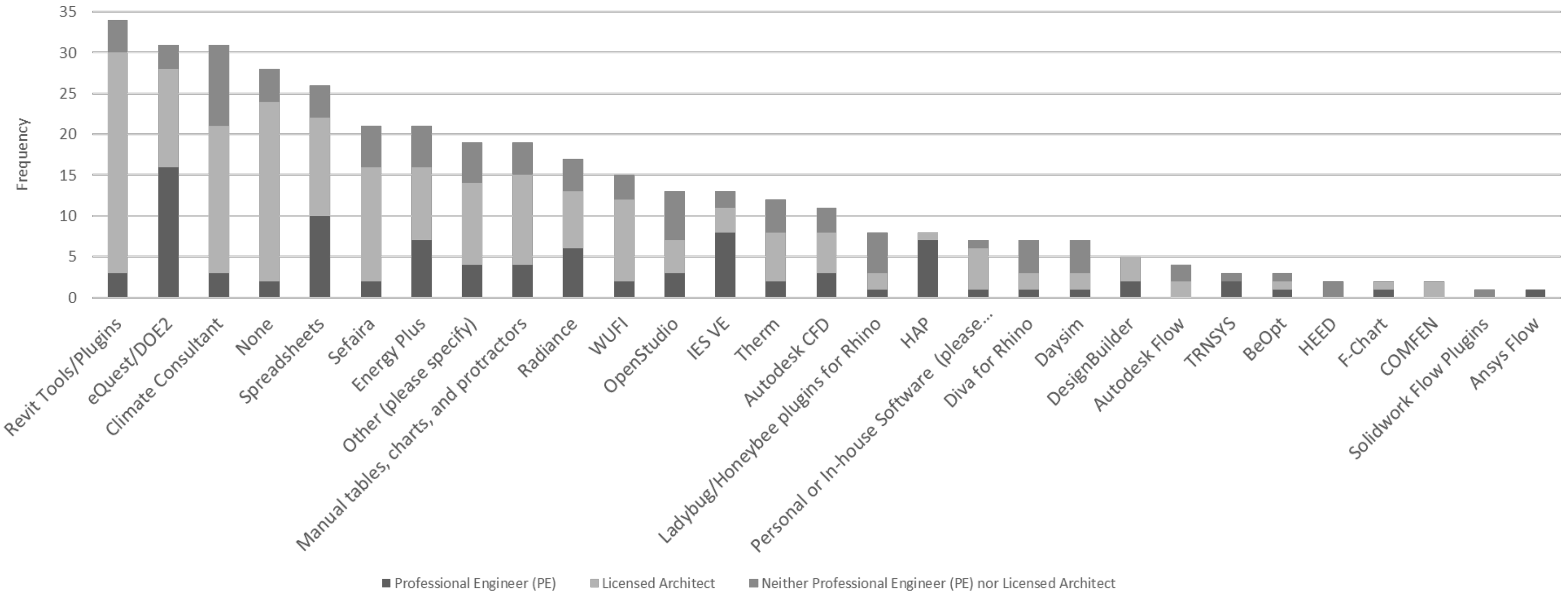


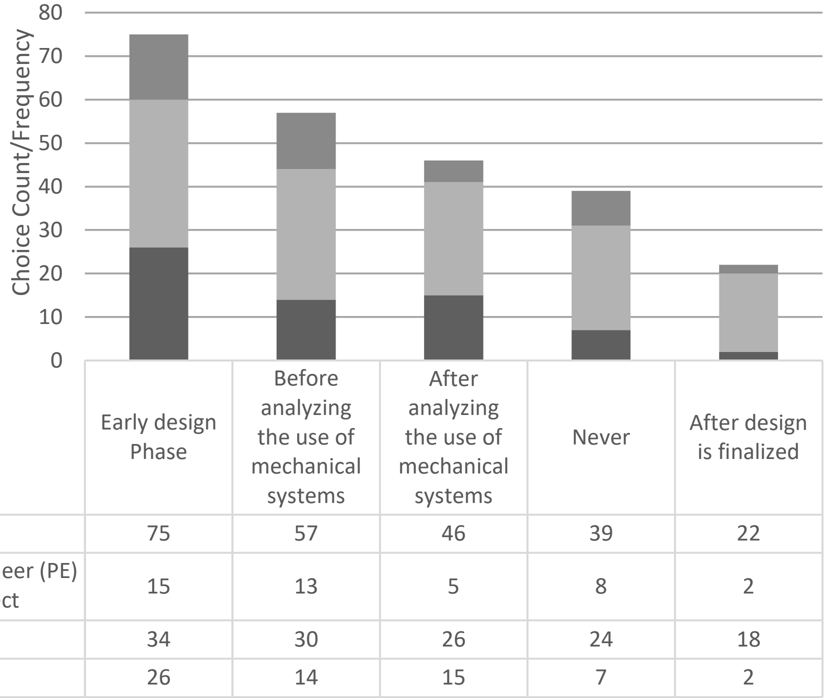
Figure 4.30 Tools used for analyzing the feasibility of passive systems categorized by professionals registrations

Table 4.16 Passive systems' analysis tools, their application frequency, and percentage

Tools	**Count**	**% Count**	**% Professionals**
Revit Tools/Plugins	35	9.4%	25.4%
Climate Consultant	31	8.4%	22.5%
eQuest/DOE2	31	8.4%	22.5%
None	28	7.6%	20.3%
Spreadsheets	26	7.0%	18.8%
Energy Plus	21	5.7%	15.2%
Sefaira	21	5.7%	15.2%
Manual tables, charts, and protractors	19	5.1%	13.8%
Radiance	17	4.6%	12.3%
WUFI	15	4.0%	10.9%
IES VE	13	3.5%	9.4%
OpenStudio	13	3.5%	9.4%
Therm	12	3.2%	8.7%
Autodesk CFD	11	3.0%	8.0%
HAP	8	2.2%	5.8%
Ladybug/Honeybee plugins for Rhino	8	2.2%	5.8%
Daysim	7	1.9%	5.1%
Diva for Rhino	7	1.9%	5.1%
Personal or In-house Software	7	1.9%	5.1%
DesignBuilder	5	1.4%	3.6%
Trane Trace	5	1.3%	3.6%
Autodesk Flow	4	1.1%	2.9%
PHPP	4	1.1%	2.9%
Specialty consultant	4	1.1%	2.9%
BeOpt	3	0.8%	2.2%
TRNSYS	3	0.8%	2.2%
COMFEN	2	0.5%	1.4%
F-Chart	2	0.5%	1.4%
HEED	2	0.5%	1.4%
Other (unspecified)	1	0.3%	0.7%
Ansys Flow	1	0.3%	0.7%
Solidwork Flow Plugins	1	0.3%	0.7%
CONTAM	1	0.3%	0.7%
Autodesk Maya	1	0.3%	0.7%
RETscreen	1	0.3%	0.7%
TAS	0	0.0%	0.0%
Total	371	100%	

4.9. Phase of the Calculation of Passive Strategy Savings (Practitioners)

A major finding of the survey was that 28.3% of professionals (24 architects,7 engineers, and 8 without professional registrations) never calculate the savings from passive systems (Figure 4.31 and Table 4.17). This finding could help explain the lack of the implementation of passive systems because the clients were not allowed to understand potential savings from passive design strategies to provide the required cost in their projects.



	Early design Phase	Before analyzing the use of mechanical systems	After analyzing the use of mechanical systems	Never	After design is finalized
Total	75	57	46	39	22
■ Neither Professional Engineer (PE) nor Licensed Architect	15	13	5	8	2
■ Licensed Architect	34	30	26	24	18
■ Professional Engineer (PE)	26	14	15	7	2

Figure 4.31 Phase of calculating passive systems savings broken out by professional registration

Most of the practitioners (54.3%) calculate the savings of passive systems in the early design phase. Based on the survey results, this response was given by both engineers and architects. The use of calculations is reduced as we move toward the final phases of design. Engineers responded that they calculated passive system savings mostly after analyzing the use of the mechanical system (15 counts) rather than before analyzing the mechanical systems application (14 counts). However, for architects the use of a passive system saving analysis was more before the choice of mechanical systems (30 counts) versus after the use of mechanical systems (26 counts). It seems that architects are adopting a more reasonable design method in analyzing passive systems before active systems with respect to Lechner's three-tier approach of sustainable design, which was discussed in section 2.1 of the literature review.

Finally, the survey results showed that 15.9% of the professionals calculated the savings after design was finalized, which shows the importance of continuous monitoring and evaluation of the passive system performance until the end of the project. The group of professionals that chose this response was mainly architects (28 counts) rather than engineers (2 counts).

Table 4.17 passive systems' saving calculation frequency in each phase

Design Phase	**Count**	**%Count**	**%Professionals**
Early design Phase	75	31.4%	54.3%
Before analyzing the use of mechanical systems	57	23.9%	41.3%
After analyzing the use of mechanical systems	46	19.3%	33.3%
Never	39	16.3%	28.3%
After design is finalized	22	9.2%	15.9%
Total	239	100.0%	

4.10. Influential Factors in Increasing/Reducing the Use of Passive/Natural Systems (Practitioners)

One of the important questions of the survey, if not the most important question, was to find out about the top three challenges/opportunities that practitioners select from proposed eleven choices that increase the use of passive systems in buildings. The top three selected choices (Table 4.18) included “clients desire and collaboration to include passive systems” (19.1% count), “building codes and rating systems” (16.4% count), and “simulation tools with capabilities for analyzing passive systems” (9.7% count).

The next eight items were ranked based on the frequency of selections including: fourth, “experience of the project team in the design, implementation, and integration of passive systems (8.2% count); fifth, “cost of material and construction of passive systems” (8%); sixth, “avoiding complexity and simplifying the implementation of passive systems” (7.7%); seventh, “climate of the location of the project with passive systems” (7.5%); eights, “architect-engineer collaboration” (7.2%); ninth, “knowledge of the modeling and simulations of passive system strategies” (6.8%); tenth, “knowledge integrating mechanical and passive systems performance” (4.8%); and eleventh, “Occupants training for the use and maintenance of the passive systems” (4.6%).

While the first rank (client’s desire) and second rank choices have only 2.7% percent selection difference, there is a sharp reduction of about 6.7% from selecting the second choice (i.e., building codes) to the third choice (i.e., simulation tools) by practitioners.

Again the reduction between choices of the third rank up to the ninth rank is minor (1.5% to 2.9%). Therefore, it is more logical to claim that the first and second item (i.e. building code and client's desire) are of the same importance.

Table 4.18 Items ranked based on the practitioners' top three choices to increase the use of passive systems in the US

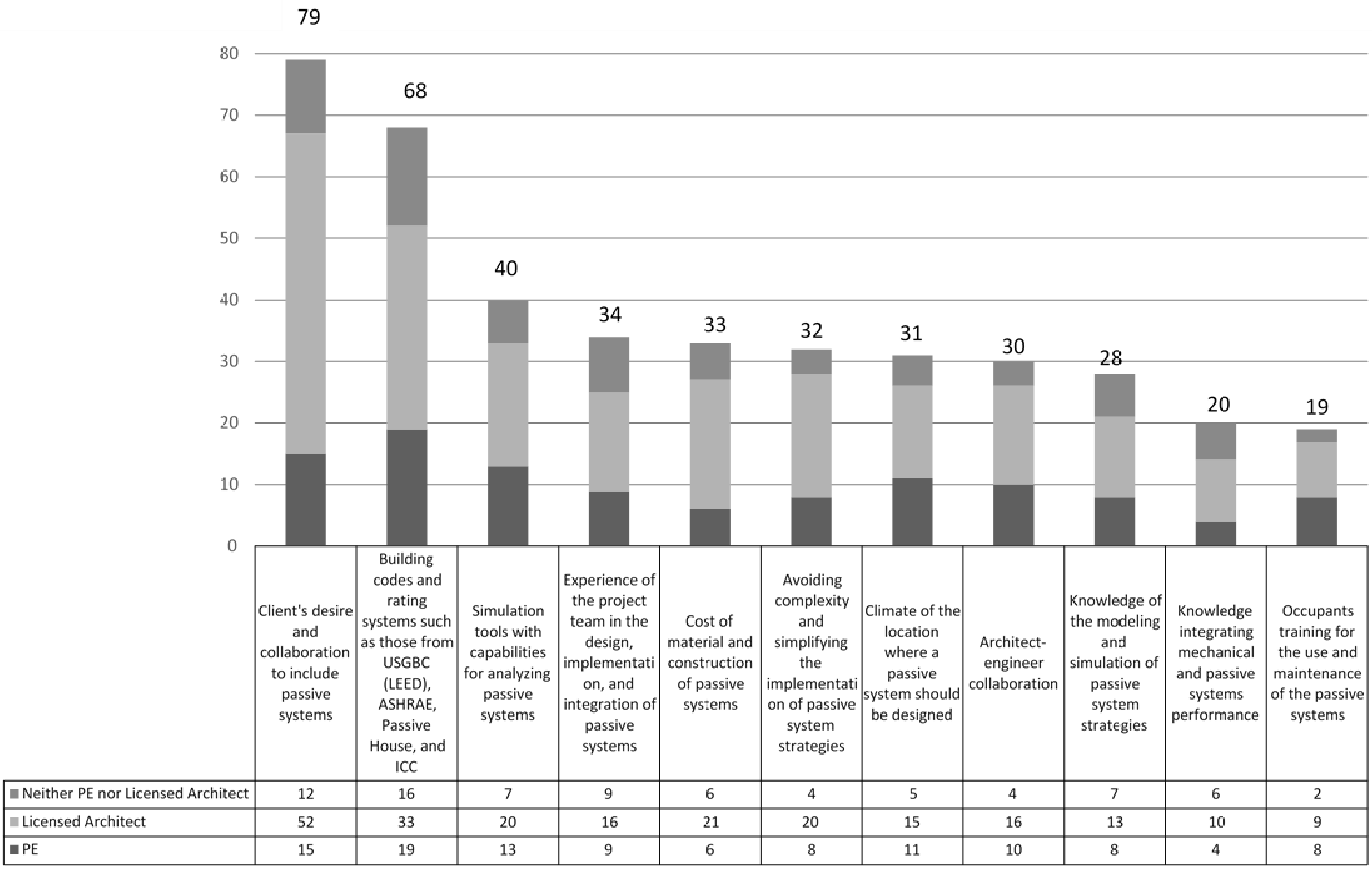
Rank	Influential factor	Count	%Count	% Practitioners
1	Client's desire and collaboration to include passive systems	79	19.1%	57.2%
2	Building codes and rating systems such as those from USGBC (LEED), ASHRAE, Passive House, and ICC	68	16.4%	49.3%
3	Simulation tools with capabilities for analyzing passive systems	40	9.7%	29.0%
4	Experience of the project team in the design, implementation, and integration of passive systems	34	8.2%	24.6%
5	Cost of material and construction of passive systems	33	8.0%	23.9%
6	Avoiding complexity and simplifying the implementation of passive system strategies	32	7.7%	23.2%
7	Climate of the location where a passive system should be designed	31	7.5%	22.5%
8	Architect-engineer collaboration	30	7.2%	21.7%
9	Knowledge of the modeling and simulation of passive system strategies	28	6.8%	20.3%
10	Knowledge integrating mechanical and passive systems performance	20	4.8%	14.5%
11	Occupants training for the use and maintenance of the passive systems	19	4.6%	13.8%
	Total	414	100%	

Next, comes the importance of the simulation tools' capability in passive systems simulation, and on a lower importance comes experience, cost, simplification, climate, architect-engineer collaboration, and knowledge of passive strategies simulations. The 10th item (i.e., knowledge integrating passive and mechanical systems) and the 11th item (occupant training) have also a close selection count (only 0.2% percent difference) and therefore it should be logical to consider their importance on an equal footing.

Figure 4.32. Shows all the eleven factors in a chart with a breakout based on the respondents' professional registration. Comparing the first and the second choice by registered architects and engineers reveals a difference in prioritizing clients desire and building codes to increase the use of passive systems. Accordingly, while architects consider the clients desire for passive systems the most important factor (55 to 33), engineers have given priority to building codes and rating systems (19 to 15 counts). One reason for such a difference could be the fact that most architects manage and direct projects and therefore they are more directly in contact with the clients, compared to engineers who might be working as a third party entity or through an architect/architecture firm with the clients. Also, in a similar manner, engineers are more dealing with energy and code requirements of building in building which support the reason for their difference with architects in selecting the important factor.

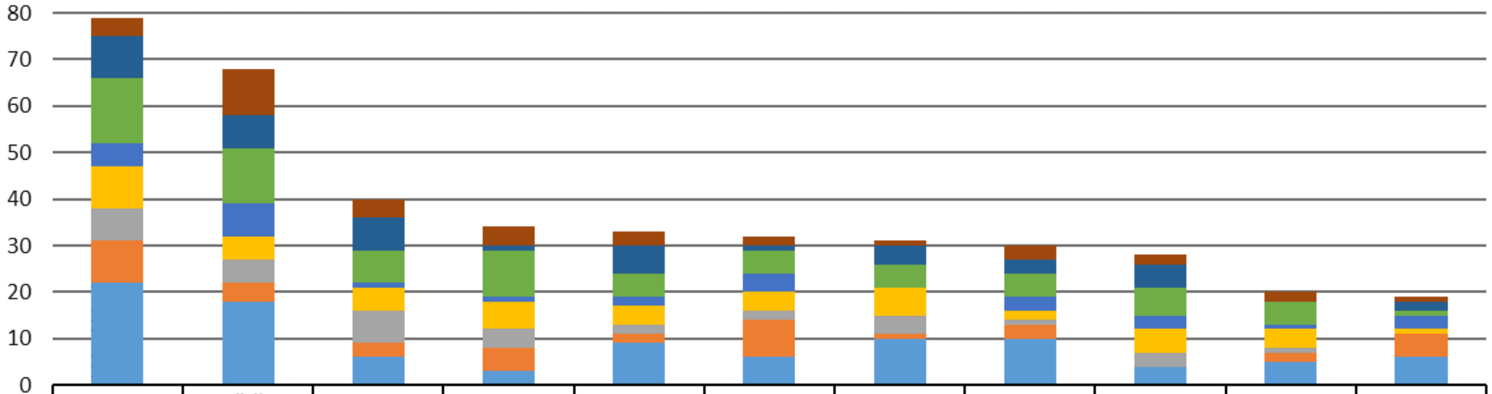
The number of years of professional experience could also be an important factor in selecting the most influential factor in increasing the application of passive systems as shown in Figure 4.33. On this basis, “building codes” item has been selected by practitioners with less than 5 years or 15-19 years of work experience, and “client’s desire and collaboration” item was selected by the rest of the practitioners who have 5-9, 10-14, or from 20 to over 34 years of work experience. Simulation tools and clients desire for the practitioners with 25-29 years of work experience both are of the same importance as the first ranked choice for increasing the use of passive systems in buildings.

A very interesting finding of the survey is that despite the general belief, climate, as ranked seventh among eleven items, does not play a key role in using or not using passive design strategies in the US. The role of occupants training in increasing the use of passive systems although ranked last, needs further analysis to be more inclusive. In particular, a survey should focus on occupants rather than designers to ask how important to building occupants is the use of passive systems.



	Client's desire and collaboration to include passive systems	Building codes and rating systems such as those from USGBC (LEED), ASHRAE, Passive House, and ICC	Simulation tools with capabilities for analyzing passive systems	Experience of the project team in the design, implementation, and integration of passive systems	Cost of material and construction of passive systems	Avoiding complexity and simplifying the implementation of passive system strategies	Climate of the location where a passive system should be designed	Architect-engineer collaboration	Knowledge of the modeling and simulation of passive system strategies	Knowledge integrating mechanical and passive systems performance	Occupants training for the use and maintenance of the passive systems
■ Neither PE nor Licensed Architect	12	16	7	9	6	4	5	4	7	6	2
■ Licensed Architect	52	33	20	16	21	20	15	16	13	10	9
■ PE	15	19	13	9	6	8	11	10	8	4	8

Figure 4.32 Factors influential in the use of passive/natural systems broken out by professional registrations of the respondents



	Client's desire and collaboration to include passive systems	Building codes and rating systems such as those from USGBC (LEED), ASHRAE, Passive House, and ICC	Simulation tools with capabilities for analyzing passive systems	Experience of the project team in the design, implementation, and integration of passive systems	Cost of material and construction of passive systems	Avoiding complexity and simplifying the implementation of passive system strategies	Climate of the location where a passive system should be designed	Architect-engineer collaboration	Knowledge of the modeling and simulation of passive system strategies	Knowledge integrating mechanical and passive systems performance	Occupants training for the use and maintenance of the passive systems
Total	79	68	40	34	33	32	31	30	28	20	19
🟫 Under 5 years	4	10	4	4	3	2	1	3	2	2	1
🟦 5 to 9 years	9	7	7	1	6	1	4	3	5	0	2
🟩 10 to 14 years	14	12	7	10	5	5	5	5	6	5	1
🟦 15 to 19 years	5	7	1	1	2	4	0	3	3	1	3
🟨 20 to 24 years	9	5	5	6	4	4	6	2	5	4	1
⬜ 25 to 29 years	7	5	7	4	2	2	4	1	3	1	0
🟧 30 to 34 years	9	4	3	5	2	8	1	3	0	2	5
🟦 Over 34 years	22	18	6	3	9	6	10	10	4	5	6

Figure 4.33 Factors influential in increasing the use of passive/natural systems in buildings categorized by respondents' years of work experience

4.11. The Open-Ended Question for Practitioners

In order to find out about other factors that can reduce or increase the contribution of passive systems into the design of buildings in the US as well as its other unknown aspects an open ended text question was included in the survey. The logic of this question was that instead of having interviews with a few number of practitioners, which usually imposes additional cost and demands more time, a text question can provide opportunities for the participants to include any information relevant to the content of the survey. The advantage of this inclusion is twofold: first, it reduces the cost and time required for interviews while increasing the number of participants to embrace a wider scope of opinions; and second it reduces the possibility of influencing the participants' opinions by removing the interviewer's physical presence. This open ended question asked practitioners to write their comments or notes if there is anything not addressed in the survey about the application of passive/natural systems in buildings.

The results included several findings about practitioners' opinions on the application of passive systems, which will be summarized here. A color coding approach was used to categorize the participants' responses. As such, responses with similar or shared themes were colored the same. At the end of color coding process, the following classifications along with their findings were realized:

- Actions needed to increase the use of passive design:

To increase the use of passive systems, it was mentioned by one of the respondents that the issue is not on the supply side or is not an issue of knowledge/capabilities. The issue is demand by owners and clients. It was suggested by this practitioner to adopt three strategies to increase this demand: first, by legislation (i.e. code requirements); second, by incentivizing it as in tax incentives or development incentives; and three, by decreasing the cost, since high-performance buildings generally cost more even if a well-integrated design process has been applied.

One of the respondents had a different view towards the role of clients in passive design compared to the practitioner's view who claimed that the issue is the client's demand for including passive systems: "Most of our clients want buildings which include passive solar or active solar strategies. However, almost none of them want to pay for it." Therefore, it might be possible that the major issue is not the supply/demand side, but more the additional cost which could be foisted on the design team without any compensation.

Sometime the design team may not approach the inclusion of passive systems in buildings due to concerns about building codes or the clients'/occupants' satisfaction after building occupancy. One of the practitioners mentioned that: "Fear of potential owner/user dissatisfaction with the comfort delivered by the HVAC system, and compliance with ASHRAE guidelines as now referenced in building codes, are a great disincentive in the use of passive systems in commercial/institutional projects." In this case, design tools and protocols can be developed to help designers deal with such circumstances in the process of designing and implementing passive systems.

For example, building protocols or codes can be developed with a focus on the function of buildings in power outages or natural disasters. One of the practitioners with a focus on healthcare facilities wrote about this issue: “How does a building react during an outage at various weather conditions? We're developing tools and protocols to simulate failures of mechanical systems and determine the impact on the occupied space.” Another solution proposed by a practitioner was to ask for collaboration with the power companies and to review the exiting incentives in different states: “Finding out what incentive states are providing would also help. Getting the power company to be more collaborative, so we can show the financial benefit to the owner and also reviewing agency to learn about it.” Another practitioner added in this regard that “certain states are behind the times in innovations and technology use. This drives the cost of new systems or construction styles way up, making it nearly impossible to get clients on board.”

Some of the practitioners indicated that consideration of the architectural aesthetics and their integration with passive systems and the whole building could be an important factor in increasing the use of passive systems: “You left off the most important single criteria for the adoption of passive strategies in building design and construction: Beauty. For decades we have concentrated on the savings, cost benefits and justification of passive strategies when in reality the customer usually only wants a beautiful building and becomes suspicious when we begin justifying a design. They will even pay more for a beautiful design. That beauty should include at least four of the five senses. They should feel better, smell better, sound better, and look better. And they usually do. But above all they should look better, because that is what the public sees in magazines, films, and on the internet."

A comment from a practitioner mentioned that for increasing the use of passive systems we need better definitions of passive design/systems. Today by using the term "passive" it is ambiguous what can be counted or not counted as a passive design strategy. In some cases, "it is not even clear how passive design may differ from existing terms such as high-performance buildings." As was explained in the literature review, such a confusion in limiting/delimiting the inclusion of passive design through its definitions even exists in green building rating systems. Most of the rating systems consider superinsulation and airtightness as passive design strategies, which along with the advocacy of some influential institutions in passive design such as PHIUS, may not necessarily consider the usefulness of add-on passive systems such as Trombe' walls or downdraft cooling systems. [44]

Another Practitioner mentioned that we evaluate passive systems frequently but almost never employ them. This practitioner mentioned that longer than ten years ago was using

---

[44] During the author's informal conversation with some experts this confusion in the definition of passive design was also perceptible. For example, in the course of designing the survey questionnaire on passive systems the author came across conversations such as this one: "do you mean passive design such as insulation and air tightness, or do you mean like for example roof ponds, Trombe' walls, etc."

some passive systems, but practically have not used any passive system since then. Such a response could be indicative of the interests in the past for using passive systems, which almost have disappeared today. Building codes and rating systems could play a key role in rekindling this interest as mentioned by another respondent: “the factors influencing the increase/reduction of the use of passive/natural systems in buildings [is] building code.” Another practitioner added to this quotes by emphasizing the greater role of codes versus rating systems in increasing the use of passive systems in buildings: “I would like to specify that I believe codes have a greater impact on the increase in [the] use of passive systems than rating systems. Rating systems are not practical for smaller scale projects due to cost. They serve as great guidelines, but codes need to be stricter.”

- Usefulness of passive system strategies:

“A majority of the strategies listed in this survey are simply not useful. The primary passive tactics to improve energy performance in a high heating climate are continuous insulation and exceptional air-tightness-neither of which are mentioned. Plus, exterior shading is good for cooling to avoid overheating.” This is one of the practitioners’ responses, who is also PHIUS certified consultant, with respect to the usefulness of the passive design strategies in the survey. This practitioner mentioned that “the most recurring types of passive/natural system strategies are continuous insulation, superinsulation, and exceptional air-tightness.”

Another practitioner in contrast to this response mentioned that: “Much of the earliest energy analytical work done in residential passive systems is documented in the publications (e.g. Passive Solar Design Handbook, Jan. 1980) of Dr. Doug Balcomb et al. working at the Los Alamos National Lab. In my estimation, those publications are the most significant contributions in the current field of passive/natural system design.” This discrepancy in considering passive systems useful, as described above, could be the result of unclear definitions of what is or is not included in passive design categories. More importantly, this difference could be the result of the institutions’ roles, such as PHIUS, in defining passive design/systems.

Another practitioner mentioned that “the usual problem is that passive systems don't do the whole annual job, and are not able to displace much of the required capacity of active systems.” This practitioner extended that “insulation, proper use of glazing, orientation and building tightness are the real winners in passive construction.” Some of the practitioners added to these strategies by providing creative ideas on how passive systems incorporated to a building can become more functional: “Perhaps a RED/GREEN light to tell people they can open up or not [the windows] is the best solution.”

Therefore, what is perceptible from the usefulness of passive design strategies is that some practitioners do not consider the traditional add-on passive design strategies useful, although some of the practitioners are still using these strategies, as showed in the survey results about passive cooling/heating systems used in the US. It seems that passive design today is diverging to two categories: in one category for most practitioners today passive design boils down to only typical building envelope solutions such as R values, superinsulation, and airtightness; for another category of designers a design which is only focused on these building envelope features without considering traditional add-on passive systems cannot be counted as a passive design. Some practitioner's responses emphasize this importance of the traditional passive systems in design: "Passive systems are actually part of indigenous design that existed prior to modern mechanical systems. The renewed interest in using passive heating and cooling as well as humidification strategies for buildings comes from the need for long term cost saving solutions as well as the aesthetic value of natural building modeling," or "our firm has been designing passive buildings since 1970s."

- Useful design tools for passive design:

Based on the practitioners' responses it seems that: first, the range of design tools for passive design are very limited. Second, in some cases, the same limitations imposed by institutions on the definition of passive design strategies have also influenced consideration of what can be a passive design tool. Third, the knowledge of passive building simulation is limited among professionals. And forth, the tools existing do not satisfy the practitioners' needs for the analysis of passive systems.

For instance, a PH certified consultant mentioned that “the design tools being used for passive design [are] PHPP or WUFI Passive,” which limits the range of passive design tools to the tools recognized by PHIUS. However, tools such as Climate Consultant or IES-VE have partial capabilities for the simulation of passive design strategies. This lack of attention to other tools’ capabilities in some cases could lead to overestimating or underestimating some of the tools capabilities in simulating or analyzing passive systems. For example, one of the practitioners mentioned that: “I believe that DOE2 is the most powerful building energy analysis tool to use when integrating passive and mechanical system design in commercial and institutional buildings.”

Finally, some of the practitioners expressed concerns about the unavailability of the simulation tools that can only analyze a passive system’s performance. For example, one the practitioners wrote that: “I have asked Autodesk for years to allow me to model the temperature swing in my buildings without taking into effect HVAC in an effort to judge efficacy of passive measures. Need a “naked” button, haven’t seen it.”

- The importance of an integrated design:

A practitioner responded that “[…for] incorporating passive/natural system strategies in a practical design process with respect to their integration with mechanical systems building form, orientation, layout, and percentage of glazing are important. So during schematic design. Then insulation and window selections during design development. Then construction details for thermal bridging, continuous insulation, and air tightness.”

Therefore, the general perception is that the majority of design integration for a passive design for some practitioners happens in its schematic phase.

Another practitioner mentioned that because passive systems cannot fulfil the whole annual heating/cooling “you have to buy two systems. If the building is well insulated, shaded and oriented, the active systems are not too expensive to deploy and operate, leaving little to save from passive systems.” Therefore, design integration is not only about technical design features, but also is a matter of proper integration between passive and active systems costs. Accordingly, it should be shown to the practitioners that both capital costs and operational costs should be considered in cost evaluations to include or exclude passive systems in buildings. Currently, the practice seems lacking a transparent approach in calculating these costs and savings from passive systems.

Lastly, design integration should be considerate of not only active and passive systems, but also of integration with a building’s function. This point was understandable from one of the practitioners’ comments: “For example, what happens in a building is important and often can present opportunities if those operational systems are integrated with the building systems; we do a lot of this with brewery projects.” This brings us to the importance of the role of building typology in passive design.

- The role of building typology in using passive systems:

One of the practitioners mentioned that “passive/natural systems are largely applicable to new buildings, and particularly buildings with substantial lots. [Therefore] more focus is needed on existing buildings and building compactly." However, it could be actually contrary to this claim, since passive heating of small buildings seems to be easier if they have an appropriately wide glazing area facing south. The reason being a small depth for the sunlight to reach the interior of the building and a proper ratio between the glazing area and the floor area for accumulating solar heat. Increasing the size of a building may make the maximum glazing area not sufficient for direct solar gains to be stored in the thermal mass of the floors and walls.

In some cases, even the size of a building may become of secondary importance compared to the form and geometry of its floor plan for passive heating if all of its sides can receive the proper amount of solar radiation during the day. This practitioner's comment suggests that a better education about the use/design of passive systems is necessary, as some of the practitioners avoid using passive design just because they are not properly informed about the potential benefits and opportunities for the contribution of these systems to energy savings.

Some of the practitioners mentioned that the use of passive systems in certain building typologies is difficult. One of the participants wrote that it is "difficult to do [passive design] in heavy commercial applications such as healthcare architecture." This response was similarly expressed by another practitioner who wrote that "I was educated in California but now practice in Connecticut and focus on healthcare projects where the environment is highly regulated and mechanical systems are not intended to include passive systems. Furthermore, healthcare projects tend to be hospitals with large footprints (limited perimeter) or developer projects where little thought goes into the core and shell." Therefore, as mentioned in the previous category of findings about passive systems, a building's functions can expand or limit opportunities for the incorporation of passive systems in practice: "what happens in a building is important and often can present opportunities if those operational systems are integrated with the building systems; we do a lot of this with brewery projects."

Finally, it seems that passive design is more becoming a matter of design resiliency rather than energy saving when it comes to building typologies other than residential buildings. In this regard, one of the practitioners mentioned this point: "Passive design is not commonly applied in healthcare facilities. However, from a resilience perspective, passive design is starting to pick up. For some healthcare facilities, evacuation is not possible."

- The drawbacks of using passive systems

Similar to any kind of design intervention, there are pros and cons in using a passive design strategy. Some of the practitioners explained their concerns over the drawbacks of using passive systems: "The negatives we have seen with passive systems are: one, Europeans pushing it in the USA when their summers have similar Dry Bulb temperatures, but much lower Wet Bulb temperatures and then our clients hate it; two, occupants who have no understanding of controlling operable windows in passive systems. It takes a fair amount of education to make a person understand weather, psychrometrics, and the [potential] effects [of passive design] on the building. One open window can humidify an entire building."

Therefore, lack of occupants' training and climate incompatibility could be two of the main drawbacks of using passive systems, which may result in dissatisfaction and more energy consumption if not properly addressed in design. The same practitioner mentioned that using simple methods, such as a red/green light to open the window when the weather outdoor is appropriate for natural ventilation, could be a solution to occupants' lack of training.

Finally, to conclude this section, one of the practitioners' comments seem to be appropriate at this point who mentioned that "the construction of energy efficient buildings need not be so over thought."

4.12. Major Findings of the Practitioners' Survey

Table 4.19, which concludes this section, shows some of the major findings of the survey from practitioners.

Table 4.19 Major findings of the survey from practitioners

Themes	Findings
Age Group/Work Experience	Passive/natural systems appeal to all age ranges in terms of work experience from young to old professionals. Meanwhile, older professionals and professionals who are in the middle of their career with 10-14 years of work experience might have a greater passion for passive designs. This outcome might be the result of the trends of these generations education and practice when passive/natural systems were of greater interest and focus in universities and firms in the 1970s and the 1980s and the beginning of the 21st century. Additionally, having a large percentage of the participants in the age group of 55 or more (36%) could be indicative of their educational background in the heyday of passive system design/education in the 1980s.
Type of Projects and Passive Design Opportunity	Based on the data collected, there is a greater potential for energy saving through the incorporation of passive/natural systems, not only in residential buildings, but also in educational and office buildings among other types of commercial buildings. Educational and office buildings with daytime occupancy schedules provide opportunities for the utilization of passive system strategies during the night time to prepare the building for daytime use. Such strategies could be particularly applicable in hot climates with high diurnal temperature variations.
Passive Cooling in the US	According to the collected data the majority of the practitioners' passive projects in the last ten years is located in the east central part of the US, including in the East-Center 5-6 zone embracing the climate 5A and small areas of climate 6A (35.9%). The second most selected area is the southern part of the US including the states of Texas and Florida (14.7%) with climate zone 2A. Based on the survey results, the high percentage of passive design projects in the eastern and southern areas of the US give evidence, despite the general misbelief, of the high possibility of applying passive design strategies in harsh hot humid or cold humid US climates.
Use of Renewables in Practitioners' Projects	About 23% of the participating practitioners have not used any renewable energy system in their projects. This number seems to be high with respect to the Architecture Challenge 2030 aiming to get to net zero carbon emission by the year 2030. In other words, to reach that target there should be more incentives to encourage all practitioners to incorporate renewable energy systems to their designs. Other types of renewables applied by practitioners included hydro and biomass/biogas systems (2.2%). Photovoltaics (PV panels), Geothermal, Solar thermal collectors for domestic hot water, None, Solar thermal collectors for space heating, Wind turbines, Other (Hydro, Biomass/BioGas)
Architects' and Engineers' Interests in Renewables	A comparison shows that the ratio of engineers using solar collectors for domestic hot water (i.e. 20 choices out of 85 total choices by engineers) is higher than the ratio of licensed architects using the same system (i.e. 21 choices out of 139 choices by licensed architects). Similarly, a comparison shows a higher ratio for engineers in the use of solar collectors for space heating. One reason for such a difference could be a more detailed calculation needed for the implementation of solar collectors, which is usually more appealing to engineers rather than architects

Table 4.19 Continued

Themes	**Findings**
Simplicity versus Complexity of Passive Systems	The results showed that the use of simple passive systems on new buildings were preferred over complex passive systems or add-on passive systems. As a result, external shading devices integrated with buildings façades, green roofs on the idle roof surfaces, and the appropriate location of building openings for cross ventilation are more likely to be applied by practitioners for the passive cooling of a building compared with strategies such as complex earth tubes or roof ponds, which are more difficult to maintain. The findings also showed that, despite the general misbelief that passive solar is more appealing to practitioners in the US, passive cooling strategies in the US are widely being applied. Finally, the complexity and cost of the selected passive cooling systems, such as for earth tube, solar chimney, night ventilation with thermal mass, or downdraft cooling seemed not to hinder their selection (3% to 13%).
Passive Heating Systems for Architects and Engineers	About half of the practitioners (45.7%) did not use any passive heating strategy in their designs. Application of direct solar gain (44.2%), deciduous plants (37%), and isolated solar gain throughout the sunspace/greenhouse space (13%) defined the practitioners top three applied passive heating strategies. The findings of the survey suggest that the majority of practitioners do not use passive heating strategies. While the climate of the US is more accommodating for the application of passive heating rather than passive cooling strategies, the percentage of practitioners who do not apply passive heating versus passive cooling in their designs is much higher (45.7% versus 14.5%). Additionally, architects are more interested in using passive heating systems compared with engineers. In this case, other than direct solar gain, engineers showed more interest in the use of Trombe' wall variations without water and earth tube. However, architects are more interested in the use of direct solar gain, deciduous plants, and isolated solar gain (i.e. sunspace or greenhouse).
Daylighting	The top four choices of practitioners for daylighting included: skylights (73.9%), clerestory windows (73.2%), sidelights (57.2%), and atriums (50.7%). Compared to add-on systems for passive heating or cooling, add-on daylighting systems were more appealing to practitioners. For instance, 39.9% use light shelves and 24.6% use light shafts. Among practitioners 13.8% do not use any daylighting design strategies. Strategies such as light pipes and light ducts (10% of the applications) suggest that innovative and costly daylighting solutions could be more favored by practitioners, particularly by architects, compared to passive heating/cooling add-on systems. A higher percentage of the application of skylights and clerestory windows compared with sidelights might be indicative of a change in building envelope design in which the desire to bring daylight from the ceiling is replacing the desire to bring in daylight from the sidewalls. about 60.4% of the professionals preferred daylighting from the ceiling compared with daylighting from the sidewalls (15.2%). This is without considering the choice of atrium (13.5% frequency) which may not necessarily draw light inside from only the ceiling. Issues such as glare, controllability, energy saving, and privacy could be hypothetical reasons for such a change. Dynamic daylighting, although very efficient for both comfort and energy saving, was rarely being applied by professionals (2.2%).

Table 4.19 Continued

Themes	**Findings**
Passive House Planning Package Tool (PHPP)	Passive House Planning Package (PHPP) as an exclusively designed tool for passive performance analysis is used by a small fraction of practitioners (2.9%). This small percentage of application seems to be due to lack of training resources available to all practitioners. Another reason for the low level of PHPP application could be the focus of the tool on only the five criteria of the Passive House Institute US in defining a passive building including air-tightness, continuous superinsulation, high performance windows for solar heating, MHRV, and minimized air conditioning. The shortages in these criteria were discussed in earlier sections. About 20.3% of practitioners mentioned they do not use any tools for analyzing the feasibility of passive systems on a project. With respect to the answers to other questions, particularly the last question on the phase of analysis, the interpretation is that they are either part of a team of designers and the analysis of passive systems is delegated to other members of the team or they analyze the use of passive systems in terms of cost/savings other than energy such as in the case of construction cost. Given this assumption, the lack of a cost analysis capability in existing simulation tools or the unfamiliarity of some practitioners with the analysis capability of these tools could be a reason for not using them.
Calculating the Savings From Passive Design Strategies	A major finding of the survey was that 28.3% of professionals never calculate the savings from passive systems. This finding could help explain the lack of the implementation of passive systems because the clients were not allowed to understand the potential savings from passive design strategies to provide the required cost in their projects. Most of the practitioners (54.3%) calculate the savings of passive systems in the early design phase. Based on the survey results, this response was given by both engineers and architects. The use of calculations is reduced as we move toward the final phases of design. Engineers responded that they calculated passive system savings mostly after analyzing the use of the mechanical system (15 counts) rather than before analyzing the mechanical systems application (14 counts). However, for architects the use of a passive system saving analysis was more before the choice of mechanical systems (30 counts) versus after the use of mechanical systems (26 counts).
Influential Factors in Passive Design	Building codes and client's desire are of the highest and same importance in increasing the use of passive systems. Next, comes the importance of the simulation tools' capability in passive systems simulation, and on a lower importance comes experience, cost, simplification, climate, architect-engineer collaboration, and knowledge of passive strategies simulations. The knowledge integrating passive and mechanical systems and the occupant training should be considered with equal importance as the last items based on the survey results. However, another survey targeting the occupants and their roles in using passive systems is needed to better support this last result.

Table 4.19 Continued

Themes	Findings
Advanced Passive Building Envelope Systems	The double-skin façade strategy with 20.83% choice count has been used by 21.7% of the practitioners in their projects during the last ten years. Other strategies including phase change materials, movable insulations, and non-motorized kinetic façades have been used by only 2.9%, 1.4%, and 0.7% of the practitioners, respectively. This low level of the application of unorthodox passive building envelope strategies might be an indicator of several issues: the lack of professionals' familiarity in large with the design and performance analysis of these strategies, the lack of exclusive tools and approaches appropriate for their simulation, the lack of demand in the market for their mass application, and complexity in their implementation with respect to the required cooperation between different members involved in a certain project.
Phase of Analysis for Using Passive Systems	With the exception of 13.8% of the practitioners who never analyze the use of passive systems in a design-to-construction phase, the passive system analysis was the highest in the schematic phase (77.5% of professionals). The remaining choices reduced as we move toward the project close-out phase. There is a sharp drop in the analysis of passive systems beginning from the preparation of construction documents phase which indicates that the majority of analyses is conducted in earlier phases of programming, schematic, and design development. The fact that about 14% of professionals do not have any interest in analyzing the use of passive systems could partially be explained by the lack of the application of these systems in general.
Passive Design/Analysis Tools	The professionals' interests in choosing simulation tools included in order: Revit Tools/Plugins, Climate Consultant, eQuest/DOE2, No Tools, Spreadsheets, Energy Plus, Sefaira, Manual tables, charts, and protractors; Radiance; WUFI; IES VE; OpenStudio; Therm; Autodesk CFD; HAP; Ladybug/Honeybee plugins for Rhino; Daysim; Diva for Rhino; Personal or In-house Software; DesignBuilder; Trane Trace; Autodesk Flow; PHPP; Specialty consultant; BeOpt; TRNSYS; COMFEN; F-Chart; HEED; Other (unspecified); Ansys Flow, Solidwork Flow Plugins, CONTAM, Autodesk Maya, RETscreen, and TAS. The public availability of a building performance analysis tools and its training resources as well as having a platform possible to be easily shared with other design/BIM tools such as Revit could be a main reason for the professionals' higher interest in using Autodesk simulation tools such as Autodesk CFD.

5. EDUCATORS SURVEY: RESULTS AND DATA ANALYSIS

5.1. Introduction

This chapter will present and analyze the results of the data that was collected through the online survey questionnaires focused on educators. To add to the findings of the practitioners' survey, the purpose of this survey was to obtain a more accurate perception of the level of education of passive systems in the US architecture schools as well as the background and experience of the educators. A key reason for conducting this survey was that the building industry practitioners usually build their expertise upon the knowledge and skills that they gain in the academic institutions. The survey procedure and tools were previously explained in the chapter four.

5.2. Demographic Information (Educators)

5.2.1. Professional Role (Educators)

5.2.1.1. Primary Additional Professional Role (Educators)

Among educators, as shown in Table 5.1 and Figure 5.1, 50% also practice mainly as an architect (18 counts) and 16.7% practice as an architectural engineer (6 counts). 11.1% of educators did not practice as an architect or engineer (4 counts). Sustainable design consultant is the third highest selected additional role (3 counts; 8.3%). In other categories there was 1 person (2.8%) for the following professions: Sustainable Design Consultant, Daylighting Consultant, Energy Consultant, Energy Lab Researcher, Engineer, and Researcher. Therefore, about 78% of the educators are either architects, architectural engineers, or sustainability experts. This high percentage of educators who also practiced indicates that there is a great potential to inform the building industry through educators who practiced in the building industry and vice versa.

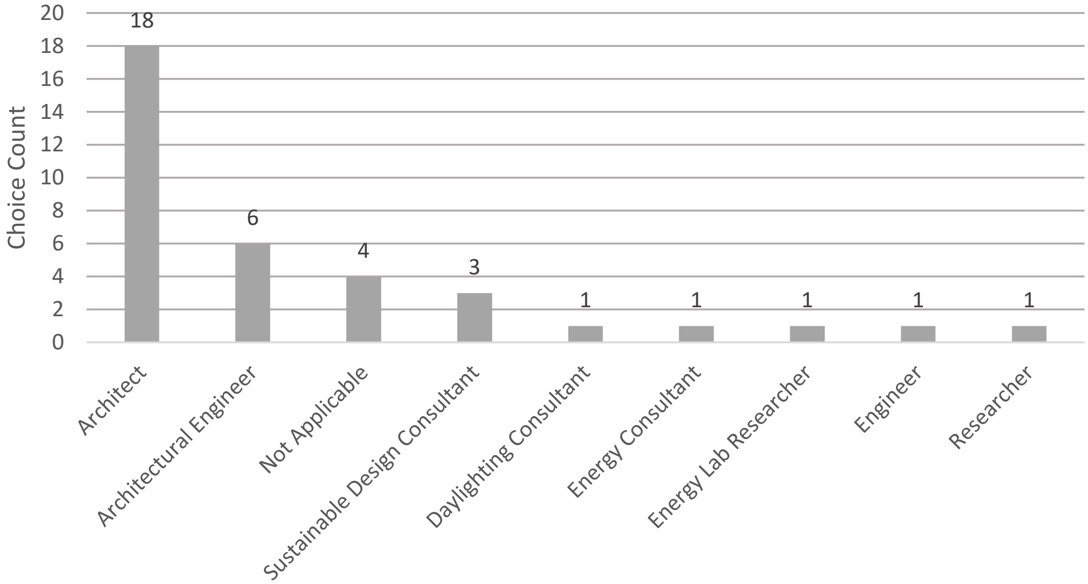


Figure 5.1 Educators additional current professional role

Table 5.1 Educators additional current professional role

Primary professional role in addition to being an educator	**%Count**	**Count**
Architect	50%	18
Architectural Engineer	16.7%	6
Not Applicable	11.1%	4
Sustainable Design Consultant	8.3%	3
Daylighting Consultant	2.8%	1
Energy Consultant	2.8%	1
Energy Lab Researcher	2.8%	1
Engineer	2.8%	1
Researcher	2.8%	1
Total	**100.0%**	36

5.2.1.2. Primary Previous Professional Role (Educators)

This question was asked to find out about the background of the educators who currently do not have any additional professional roles. Similar to the responses of the previous question, 50% of the respondents were previously an architect (18 counts) and 11.1% did not have any previous roles other than being an educator (4 counts). The percentage of the respondents who were previously practicing as an architectural engineer was 13.9% (5 counts). Since 16.7% of the current educators were also architectural engineers, there appears to be a 3% increase toward hiring architectural engineers to teach courses on passive/natural systems in universities.

However, the results show architecture schools still hire architects rather than engineers/architectural engineers as evidenced by 50% of the educators having architecture as their current and previous professional roles. Table 5.2 shows other previous professional roles including engineer (5.6%), sustainable design consultant (5.6%), energy consultant (2.8%) and lighting consultant (2.8%). The three respondents in the category of "other" (8.3%) were previously practicing as designers, marketing professors, or facility planners. Considering the number of architects and engineers, there is a 3 to 1 ratio in terms of the educators' background being an architect versus an engineer. This finding implies that very few architectural engineers are teaching at architecture schools.

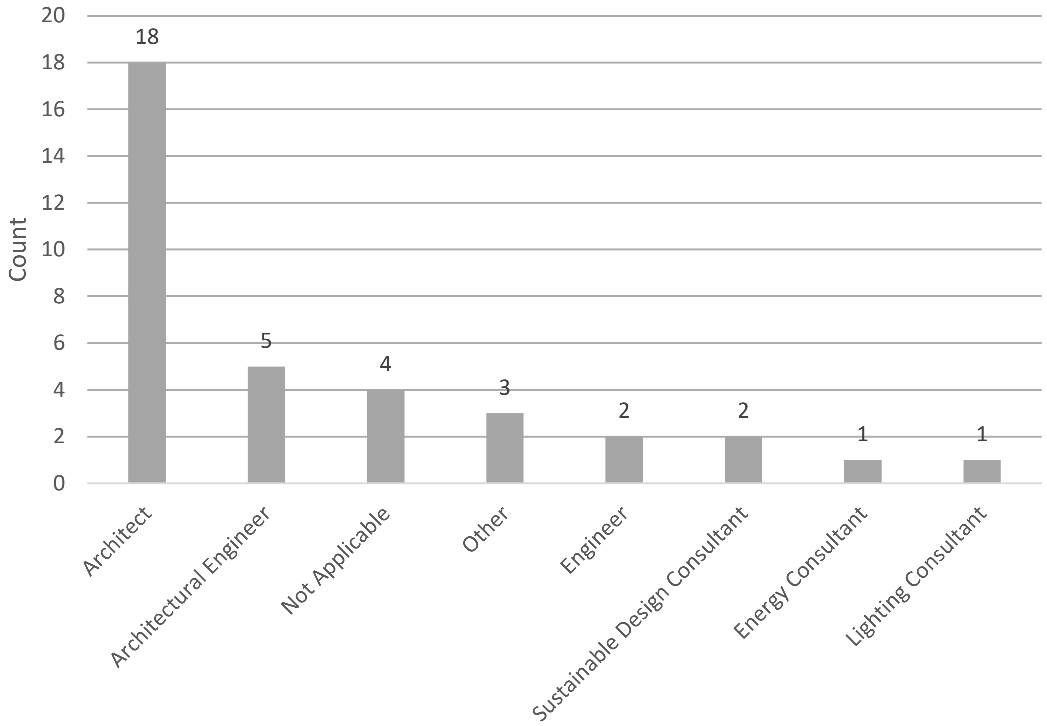


Figure 5.2 Educators previous professional role

Table 5.2 Educators' previous professional role

Professional Role	**%Educators**	**Number of Educators**
Architect	50%	18
Architectural Engineer	13.9%	5
Not Applicable	11.1%	4
Other	8.3%	3
Engineer	5.6%	2
Sustainable Design Consultant	5.6%	2
Energy Consultant	2.8%	1
Lighting Consultant	2.8%	1
Total	100%	36

5.2.2. Affiliations (Educators)

The SBSE, ACSA, and LEED AP define the first three affiliations chosen by the educators. Of these choices about 66.7% of the respondents are SBSE, 50% are ACSA, and 47.2% are LEED AP members (Table 5.3). The AIA and ASHRAE affiliations, which were among the top three choices for the practitioners in the previous survey, now stand on the fourth and fifth ranking and are selected by 44.4% and 33.3% of the educators, respectively. However, considering the fact that SBSE and ACSA are educational affiliations rather than professional affiliations, we can say that LEED AP, AIA, and ASHRAE still represent the top three professional affiliations for educators similar to practitioners. The difference is that LEED AP becomes the top choice for educators compared to AIA for practitioners.

About 22.2% of the participants were also members of the Building Technology Educators' Society (BTES). ASES and IESNA affiliations each define 16.7% of the respondents' affiliations. About 13.9% of the respondents are IBPSA members and 13.9% of them are members of the PHIUS. Table 5.3 and Figure 5.3 show the distribution of the affiliations among educators. In the category of "other" (6 counts) which was selected by 16.7% of educators, the following affiliations were mentioned: ICC (International Code Council), NFPA (National Fire Protection Association), ARCC (Architectural Research Centers Consortium), AEI (Architectural Engineering Institute), ASCE (American Society of Civil Engineers), SCUP (Society of College and University

Planning) AASHE (The Association for Advancement of Sustainability in Higher Education), ISCN (International Sustainable Campus Network), and A+CA.

Table 5.3 Educators' affiliations

Affiliations	% Out of Total Affiliations	Count	% of Educators
SBSE (Society of Building Science Educators)	19.5%	24	66.7%
ACSA (Association of Collegiate Schools of Architecture)	14.6%	18	50.0%
LEED AP	13.8%	17	47.2%
AIA	13.0%	16	44.4%
ASHRAE Member	9.8%	12	33.3%
BTES (Building Technology Educators' Society)	6.5%	8	22.2%
ASES (American Solar Energy Society)	4.9%	6	16.7%
IESNA (Illumination Engineering Society of North America)	4.9%	6	16.7%
Other (please specify)	4.9%	6	16.7%
IBPSA (International Building Performance Simulation Association)	4.1%	5	13.9%
PHIUS (Passive House Institute US)	4.1%	5	13.9%
Total	100.0%	123	

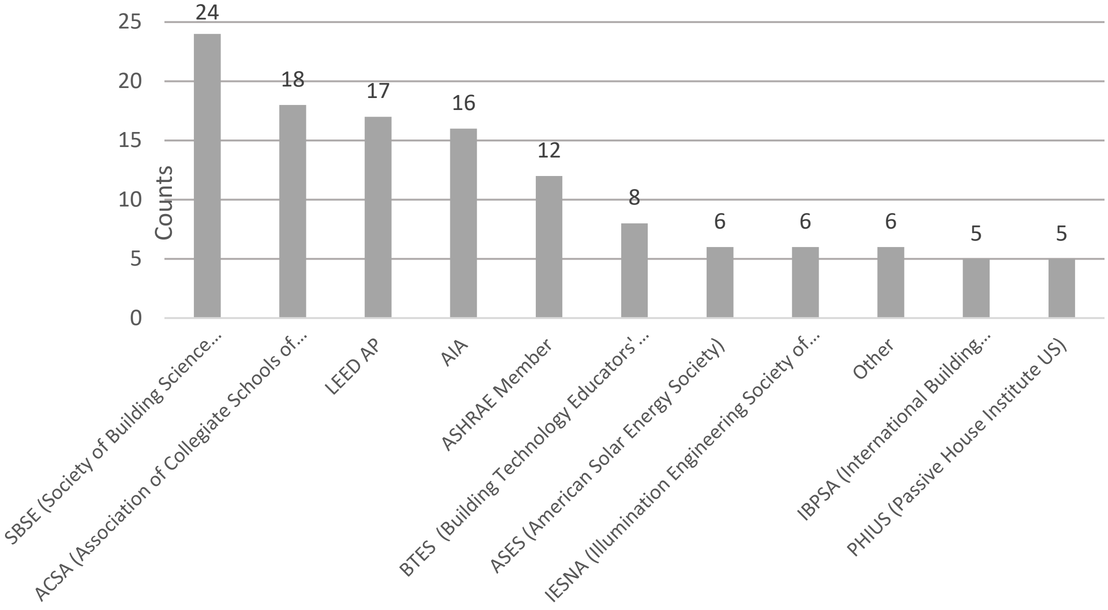


Figure 5.3 Educators' affiliations

5.2.3. Teaching Experience

The majority of the respondents (55.6%) had less than 20 years teaching experience. About 27.8% of the educators had 10-14 years teaching experience, which represent the most selected group (Table 5.4 and Figure 5.4). Educators with 5-9 years and over 34 years of teaching experience were the second most selected group each defining 13.9% of the total respondents. Other groups, in order, included 25-29 years (11.1%), 30-34 (11.1%), under 5 years (8.3%), 20-24 (8.3%), and 15-19 (5.6%). The results showed that the combination of old educators who had over 34 years teaching experience with young educators who had 5-14 years teaching experiences define the majority of the educators in the sample group. With this in mind, there seems to be a large experience gap between those who are about to retire and those who are starting their career as educators in higher education. On the other hand, the shift toward new passive concepts in higher education, such as adaptive facades or biomimetic design of building envelope components, could be the result of the replacement of the retiring educators with younger educators.

Table 5.4 Educators teaching experience

Years of teaching experience	**% of educators**	**Number of educators**
Under 5 years	8.3%	3
5 to 9 years	13.9%	5
10 to 14 years	27.8%	10
15 to 19 years	5.6%	2
20 to 24 years	8.3%	3
25 to 29 years	11.1%	4
30 to 34 years	11.1%	4
Over 34 years	13.9%	5
Total	100.0%	36

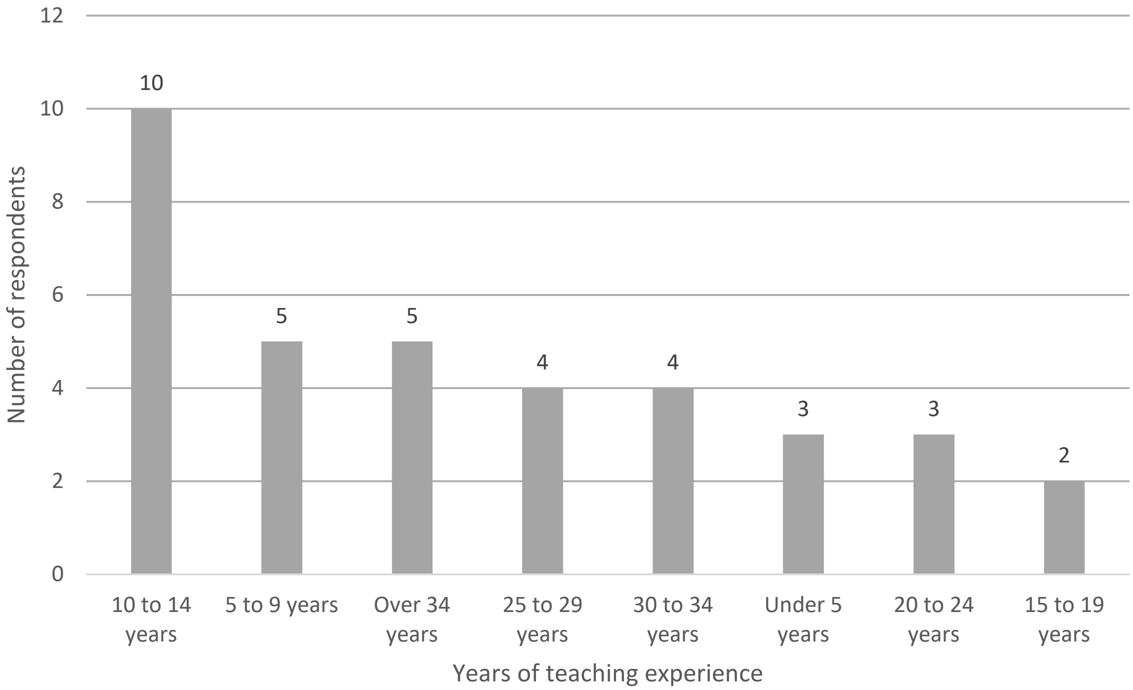


Figure 5.4 Educators teaching experience

5.2.4. Age Groups (Educators)

About 51.4% of the educators are more than 55 years old, which implies that they had the opportunity of developing their educational or professional experience during the peak periods of the 1980s and the 1970s passive design. More precisely, 31.4% of the respondents are over 59 years old, 20% of them are between 55 and 59 years old, and 20% are 45-49 years old (Table 5.5 and Figure 5.5). If we sum up the percentage of the age groups beyond 45 years old, 74.3% are above 45 years old. The age groups for 40-44 years, 35-39 years, and 30-34 years each represent 8.6% of the respondents age groups and share the fourth most selected age groups. The least selected age group is 50-54 years old with only 2.9% selection. Due to the nature of this question, the answer in the survey was set as optional, and therefore the total responses of this question was less than the totals of other questions.

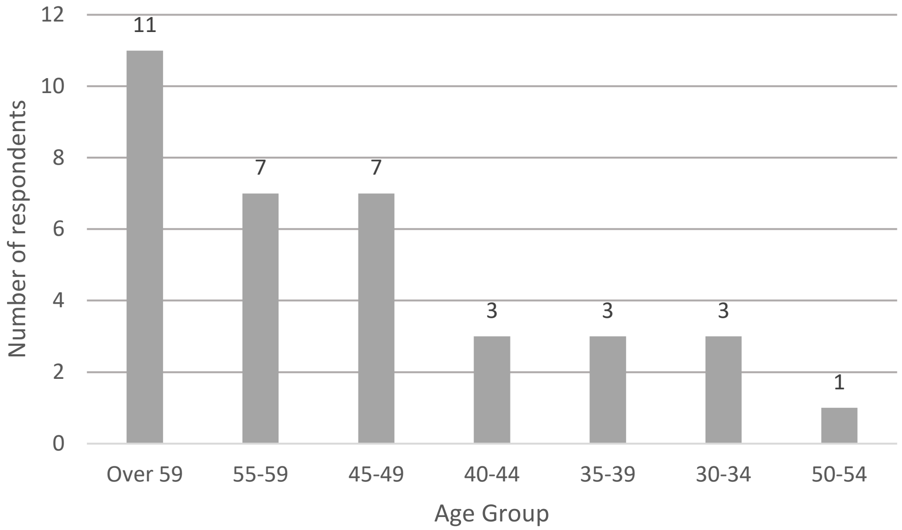


Figure 5.5 Educators' age group

Table 5.5 Educators' age group

Age groups	**%Respondents**	**Respondents**
Over 59	31.4%	11
55-59	20.0%	7
50-54	2.9%	1
45-49	20.0%	7
40-44	8.6%	3
35-39	8.6%	3
30-34	8.6%	3
Total	100%	35

5.2.5. Location (Educators)

Figure 5.6 shows the locations of the respondents in the US. Accordingly, most of the participants were from the East Coast and West coast of the country. However, it could not be determined from this survey if the respondents had been teaching in other areas of the country before their current teaching position. As shown on the map, a majority of the participants either teach or were located in the North East, Mid-lands, Great lakes, Pacific Northwest and West Coast of the country. Since the survey was distributed to the top 40 architecture colleges and schools in the US, the results indicate that passive/natural systems are receiving much more attention and education in universities in the East Coast and West Coast, which is also evidenced by the participation interests from educators in these areas.

Figure 5.6 Educators locations

5.2.6. Professional Registration (Educators)

Table 5.6 and Figure 5.7 show that the majority of respondents were licensed architects. About 61.8% of the participants were licensed architects while 11.8% of the participants were professional engineers (PE), and 2.9% of them had both PE and architectural licensure. Therefore 76.5 % of the total educators had professional registration in the US, which is only about 6% less than the total number of registered practitioners found from the practitioners' survey results (81.2%). This number indicates that the majority of educators are informed with the building industry's practice regarding passive systems. This same majority can also have an influence with their educational practice on the building industry. Among respondents 23.5% did not have either architectural licensure or PE. As shown in Table 5.7, most of the registered professionals (64.3%) have Architectural Licensure or PE in only one state, 32.1% in one state, and 3.6% (only one person) have professional registration in 26 states.

Based on Figure 5.8 the number of times that states were selected by educators for PE registration (28 times) was almost equal to the times that states were selected for Architectural Licensure (29 times). In this case Massachusetts (4 times) had the highest number of educators with architectural licensure while Michigan and Delaware (each two times) had the highest number of educators with PE registration.

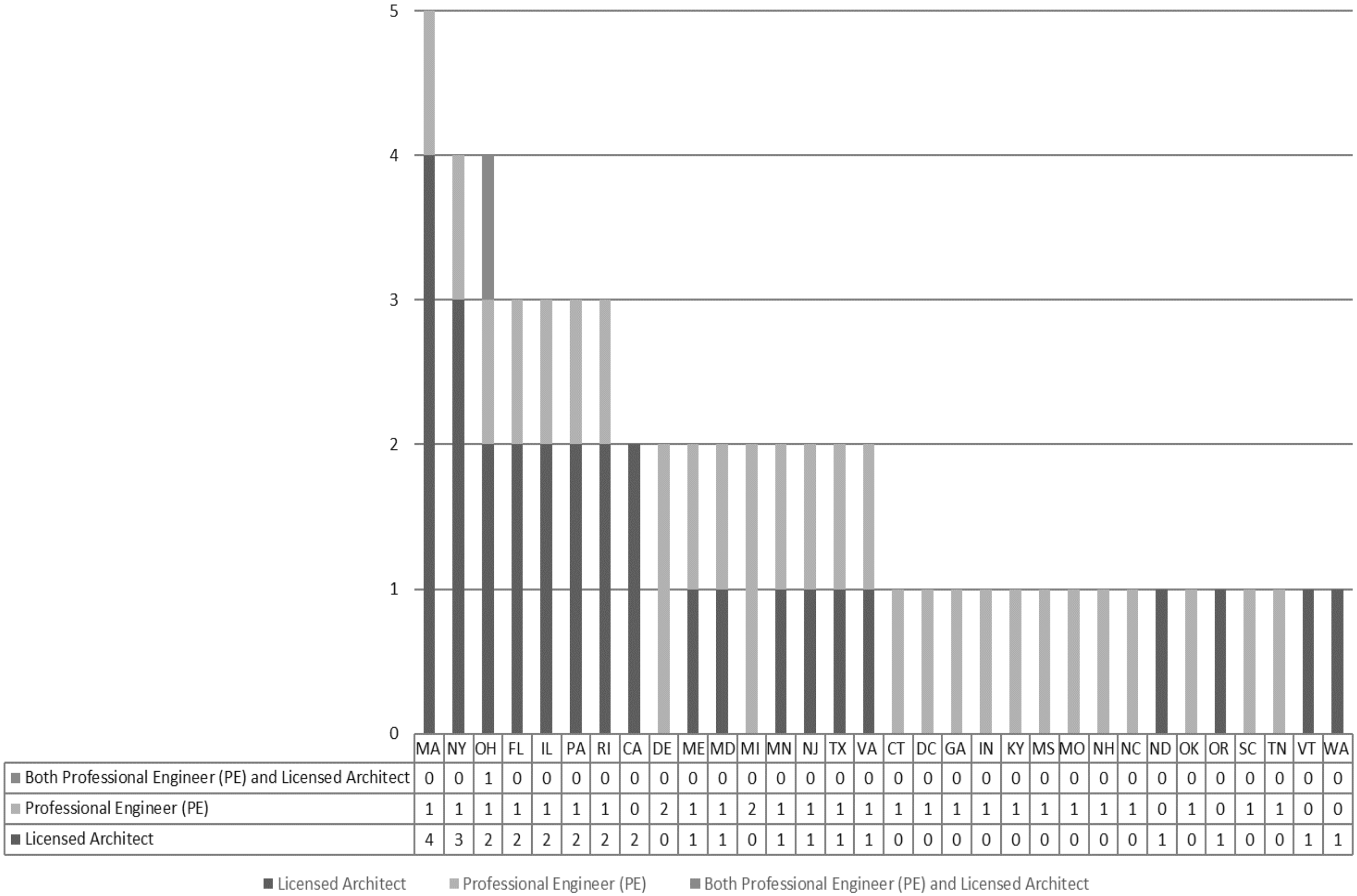
Figure 5.7 Professional registration of the educators

Table 5.6 professional registration of the educators

Answer	%Respondents	Respondents
Licensed Architect	61.8%	22
Neither Professional Engineer (PE) nor Licensed Architect	23.5%	9
Professional Engineer (PE)	11.8%	4
Both Professional Engineer (PE) and Licensed Architect	2.9%	1
Total	100%	36

Table 5.7 Number of states for the professional registration of the educator

Number of states	Number of respondents	% Respondents
1 state	18	64.3%
2 states	9	32.1%
26 states	1	3.6%
Total	28	100.0%



	MA	NY	OH	FL	IL	PA	RI	CA	DE	ME	MD	MI	MN	NJ	TX	VA	CT	DC	GA	IN	KY	MS	MO	NH	NC	ND	OK	OR	SC	TN	VT	WA
■ Both Professional Engineer (PE) and Licensed Architect	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
■ Professional Engineer (PE)	1	1	1	1	1	1	1	0	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	0
■ Licensed Architect	4	3	2	2	2	2	2	2	0	1	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1

Figure 5.8 Professional registration of the educators broken by their states of professional registration

5.2.7. Location of Education (Educators)

Similar to practitioners' survey results, most of the educators have earned the degree(s) related to their current profession from the New England area. The survey results show that 15.8% of the earned degrees were from the New England area. The Mid Atlantic (East Coast) was the second most selected location with 12.3% of the degrees earned by educators in this area. The West Coast, Texas, and Pacific Northwest each shared 10.5% of the third place in this regard. Table 5.8 shows all the locations selected by the respondents for their degrees. Two of respondents who are teaching in the US earned their degrees abroad in Switzerland and UK. Based on the survey results, it seems that graduates from New England, Mid Atlantic, Pacific Northwest, Texas, and West Coast have a higher chance of being employed by universities in faculty positions focused on building technology including passive systems.

Figure 5.10 shows that Masters of Architecture (27.9%), Bachelors of Architecture (26.2%), and PhD Degrees (16.4%) form the first top three degrees earned by educators who are active in the field of passive/natural systems. Master of Science 14.8% and Bachelor of Science with 8.2% of degrees represent the fourth and fifth type of degrees pursued by educators. Given the third rank for PhD degrees in the results, there is a potential to increase the number of faculty members in higher education who have PhD degrees related to the field of passive/natural systems if research, update, and promotion of the old passive literature is desirable.

Table 5.8 Location of the respondents' degree(s) most related to their current profession

Degree Location	%Count	Count
New England	15.8%	9
Mid Atlantic (East Coast)	12.3%	7
Pacific Northwest	10.5%	6
Texas	10.5%	6
West Coast	10.5%	6
Great Lakes	8.8%	5
Algonquin	5.3%	3
Mid Lands	5.3%	3
Midwest	5.3%	3
Florida	3.5%	2
Mountain	3.5%	2
Aborad (UK)	1.8%	1
Abroad (Switzerland)	1.8%	1
Appalachia	1.8%	1
Gulf Coast (South Coast)	1.8%	1
South	1.8%	1
Total	100%	57

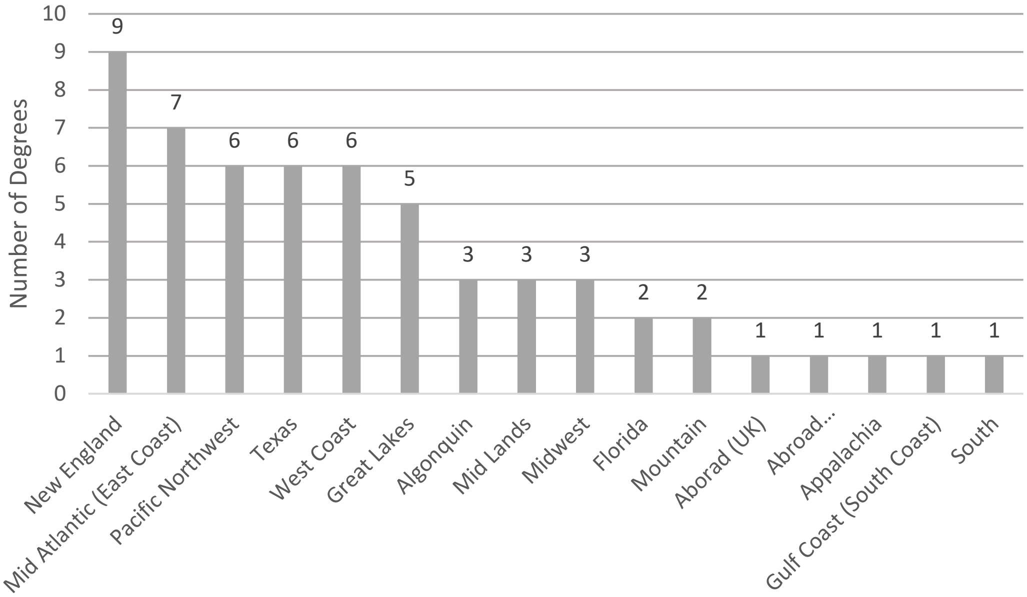


Figure 5.9 Location that the educators earned their degree(s) most related to their current profession

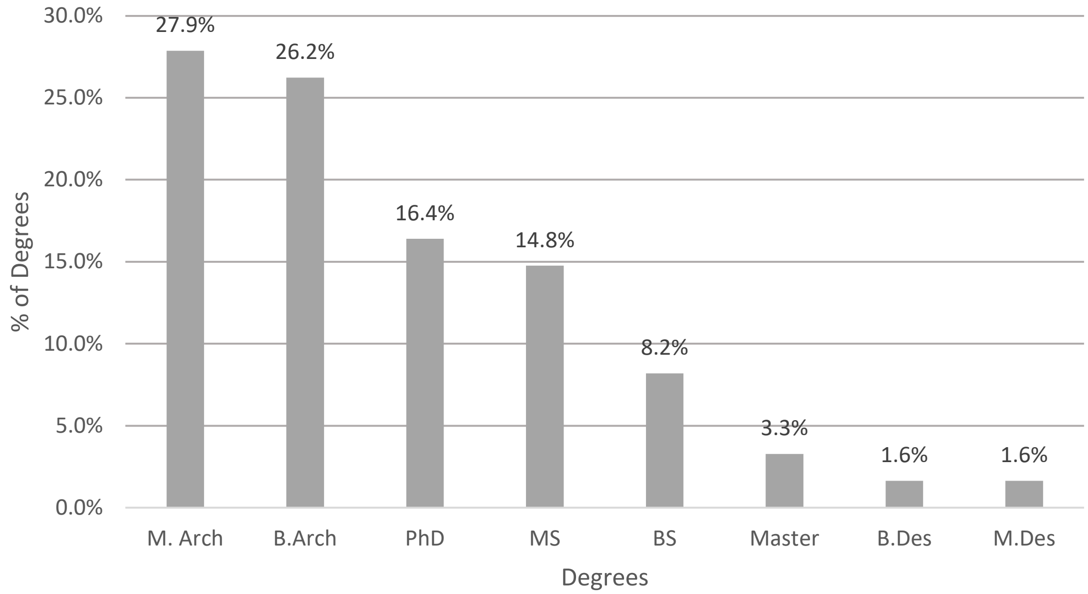


Figure 5.10 Educators degrees most related to their current profession

5.2.8. Teaching Specialty

The majority of the educators have a specialty in courses focused on sustainable building technologies (8.5%), which seems reasonable due to the current and growing interests in sustainability in architecture programs. The same can be said for courses in environmental control for passive systems (7.3%), building envelope (7%), and environmental control for active systems (6.7%). The fact that environmental control passive systems is the second most selected area of specialty reflects the current interests in architecture schools for passive design. Table 5.9 and Figure 5.11 show the fields of specialty and the number of experts in that field in the top 40 architecture colleges/schools.

A major finding of the survey is the areas of specialty that need further attention in architecture schools. These specialty areas have a low percentage based on the survey's results. Among the 20 areas of specialty included in the survey questionnaire, the last ten areas of specialty with lower percentage based on the survey results in order include: Building energy optimization (5.6%), Building simulation (5%), Building physics (4.7%), Building performance optimization (4.4%), Building performance measurement (3.8%), Green building design studios (3.8%), Energy systems (3.8%), Building services (3.2%), Building rating systems (2.6%), and Design engineering studios (0.6%).

In particular, with respect to the shift of architecture majors toward interdisciplinary/transdisciplinary architecture and sustainability, teaching areas such as design engineering studios and building rating systems need to be filled with more expert faculty. It seems that in some cases, this low percentage is due to issue in architecture curriculums rather than the lack of expert educators in architecture schools. For example, the LEED AP affiliation was among the top three choices of educators' affiliations, however, courses focused on building rating systems did not receive a high response rate in the survey. This low response rate indicates that most of the educators are not integrating their professional experience with their teaching. However, based on the survey results, there is a potential for them to bring their professional experience, such as building rating systems, into their education.

The category of other teaching areas (2.3%) is another example of this issue. This category included one response for the following teaching areas: Green building topics in theory and professional practice, Parametric Design, Lighting and Acoustics, Sustainable Design Theory, Integral Theory, Architectural lighting, Environmental Sustainability (Co-major), Competition Courses on Net-Zero, and Commissioning. Although some of these courses are not directly related to passive/natural systems, the majority of them are rarely being taught at schools as a course. For example, courses focused on post-occupancy evaluation such as commissioning can considerably promote the students' learning to a professional level and make them familiar with the real measured performance of buildings and its evaluation. This finding suggests that there is a need for a stronger emphasis in architecture schools on courses related to passive systems as well as integrated courses with respect to passive systems, active systems, and design studios, rather than pursuing each of these courses only in isolation.

Figure 5.12 shows the areas of teaching specialty for educators, the number of expert educators in each filed of specialty, and their professional registration as architects or engineers. One finding from this figure is that there is space to improve the quality of teaching in these courses in architecture schools by assigning them an appropriate mix of educators with architectural background and with engineering background. The reason is the low percentage of educators with PE indicative of a lack of knowledge for teaching courses related to active systems and their integration with passive systems. For example, educators with backgrounds in engineering might be able to supplement the teaching materials being taught by architects in passive/active environmental control systems. Probably, an educator's best professional affiliation for teaching courses on passive systems and their integration with active systems could be having both P.E. and architectural licensure, which may rarely happen (2.9% based on Table 5.7).

Table 5.9 Teaching specialty of the respondents

Rank	Teaching Specialty	%Specialty	Count
1	Sustainable building technologies	8.5%	29
2	Environmental control systems (passive systems)	7.3%	25
3	Building enclosure/envelope	7.0%	24
4	Environmental control systems (active systems)	6.7%	23
5	High performance buildings	6.7%	23
6	Daylighting systems	6.1%	21
7	Design studio	6.1%	21
8	Architectural systems	5.8%	20
9	Design studio/Integrated studio	5.8%	20
10	Building energy optimization	5.6%	19
11	Building simulation	5.0%	17
12	Building physics	4.7%	16
13	Building performance optimization	4.4%	15
14	Building performance measurement	3.8%	13
15	Design studio/Green building studio	3.8%	13
16	Energy systems	3.8%	13
17	Building services	3.2%	11
18	Building rating systems	2.6%	9
19	Other (please specify)	2.3%	8
20	Design studio/Design engineering	0.6%	2
	Total	100%	342

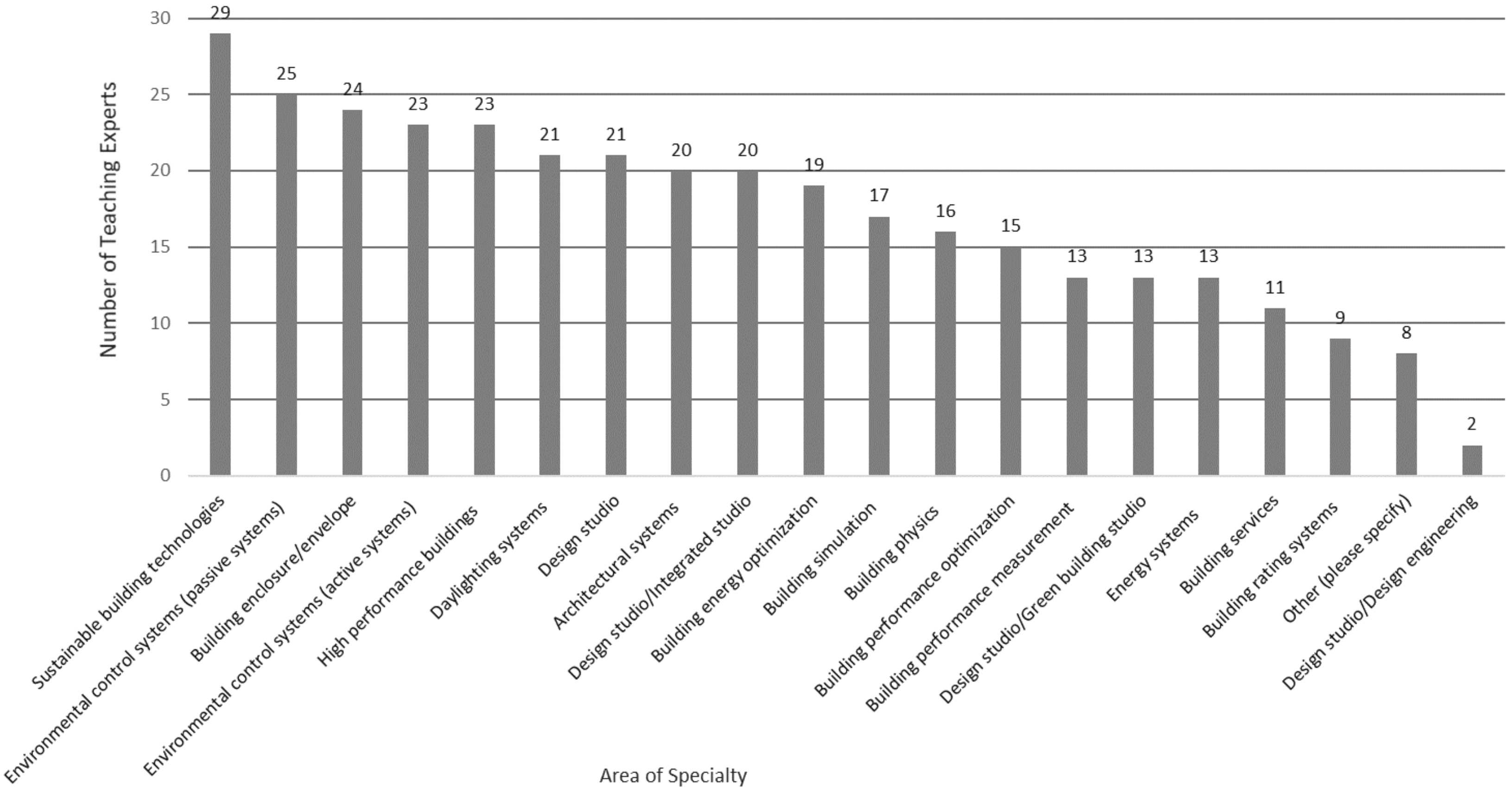
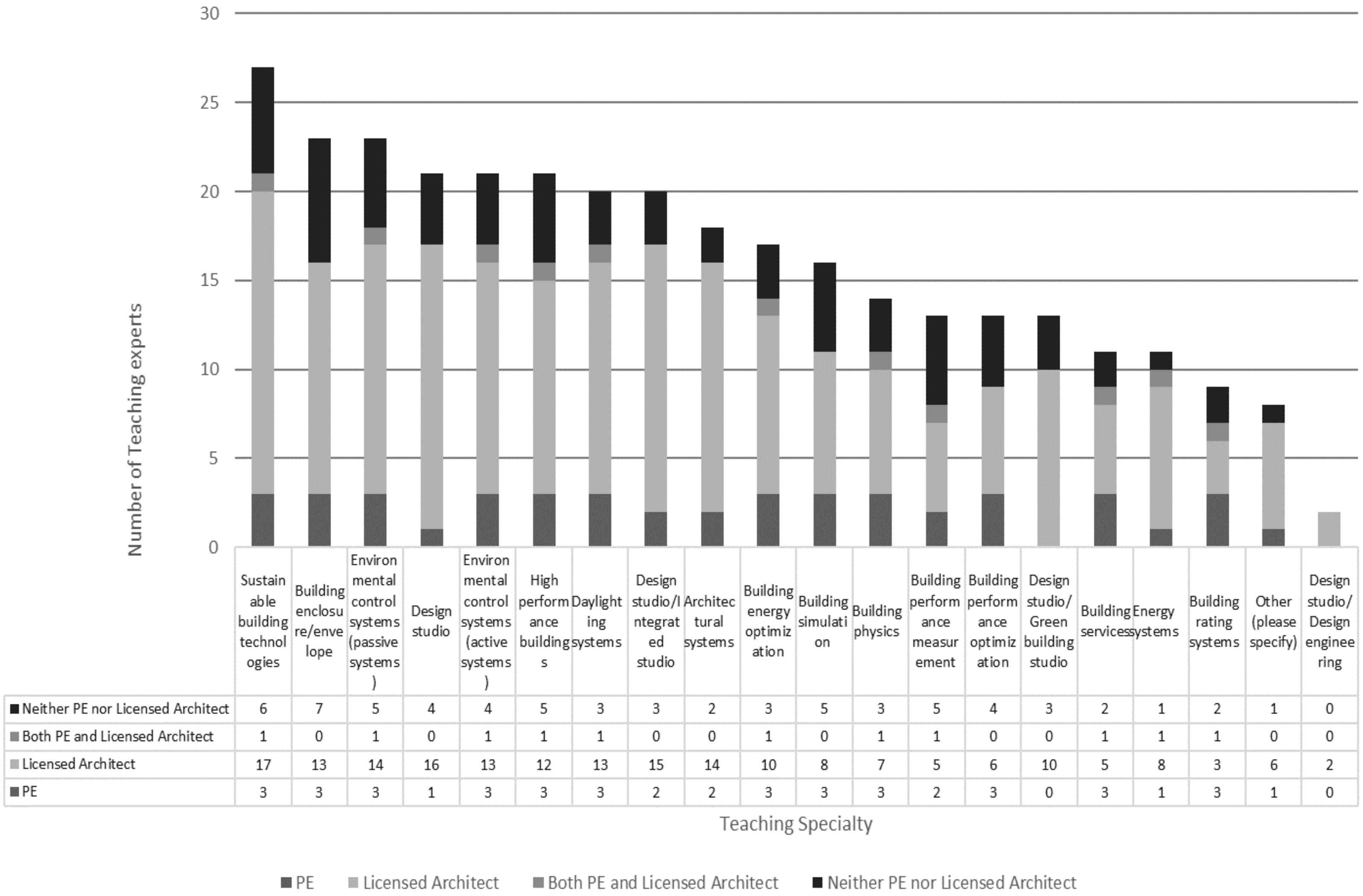


Figure 5.11 Teaching specialty of the respondents

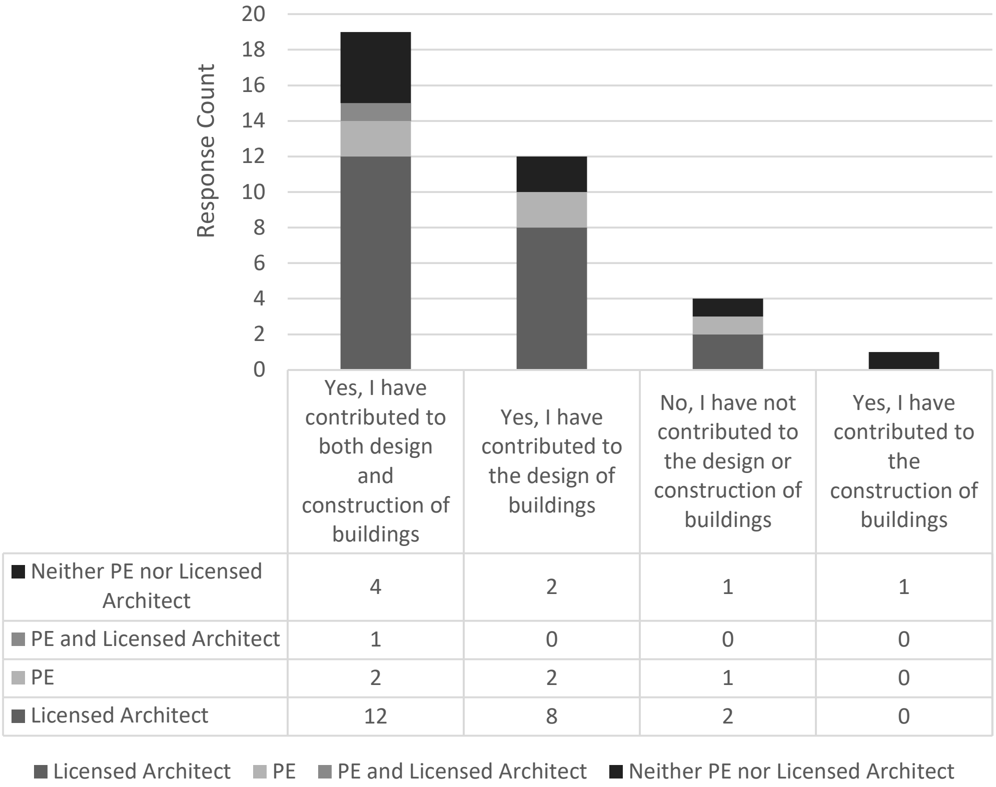


	Sustainable building technologies	Building enclosure/envelope	Environmental control systems (passive systems)	Design studio	Environmental control systems (active systems)	High performance buildings	Daylighting systems	Design studio/Integrated studio	Architectural systems	Building energy optimization	Building simulation	Building physics	Building performance measurement	Building performance optimization	Design studio/Green building studio	Building services	Energy systems	Building rating systems	Other (please specify)	Design studio/Design engineering
■ Neither PE nor Licensed Architect	6	7	5	4	4	5	3	3	2	3	5	3	5	4	3	2	1	2	1	0
■ Both PE and Licensed Architect	1	0	1	0	1	1	1	0	0	1	0	1	1	0	0	1	1	1	0	0
■ Licensed Architect	17	13	14	16	13	12	13	15	14	10	8	7	5	6	10	5	8	3	6	2
■ PE	3	3	3	1	3	3	3	2	2	3	3	3	2	3	0	3	1	3	1	0

Figure 5.12 Teaching specialty of the educators based on their professional registrations

5.3. Educators’ Projects

One questioned was asked to educators to find out if they have also contributed to the design or construction of buildings in the last ten years. If the answer was positive to both or either of these two choices (i.e., design or construction of buildings) two questions would follow with a focus on the type and climatic location of their projects. Figure 5.13 shows the results of this question categorized by the professional registration of the educators. Only about 11% of the educators (4 respondents) have not contributed to the design or construction of buildings in the last ten years. Therefore, the educational atmosphere regarding the use of passive systems in the US universities, in most cases, is also informed by practical experience.



	Yes, I have contributed to both design and construction of buildings	Yes, I have contributed to the design of buildings	No, I have not contributed to the design or construction of buildings	Yes, I have contributed to the construction of buildings
■ Neither PE nor Licensed Architect	4	2	1	1
■ PE and Licensed Architect	1	0	0	0
■ PE	2	2	1	0
■ Licensed Architect	12	8	2	0

Figure 5.13 Educators contribution to projects design/construction broken by professional registrations

5.3.1. Project Typologies (Educators)

Figure 5.14 shows that the highest mean percentage of the educators' professional projects in the last ten years was single-family residential projects with 31% of the total projects. Educational projects, was the second highest rank (22.4%), followed by office projects (20%) and multi-family residential projects (11.8%) as the next types of projects with highest mean percentage. The types of projects specified in the "other" category were expanded and included with the rest of the project typologies as shown in Figure 5.14. On this basis, the expanded category of "other" type of projects included institutional projects (3.6%), historic preservation projects (3.4%), commercial projects (2.5%), lab and data centers (2.4%), civic/governmental projects (2.4%), and cultural/recreational/mixed use projects (0.5%).

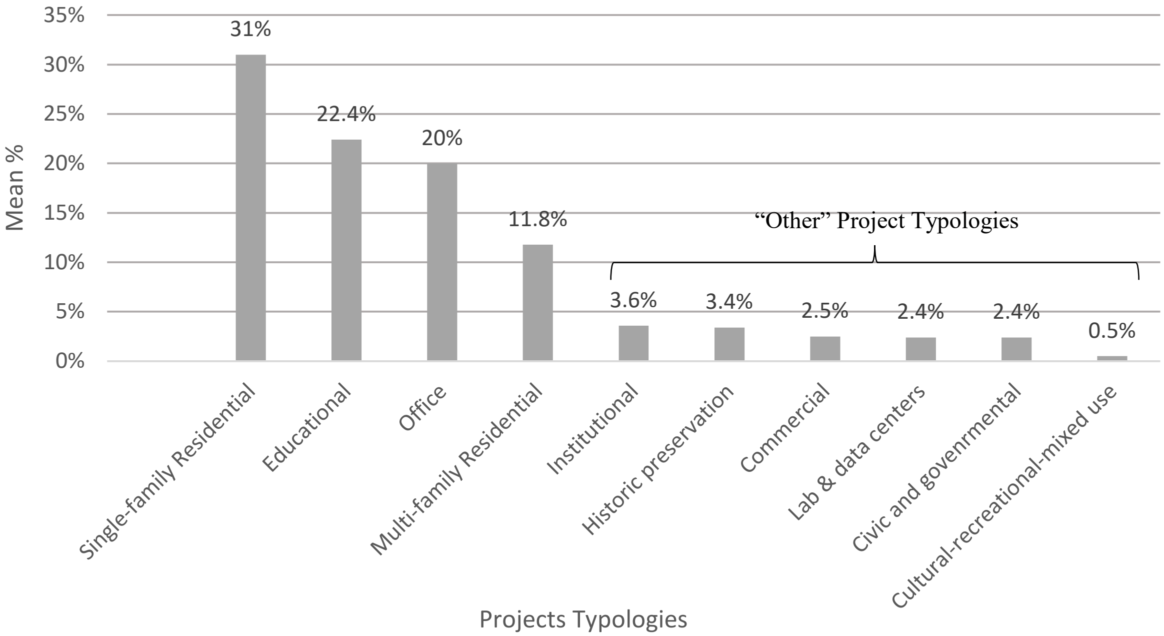


Figure 5.14 Mean percentage of educators projects in different categories for the last 10 years

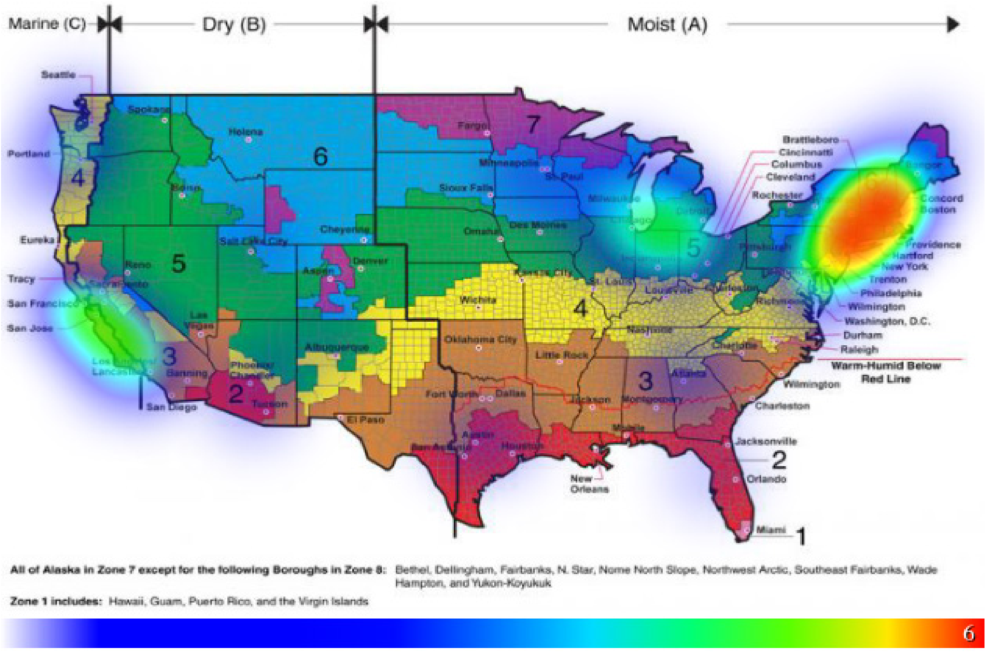
While the highest ranked projects for practitioners were educational, single family buildings define the highest ranked type of designed or constructed buildings for educators. This could be due in part to the possibility of educators' involvement in projects for personal use, which in most cases are residential projects. Single family residential projects are of smaller scales and need less administrative requirements compared to other types of projects such as educational projects. Another finding is that the majority of the educators have both designed and constructed buildings. This feature can contribute to fostering the content of course curriculums on passive/natural systems through design-build courses and programs in schools which is feasible because of educators' involvement in practice.

5.3.2. Climates of the Educators' Passive Projects

The same ASHRAE climate map that was shown to practitioners was also shown to educators (Figure ky in chapter 4) to show the locations of their projects in the last 10 years by clicking on desired points. Table 5.10, Figure 5.15, and Figure 5.16 show the number of selections/clicks inside the defined areas as well as their locations. According to the collected data (Figure 5.16) the majority of the educators' passive projects in the last ten years is located in the east central part of the US in the East-Center 5-6 zone embracing the climate 5A (40%). The focus of this selection is mostly in the New England area as indicated by Figure 5.16. This percentage is close to practitioners' selection of this zone (i.e. East-Center 5-6), which was also the most selected area for them with 35.5% of location selections. The existence of prestigious universities with expertise in sustainability and passive design could be a reason for such an overlap between the findings from practitioners and educators' surveys.

Table 5.10 Location of educators' passive project for the last 10 years

Answer	**%Count**	**Count of the zone selection**
East-Center 5-6	40.0%	18
Southwest-3-2-4	17.8%	8
West-4	6.7%	3
North-Center-6-7	6.7%	3
Center-4	6.7%	3
South-3	6.7%	3
South-2-1	6.7%	3
West-5	4.4%	2
Northeast-6-7	4.4%	2
North-7	0.0%	0
Other	0.0%	0
Total	100%	45



All of Alaska in Zone 7 except for the following Boroughs in Zone 8: Bethel, Dellingham, Fairbanks, N. Star, Nome North Slope, Northwest Arctic, Southeast Fairbanks, Wade Hampton, and Yukon-Koyukuk

Zone 1 includes: Hawaii, Guam, Puerto Rico, and the Virgin Islands

Figure 5.15 Location of the educators' passive projects for the last 10 years reflected on ASHRAE Climate Map. The climate map was reprinted with permission from ASHRAE.

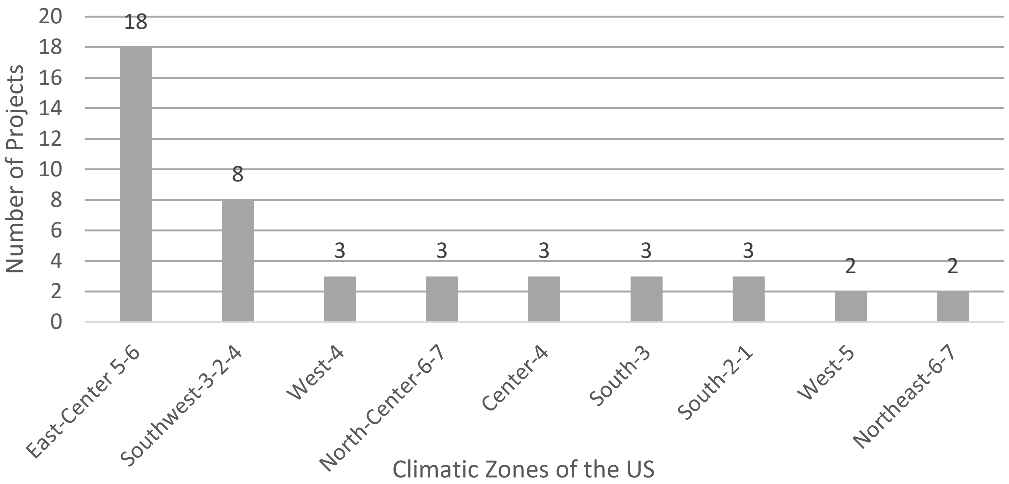
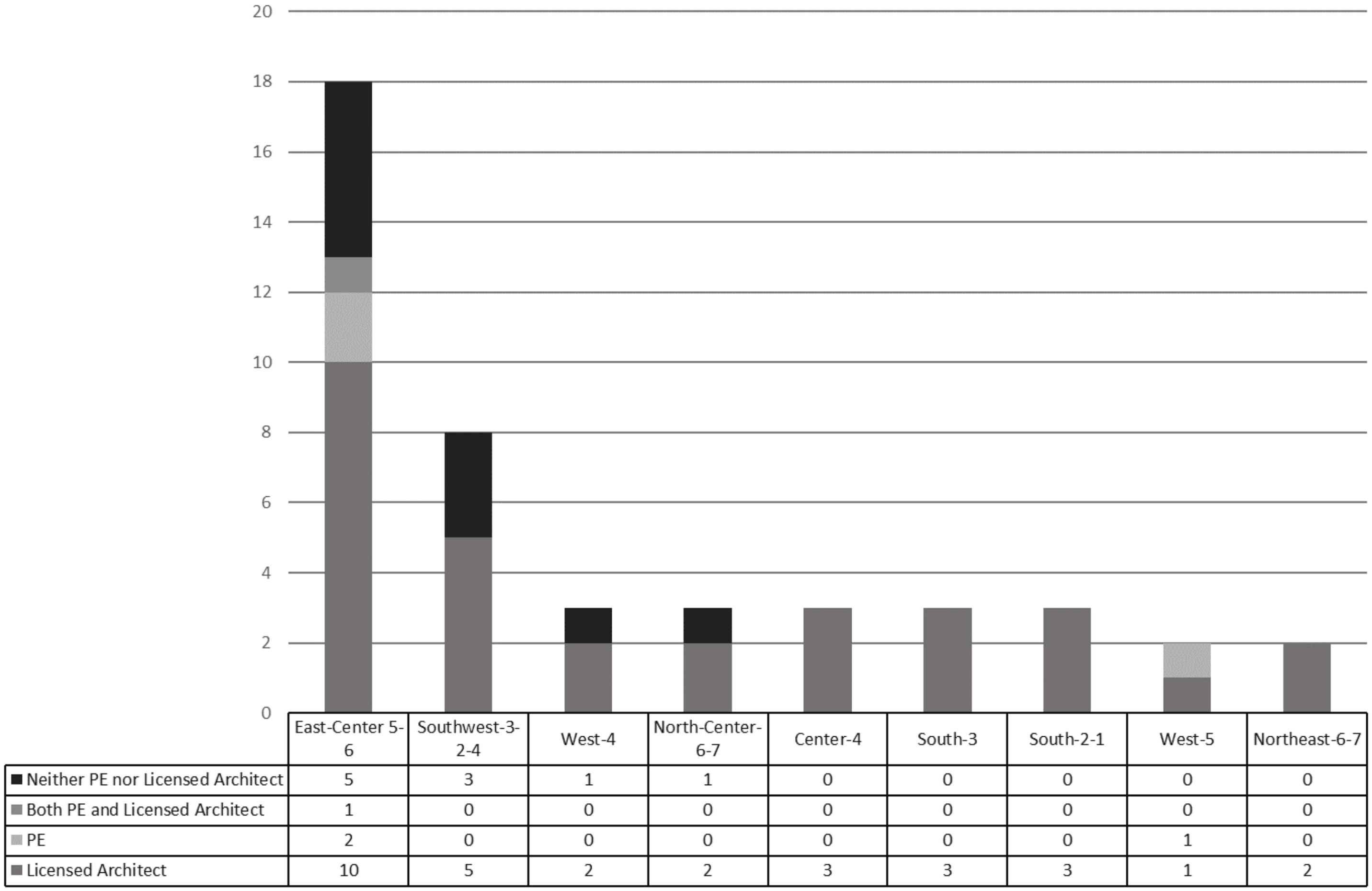


Figure 5.16 Location of educators' passive projects for the last 10 years

Second selected area is the southwest part of the US with California selected the most (17.8%). The West-4 zone which includes the States of Portland is the third most selected area (6.7%). North-center-6-7, Center-4, South-3, and South-2-1 (including Texas and Florida with selection concentration in Texas) are also the third most selected climatic zones each having 6.7% of selections. Zone South-3A is on the top of this area with climate zone 3A. While the focus of selectin is around the State of Alabama, this zone includes parts of Texas, Louisiana, Mississippi, Georgia, Alabama, Oklahoma, and South Carolina. In general, the findings of this map supplement the findings of the map produced from practitioners' survey results. Practitioners' location of their projects were indicating very few or no passive projects in zones such as West-4 and Southwest-3-2-4 due to lower participations by practitioners from these states which included California and Portland.



	East-Center 5-6	Southwest-3-2-4	West-4	North-Center-6-7	Center-4	South-3	South-2-1	West-5	Northeast-6-7
■ Neither PE nor Licensed Architect	5	3	1	1	0	0	0	0	0
■ Both PE and Licensed Architect	1	0	0	0	0	0	0	0	0
■ PE	2	0	0	0	0	0	0	1	0
■ Licensed Architect	10	5	2	2	3	3	3	1	2

Figure 5.17 Location of the educators' passive projects for the last 10 years categorized by their professional registration

To compensate for this low level of participation, educators' responses show that a high percentage of passive projects have been implemented in these areas which evidence that lack of practitioners passive projects in these states were more a matter of survey participation than reality. Since most of the educators' projects are located in mild climates or climates with low level of humidity (e.g. California, New England, and Portland) it may seem at first sight that for educators the appropriateness between a climate and the use of passive strategies is more of importance compared with practitioners. However, this pattern is resulting from the fact that many of the top ranked universities in sustainability, as selected in this survey focused on top 40 schools, are located in these states. This interpretation is only based on an assumption that educators' projects are mostly located in the same states in which their academic institutions are located.

5.4. Passive/Natural Systems

The survey asked educators in what levels they teach about passive/natural systems to students in their class projects. The levels of teaching included conceptual, calculation, and simulation. The following sub-sections include the results of educators' responses with respect to renewable energy systems as well as passive/natural cooling, heating, lighting, and ventilation systems.

5.4.1. Renewable Energy Systems (Educators)

The mots taught renewable systems by educators in the US, in order, include Photovoltaics (33.5%), solar thermal collectors for domestic hot water (17.9%), geothermal (18.4%), solar thermal collectors for space heating (16.8%), and wind turbines (10.6%) as shown in Table 5.11. However, the distribution of the level of teaching varies for each system from conceptual to simulation and calculation. In particular, except for photovoltaics, the majority of teaching level selections remain in the conceptual level as shown in figure 5.18. One reason for such a large difference could be the availability of many simulation tools exclusively tuned for the design of PV systems. Most of these tools are accessible online or in cloud-based formats. Additionally, the concept of PV panels seems to be more familiar for architecture students, and probably educators, due to its currently widespread application as well as easier installation procedures.

Table 5.11 The most taught renewable energy systems in the US by educators

Renewable Systems Taught	**Percentage of Selection in Total for All Levels of Teaching**
Photovoltaics (PV panels)	33.5%
Solar thermal collectors for domestic hot water	17.9%
Geothermal	18.4%
Solar thermal collectors for space heating	16.8%
Wind turbines	10.6%
Other (please specify)	2.2%
None	0.6%

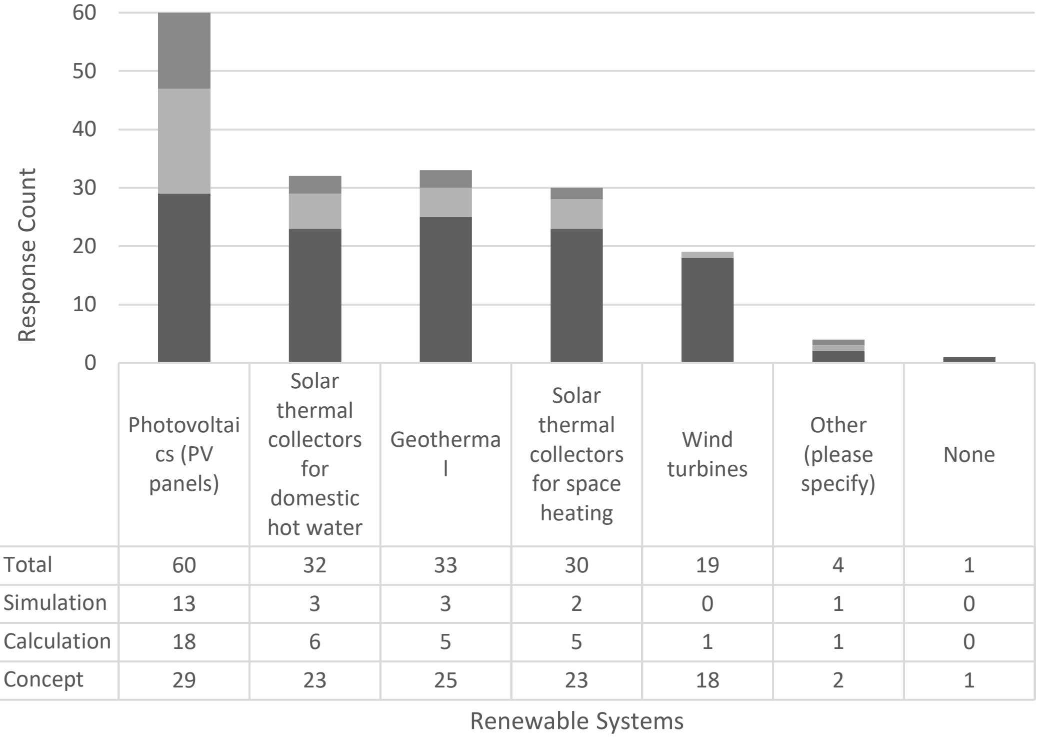
Table 5.12 shows the breakout of the total percentage in each level of teaching, which clearly shows a sharp drop from conceptual teaching level to calculation and simulation levels for renewable systems other than photovoltaics. For example, solar thermal collectors are taught in 12.8% of total teaching levels for conceptual level, in 3.4% for calculation level, and in 1.7% for simulation. Meanwhile, the conceptual, calculation, and simulation levels of teaching photovoltaics include 16.2%, 10.1%, and 7.3% of the total teaching levels respectively. Therefore, there is about 9.4% difference from the conceptual level to the calculation level for DHW solar thermal collectors, while this difference for PV panels is about 6.1%, which is much lower.

Two other major finding of the survey is that, first, educators with PE registration do not teach the simulation level of renewable systems, however, licensed architects teach in all three levels of concept, simulation, and calculation. Second, the drop from conceptual level of teaching to calculation level is much lower for PE professionals compared with licensed architects. In reading both of these findings it should be kept in mind that a total number of respondents with PE registration is much less than educators with architectural licensure as shown in Table 5.13.

About 0.6% of the participating educators have not taught any renewable energy systems in their classes which is very low. This low percentage means that virtually all the respondents teach renewable energy systems in their courses. In the category of “other,” the respondents specified topics such as net-zero and water catchment. Finally, comparing the practitioners' survey results with educators' survey results, the priority in teaching the renewable energy systems by educators reflects the priority of the selection of renewable energy systems by practitioners. In other words, for both educators and practitioners the selection frequency shows that PV systems, DHW solar thermal collectors, geothermal, space heating solar thermal collectors, and wind turbines are the most selected renewable systems in order.

Table 5.12 The level of most taught renewable energy systems in the US by educators

Renewable systems	Concept	Calculation	Simulation
Photovoltaics (PV panels)	16.2%	10.1%	7.3%
Solar thermal collectors for domestic hot water	12.8%	3.4%	1.7%
Geothermal	14.0%	2.8%	1.7%
Solar thermal collectors for space heating	12.8%	2.8%	1.1%
Wind turbines	10.1%	0.6%	0.0%
Other (please specify)	1.1%	0.6%	0.6%
None	0.6%	0.0%	0.0%



	Photovoltaics (PV panels)	Solar thermal collectors for domestic hot water	Geothermal	Solar thermal collectors for space heating	Wind turbines	Other (please specify)	None
Total	60	32	33	30	19	4	1
■ Simulation	13	3	3	2	0	1	0
■ Calculation	18	6	5	5	1	1	0
■ Concept	29	23	25	23	18	2	1

Figure 5.18 The most taught renewable energy systems in the US by educators

Table 5.13 The teaching level of renewable energy systems categorized by educators' professional registration

Professional Engineer (PE)				
Renewable systems	**Concept**	**Calculation**	**Simulation**	**Total**
Photovoltaics (PV panels)	3	2	0	5
Solar thermal collectors for space heating	3	2	0	5
Solar thermal collectors for domestic hot water	3	2	0	5
Wind turbines	4	0	0	4
Geothermal	3	1	0	4
Other (please specify)	0	0	0	0
None	0	0	0	0
Licensed Architect				
Renewable systems	**Concept**	**Calculation**	**Simulation**	**Total**
Photovoltaics (PV panels)	18	12	9	39
Solar thermal collectors for domestic hot water	14	3	2	19
Solar thermal collectors for space heating	14	2	1	17
Geothermal	17	1	1	19
Other (please specify)	2	1	1	4
Wind turbines	9	1	0	10
None	0	0	0	0
Both Professional Engineer (PE) and Licensed Architect				
Renewable systems	**Concept**	**Calculation**	**Simulation**	**Total**
Photovoltaics (PV panels)	1	0	0	1
Solar thermal collectors for space heating	1	0	0	1
Solar thermal collectors for domestic hot water	0	0	0	0
Wind turbines	0	0	0	0
Geothermal	0	0	0	0
Other (please specify)	0	0	0	0
None	0	0	0	0
Neither Professional Engineer (PE) nor Licensed Architect				
Renewable systems	**Concept**	**Calculation**	**Simulation**	**Total**
Photovoltaics (PV panels)	6	3	2	11
Geothermal	4	2	2	8
Solar thermal collectors for space heating	4	1	1	6
Solar thermal collectors for domestic hot water	5	1	1	7
Wind turbines	4	0	0	4
Other (please specify)	0	0	0	0
None	1	0	0	1

5.4.2. Passive/Natural Cooling Systems (Educators)

External shading devices (9.5%), cross ventilation (7.6%), and stack ventilation (6.9%) are the educators top three most taught topics in passive cooling strategies (Figure 5.19). External shading devices and stack ventilation were also among the top three choices of practitioners' survey which indicate that there is an overlap between practitioners and educators' interests in the case of passive cooling strategies. Educators' other passive cooling topics that were taught include night ventilation with mass (6.8%), internal shading devices (6.3%), dynamic shading devices (6.5%), evaporative cooling (5.9%), green roof (5.2%), radiant cooling (5.2%), plants and vegetation for shadow casting or evapotranspiration (5.3%), courtyard (4.8%), night ventilation without mass (4.8%), solar chimney (4.6%), cool roof (4.6%), earth contact (3.7%), earth tube (3.5%), double roof with the second roof casting shadow on the actual roof (3.3%), downdraft cooling (2.7%), roof pond (2.4%), and other strategies (0.3%). Combination of natural sources of sun, wind, and light were specified in the other category as another passive/natural cooling strategy.

All of the educators selected at least one of the passive/natural cooling strategy topics and the "none" choice was not selected by any of the respondents. Evidenced by the results, as shown in table 5.14 the simulation and calculation teaching levels of a system reduce as the system becomes more complex. For example, roof pond or downdraft cooling systems are not simulated at all by the respondents. On the other hand, shading devices and natural ventilation systems in a range from external/internal to dynamic shading or cross/natural ventilation to natural ventilation with thermal mass are the most taught systems in the simulation and calculation levels. Double roof and earth contact are two of the passive cooling strategies which are not being taught at the calculation level which could be due to the complexity of the calculation of, for example, the ground temperature.

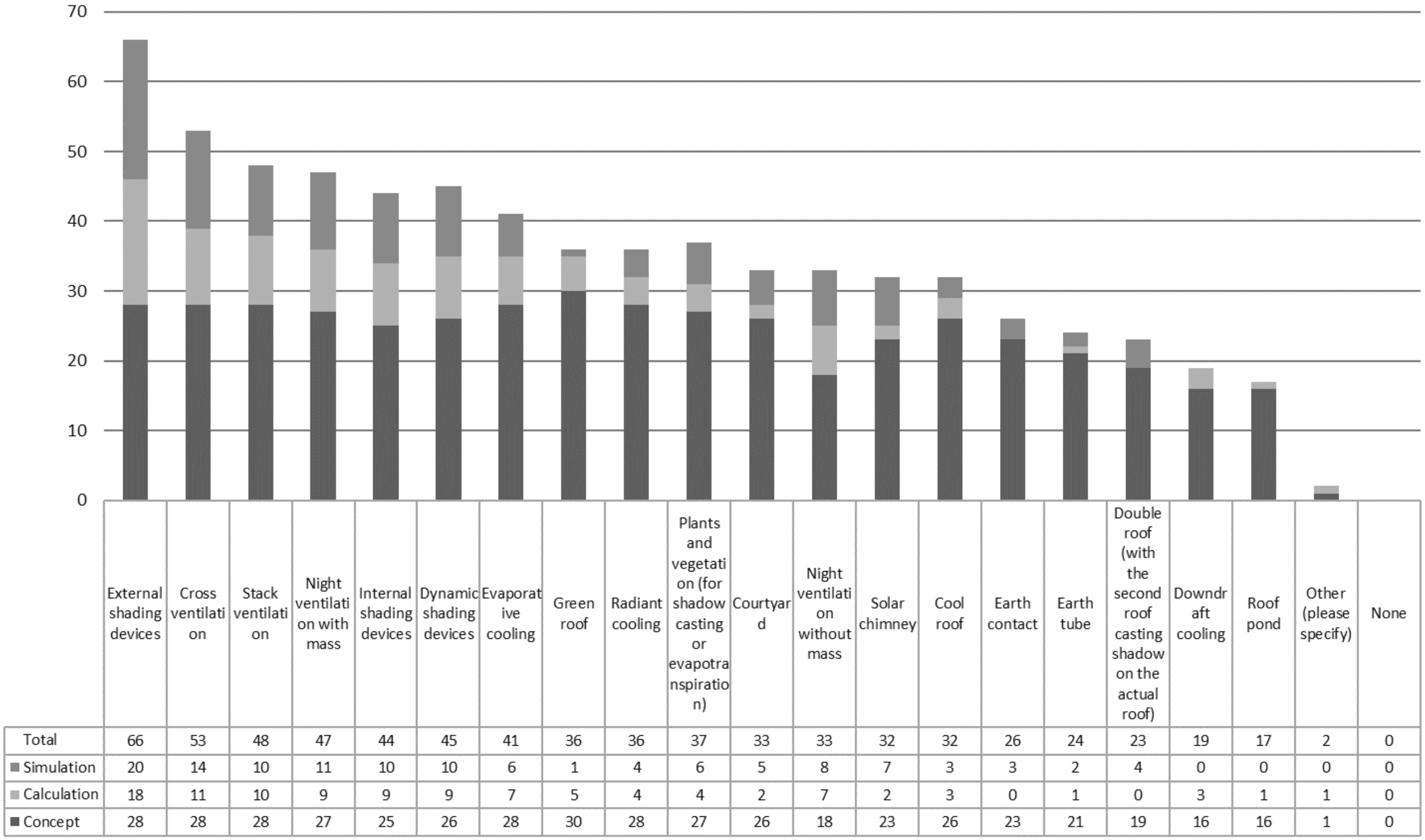
Based on the respondents' professional registration as an architect or engineer (Table 5.15), the results show that licensed architects do not teach simulation of the passive cooling strategies that contain earth as one of their design elements as in the case of earth tube or earth contact. Roof pond is one of the strategies which is only being taught at the conceptual level by both engineers and architects. Overall, the survey result shows that calculation and simulation of passive cooling strategies, except for shading devices and cross ventilation, are receiving a low level of attention in education.

Table 5.14 The teaching level of passive/natural cooling systems and their frequency percentage

Passive/Natural Cooling system	Concept		Calculation		Simulation		Total	
External shading devices	28	4.0%	18	2.6%	20	2.9%	66	9.5%
Cross ventilation	28	4.0%	11	1.6%	14	2.0%	53	7.6%
Stack ventilation	28	4.0%	10	1.4%	10	1.4%	48	6.9%
Night ventilation with mass	27	3.9%	9	1.3%	11	1.6%	47	6.8%
Internal shading devices	25	3.6%	9	1.3%	10	1.4%	44	6.3%
Dynamic shading devices	26	3.7%	9	1.3%	10	1.4%	45	6.5%
Evaporative cooling	28	4.0%	7	1.0%	6	0.9%	41	5.9%
Green roof	30	4.3%	5	0.7%	1	0.1%	36	5.2%
Radiant cooling	28	4.0%	4	0.6%	4	0.6%	36	5.2%
Plants and vegetation (for shadow casting or evapotranspiration)	27	3.9%	4	0.6%	6	0.9%	37	5.3%
Courtyard	26	3.7%	2	0.3%	5	0.7%	33	4.8%
Night ventilation without mass	18	2.6%	7	1.0%	8	1.2%	33	4.8%
Solar chimney	23	3.3%	2	0.3%	7	1.0%	32	4.6%
Cool roof	26	3.7%	3	0.4%	3	0.4%	32	4.6%
Earth contact	23	3.3%	0	0.0%	3	0.4%	26	3.7%
Earth tube	21	3.0%	1	0.1%	2	0.3%	24	3.5%
Double roof (with the second roof casting shadow on the actual roof)	19	2.7%	0	0.0%	4	0.6%	23	3.3%
Downdraft cooling	16	2.3%	3	0.4%	0	0.0%	19	2.7%
Roof pond	16	2.3%	1	0.1%	0	0.0%	17	2.4%
Other (please specify)	1	0.1%	1	0.1%	0	0.0%	2	0.3%

Table 5.15 The frequency for teaching level of passive cooling systems categorized by professional registration

Professional Engineer (PE) Teaching Levels	**Concept**	**Calculation**	**Simulation**	**Total**
Cool roof	3	1	0	4
Courtyard	3	0	0	3
Cross ventilation	2	2	1	5
Double roof (with the second roof casting shadow on the actual roof)	3	0	0	3
Downdraft cooling	2	1	0	3
Dynamic shading devices	4	0	1	5
Earth contact	4	0	1	5
Earth tube	4	0	1	5
Evaporative cooling	3	1	2	6
External shading devices	3	2	1	6
Green roof	3	1	0	4
Internal shading devices	4	1	1	6
Night ventilation with mass	3	2	0	5
Night ventilation without mass	2	1	0	3
Other (please specify)	0	0	0	0
Plants and vegetation (for shadow casting or evapotranspiration)	4	0	2	6
Radiant cooling	3	1	1	5
Roof pond	4	0	0	4
Solar chimney	3	1	0	4
Stack ventilation	3	2	0	5
Licensed Architects Teaching Levels	**Concept**	**Calculation**	**Simulation**	**Total**
Cool roof	17	0	1	18
Courtyard	19	1	3	23
Cross ventilation	19	5	6	30
Double roof (with the second roof casting shadow on the actual roof)	11	0	3	14
Downdraft cooling	10	1	0	11
Dynamic shading devices	16	4	5	25
Earth contact	13	0	0	13
Earth tube	12	0	0	12
Evaporative cooling	16	1	2	19
External shading devices	18	8	11	37
Green roof	19	2	1	22
Internal shading devices	14	4	4	22
Night ventilation with mass	17	4	4	25
Night ventilation without mass	12	4	2	18
Other (please specify)	1	1	0	2
Plants and vegetation (for shadow casting or evapotranspiration)	17	1	3	21
Radiant cooling	18	1	2	21
Roof pond	8	0	0	8
Solar chimney	15	0	3	18
Stack ventilation	19	4	4	27



	External shading devices	Cross ventilation	Stack ventilation	Night ventilation with mass	Internal shading devices	Dynamic shading devices	Evaporative cooling	Green roof	Radiant cooling	Plants and vegetation (for shadow casting or evapotranspiration)	Courtyard	Night ventilation without mass	Solar chimney	Cool roof	Earth contact	Earth tube	Double roof (with the second roof casting shadow on the actual roof)	Downdraft cooling	Roof pond	Other (please specify)	None
Total	66	53	48	47	44	45	41	36	36	37	33	33	32	32	26	24	23	19	17	2	0
■ Simulation	20	14	10	11	10	10	6	1	4	6	5	8	7	3	3	2	4	0	0	0	0
■ Calculation	18	11	10	9	9	9	7	5	4	4	2	7	2	3	0	1	0	3	1	1	0
■ Concept	28	28	28	27	25	26	28	30	28	27	26	18	23	26	23	21	19	16	16	1	0

Figure 5.19 The teaching level of passive/natural cooling systems by educators and their frequency

5.4.3. Passive/Natural Heating Systems (Educators)

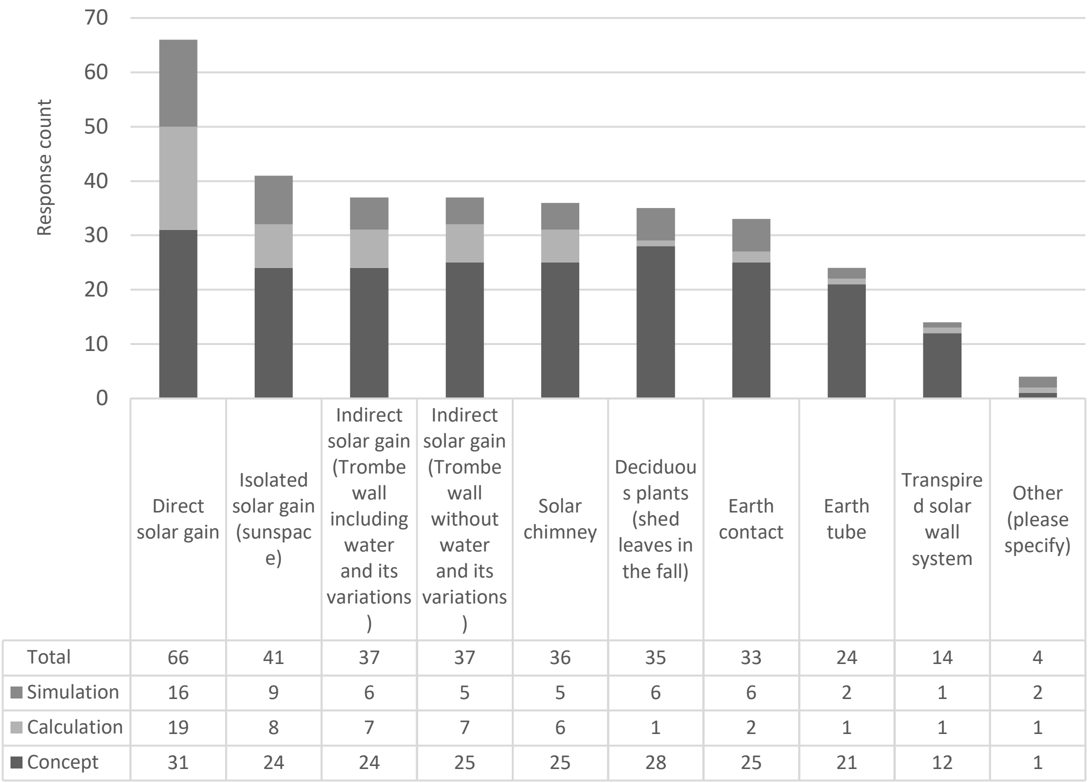
Direct solar gain (20.2%), isolated solar gain (12.5%), indirect solar gain in Trombe' wall with water (11.3%), and indirect solar gain in Trombe' wall with non-water thermal mass (11.3%) represent the most selected teaching topics respectively. Solar chimney (11%), deciduous plants (10.7%), earth contact (10.1%), earth tube (7.3%), and transpired solar wall system (4.3%) are the next most selected topics in teaching passive/natural heating systems.

Table 5.16 The frequency and frequency percentage for teaching levels of passive heating systems

Passive/Natural Heating Strategies	**Concept**		**Calculation**		**Simulation**		**Total**	
Direct solar gain	31	9.5%	19	5.8%	16	4.9%	66	20.2%
Isolated solar gain (sunspace)	24	7.3%	8	2.4%	9	2.8%	41	12.5%
Indirect solar gain (Trombe' wall including water and its variations)	24	7.3%	7	2.1%	6	1.8%	37	11.3%
Indirect solar gain (Trombe' wall without water and its variations)	25	7.6%	7	2.1%	5	1.5%	37	11.3%
Solar chimney	25	7.6%	6	1.8%	5	1.5%	36	11.0%
Deciduous plants (shed leaves in the fall)	28	8.6%	1	0.3%	6	1.8%	35	10.7%
Earth contact	25	7.6%	2	0.6%	6	1.8%	33	10.1%
Earth tube	21	6.4%	1	0.3%	2	0.6%	24	7.3%
Transpired solar wall system	12	3.7%	1	0.3%	1	0.3%	14	4.3%
Other (please specify)	1	0.3%	1	0.3%	2	0.6%	4	1.2%

Figure 5.20 shows the frequency of teaching passive heating strategies by educators in the three levels of concept, calculation, and simulation. The results show except for the direct solar gain system, teaching calculation and simulation of other passive heating strategies is not a usual teaching practice. In this case, calculation and simulation of isolated gain system, indirect gain system, and solar chimney are being taught more than other systems. More precisely, calculation and simulation teachings of the isolated gain system, indirect gain system, and solar chimney vary from 37% to 20% of each system's corresponding conceptual teaching level. Transpired wall system is the rarest teaching topic in simulation (0.3%) and calculation levels (0.3%). Based on the results, for the first five mostly taught topics by educators including systems of direct, isolated, and indirect (Trombe' walls with/without water) solar gain, and solar chimney, teaching the calculation of passive heating systems is of higher interest compared to their simulation.

In the "other" category respondents have specified natural ventilation with wind tunnel simulations as an additional passive heating strategy. Finally, among educators every respondent teaches at least one of the passive/natural heating topics in class. Overall, based on the survey results, with exception for direct solar gain systems, calculation and simulation of passive heating systems are rarely being taught at architecture schools.



	Direct solar gain	Isolated solar gain (sunspace)	Indirect solar gain (Trombe wall including water and its variations)	Indirect solar gain (Trombe wall without water and its variations)	Solar chimney	Deciduous plants (shed leaves in the fall)	Earth contact	Earth tube	Transpired solar wall system	Other (please specify)
Total	66	41	37	37	36	35	33	24	14	4
■ Simulation	16	9	6	5	5	6	6	2	1	2
■ Calculation	19	8	7	7	6	1	2	1	1	1
■ Concept	31	24	24	25	25	28	25	21	12	1

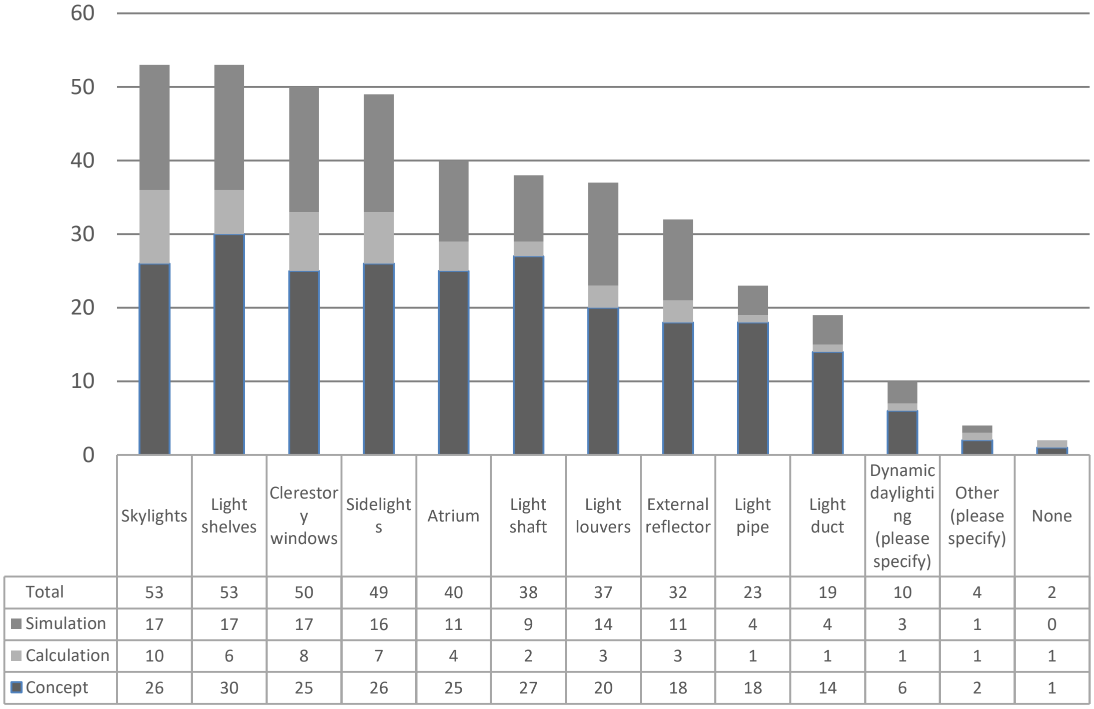
Figure 5.20 The frequency for teaching levels of passive heating systems

5.4.4. Daylighting Systems (Educators)

As show in Table 5.17 and Figure 5.21 the top choices of educators for teaching daylighting systems included skylights (12.9%), light shelves (12.9%), clerestory windows (12.2%), sidelights (12%), and atriums (9.8%). This selection, excluding the light shelves, is similar to practitioners' top choices for the use of daylighting systems. Other daylighting strategies being taught included light shafts (9.3%), light louvers (9%), external reflectors (7.8%), light pipe (5.6%), light duct (4.6%), and dynamic daylighting (2.4%). Among educators only one respondent does not teach any of the daylighting design strategies. Similar to other passive/natural design strategies, calculation and simulation of daylighting systems are being taught with a lower frequency compared to their conceptual teaching level. Frequency percentage of teaching simulation and calculation of light pipe, light duct, and dynamic daylighting systems are the lowest with 0.2% selection for calculation in each case and 1% to 0.7% selection for their simulations.

Table 5.17 The frequency and frequency percentage for teaching levels of daylighting systems

Daylighting System	**Concept**		**Calculation**		**Simulation**		**Total**	
Skylights	26	6.3%	10	2.4%	17	4.1%	53	12.9%
Light shelves	30	7.3%	6	1.5%	17	4.1%	53	12.9%
Clerestory windows	25	6.1%	8	2.0%	17	4.1%	50	12.2%
Sidelights	26	6.3%	7	1.7%	16	3.9%	49	12.0%
Atrium	25	6.1%	4	1.0%	11	2.7%	40	9.8%
Light shaft	27	6.6%	2	0.5%	9	2.2%	38	9.3%
Light louvers	20	4.9%	3	0.7%	14	3.4%	37	9.0%
External reflector	18	4.4%	3	0.7%	11	2.7%	32	7.8%
Light pipe	18	4.4%	1	0.2%	4	1.0%	23	5.6%
Light duct	14	3.4%	1	0.2%	4	1.0%	19	4.6%
Dynamic daylighting	6	1.5%	1	0.2%	3	0.7%	10	2.4%
Other	2	0.5%	1	0.2%	1	0.2%	4	1.0%
None	1	0.2%	1	0.2%	0	0.0%	2	0.5%



	Skylights	Light shelves	Clerestory windows	Sidelights	Atrium	Light shaft	Light louvers	External reflector	Light pipe	Light duct	Dynamic daylighting (please specify)	Other (please specify)	None
Total	53	53	50	49	40	38	37	32	23	19	10	4	2
■ Simulation	17	17	17	16	11	9	14	11	4	4	3	1	0
■ Calculation	10	6	8	7	4	2	3	3	1	1	1	1	1
■ Concept	26	30	25	26	25	27	20	18	18	14	6	2	1

Figure 5.21 The frequency for teaching levels of daylighting systems

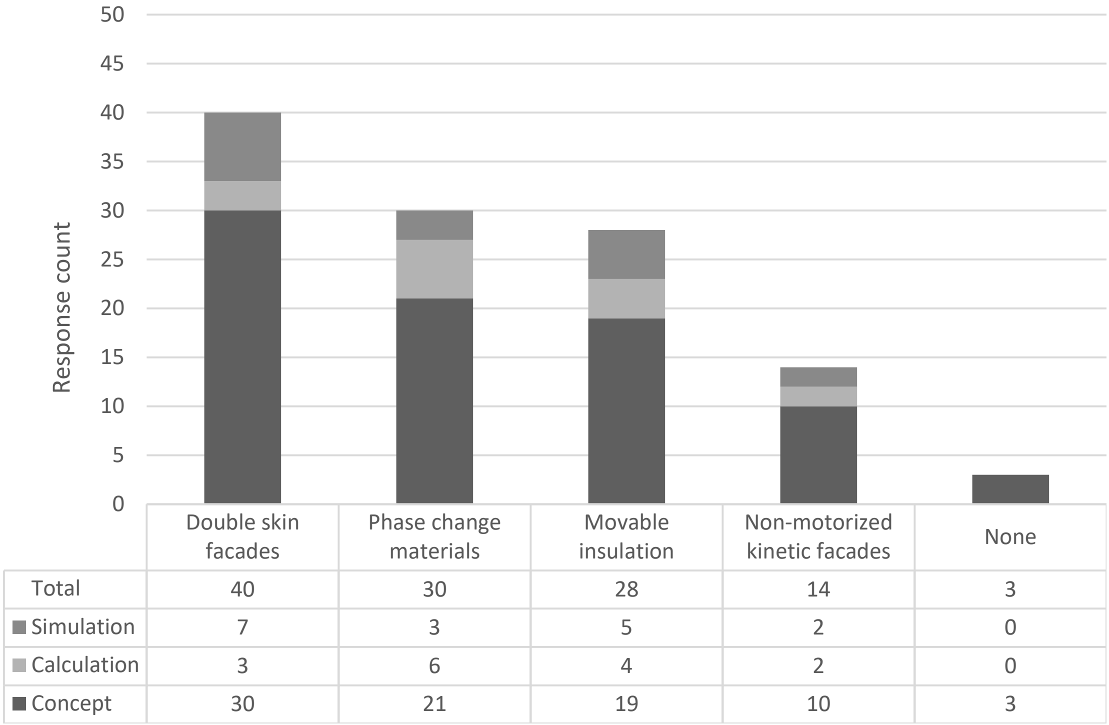
In the category of "other," respondents mentioned topics such as DA, SDA, ASE, contrast ratio, responsive control, EC glazing (electro chromic glazing), controls, and interior/exterior dynamic shading systems. Overall, the survey results show a low level of teaching for the calculation of daylighting systems in architectural education. Compared with the education of other passive systems, calculation and simulation of daylighting systems has been more taught in architecture schools. The concept, calculation, and simulation of skylights, light shelves, clerestory windows, and sidelights are better taught in all of these three levels in architectural schools compared with other daylighting systems.

5.4.5. Passive Building Envelope Strategies (Educators)

This question was asked to find out at what levels nontraditional or more advanced passive building envelope design approaches have been taught by educators. The double skin façade (34.8%), phase change materials (26.1%), movable insulation (24.3%), and non-motorized kinetic façade (12.2%) were the educators' choices respectively (Table 5.18 and Figure 5.22). Three of the respondents have not taught any of these topics in their courses during the last ten years. Among these topics, use of phase change material is the most taught strategy in the calculation level and the double skin facade system is the most taught strategy in the simulation level. Non-motorized kinetic façade is the least taught topic in all three levels of concept, calculation, and simulation. The selection priority of teaching topics in building envelope systems by educators reflects the same priority of practitioners' choice of passive building envelopes in their related survey. In this case, the only difference is that educators by large are teaching these topics in their academic institutions, however, practitioners by large (77.5% of practitioners) are not using any of these systems.

Table 5.18 The frequency and frequency percentage for teaching levels of building envelope systems

Passive Building Envelopes	**Concept**		**Calculation**		**Simulation**		**Total**	
Double skin facades	26.1%	30	2.6%	3	6.1%	7	34.8%	40
Phase change materials	18.3%	21	5.2%	6	2.6%	3	26.1%	30
Movable insulation	16.5%	19	3.5%	4	4.3%	5	24.3%	28
Non-motorized kinetic facades	8.7%	10	1.7%	2	1.7%	2	12.2%	14
None	2.6%	3	0.0%	0	0.0%	0	2.6%	3



	Double skin facades	Phase change materials	Movable insulation	Non-motorized kinetic facades	None
Total	40	30	28	14	3
■ Simulation	7	3	5	2	0
■ Calculation	3	6	4	2	0
■ Concept	30	21	19	10	3

Figure 5.22 The frequency of teaching levels for building envelope systems

5.5. Phase of Analyzing the Use of Passive Systems (Educators)

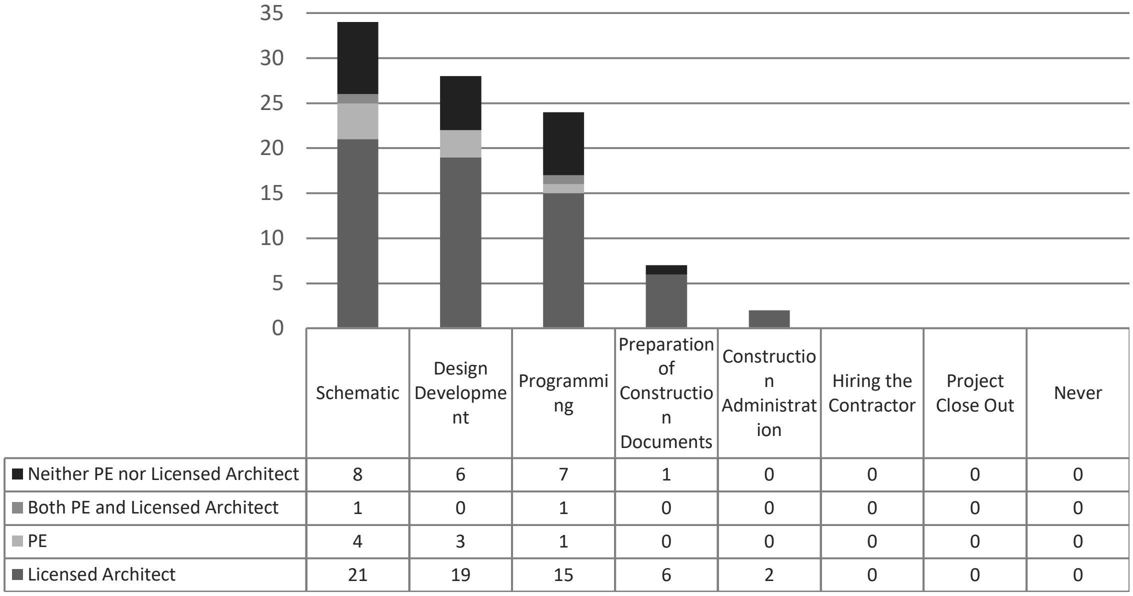
Based on AIA’s seven project phases from programming to project close-out, educators were asked about the phase of their class projects in which they teach analysis of the use of passive systems. These phases in order include programming, schematic, design development, preparation of construction documents, hiring the contractor, construction administration, and project close-out. Table 5.19 shows the frequency distribution of the phases in which educators teach the analysis of passive design strategies. Figure 5.23 shows this distribution based on educators’ professional registrations.

Accordingly, educators teach the analysis of passive design in all phases except for the phases of “hiring the contractor” and “project close-out.” Teaching passive system analysis is the highest in the schematic phase (36.2%) and reduces as we move towards later phases of design with a sharp drop at the phase of preparing the construction documents (7.4%) and the phase of construction administration (2.1%). Design development phase (29.8%) and programming phase (25.5%) follow the schematic phase as the second and third choices in which passive design analysis is being taught more often in class projects.

As it was expected, and shown by figure t26, educators with architectural registration contribute more to teaching at the programming phase (15 out of 55; 28%) compared with educators who have only PE registrations (1 out of 8 selections; 12%). In addition, preparation of construction documents and construction administration phases are only taught by educators with architectural licensure or those without either PE or architectural registrations. The low to zero percentage of teaching about passive systems in the phases of construction documents preparation, hiring the contractor, construction administration, and project close-out indicates that students before graduation will not learn about the required analysis and administration for the implementation of passive/natural systems or their related post occupancy evaluation.

Table 5.19 The frequency and frequency percentage of the phase of teaching passive design in a class project

Phase of teaching passive design analysis	**%Count**	**Count**
Schematic	36.2%	34
Design Development	29.8%	28
Programming	25.5%	24
Preparation of Construction Documents	7.4%	7
Construction Administration	2.1%	2
Hiring the Contractor	0.0%	0
Project Close Out	0.0%	0
Never	0.0%	0
Total	100%	95



	Schematic	Design Development	Programming	Preparation of Construction Documents	Construction Administration	Hiring the Contractor	Project Close Out	Never
■ Neither PE nor Licensed Architect	8	6	7	1	0	0	0	0
■ Both PE and Licensed Architect	1	0	1	0	0	0	0	0
■ PE	4	3	1	0	0	0	0	0
■ Licensed Architect	21	19	15	6	2	0	0	0

Figure 5.23 The frequency/frequency percentage of the phase of teaching passive design in a class project

5.6. Educators Tools

Educators were asked about more than 36 manual and digital tools for the analysis of the feasibility of passive systems in their class projects. After redefining and reassigning the category of "other" tools based on the survey responses, a variety of 43 different digital and manual tools were among the responses selected by educators (Table 5.20 and Figure 5.24). Climate Consultant (10.4%), Sefaira (7.4%), Manual tables, charts, and protractors (7.0%) were the top three choices mostly used by educators in their class projects. Such a selection only shares Climate Consultant with the three top tool choices of practitioners (i.e. Revit Tools/Plugins, Climate Consultant, and eQuest/DOE2) based on the practitioners' survey results. Additionally, some of the practitioners' top ten tools, such as IES VE, are not being used by educators frequently. The high frequency of using

Climate Consultant and Sefaira by educators could be due to their friendly fast grasping interface as well as the possibility of integrating them with modeling software such as SktechUp which are easier for students to learn. The high use of manual tools by educators in class shows that the majority of educators consider it a requirement for students to learn manual tools. The additional time required for instructors/students to learn a new software could be another reason for the inclusion of manual tools among the educators' top three tools.

The next set of tools among the top ten tools being used by educators include Diva for Rhino (6.5%) Energy Plus (6.1%), Ladybug/Honeybee plugins for Rhino (6.1%), Spreadsheets (6.1%), Radiance (4.3%), WUFI (3.9%), Therm (3.9%), Revit Tools/Plugins (3.5%), eQuest/DOE2 (3.0%), HEED (3.0%) OpenStudio (3.0%), COMFEN (3.0%), Daysim (3.0%), DesignBuilder (3.0%), and Autodesk Flow (1.7%). Perceptible from these numbers, some of the top ten tools mentioned have similar application frequency.

Other tools being used by educators included BeOpt (1.3%) Autodesk CFD (0.9%), HAP (0.9%), PHPP or Passive House Planning Package (0.9%), TRNSYS (0.9%), Personal or In-house Software (0.9%), and Archsim (0.9%). F-Chart and Ansys Flow with 0.4% are the least frequently used tools by educators. None of the educators use TAS and Solidwork Flow Plugins (0%). Similar to practitioners' survey results, educators rarely use TRNSYS (0.9%) despite the potential power of this tool for exclusive analysis of passive systems in buildings. This lack of tool application or low application could be the result of educators’ and students’ unfamiliarity with the tools due to difficult accessibility to open source and comprehensive training resources.

Each of the tools that educators specified in the “other” category had 0.4% application frequency and included: Trane Trace, SWL Tools Excel workbook, Students software selection, REM/Rate, LBNL Optics 6, HTflux, Elum tools, Licaso, Velux Daylight Visualizer, CoolVent, 35-foot Boundary Layer Wind Tunnel, and physical model for daylight modeling. Among the daylighting tools, Diva for Rhino, Ladybug/Honeybee plugins for Rhino, Radiance, and Daysim were the educators most selected tools respectively. These tools were followed by the tools specified in the other category including LBNL Optics 6, Licaso, Elum tools, Velux Daylight Visualizer and physical model for daylight modeling. Among tools exclusive to CFD analysis Autodesk Flow, Autodesk CFD, and Ansys Flow were selected respectively. Availability of Autodesk performance analysis tools, their publicly available training resources, and their possible integration with other design/BIM tools such as Revit could be a main reason for their higher selection by educators for exclusive CFD analysis. However, due to the expertise required for using the interface of these CFD exclusive software packages, it seems that students and educators use mostly plugin tools such as those for Rhino for natural ventilation simulations.

Among the tools with exclusive packages for only CFD analysis, Autodesk CFD, Autodesk Flow, ANSYS Flow, and Solidwork Flow Plugins, are the most frequent tools used by 8%, 2.9%, 0.7%, and 0.7% of practitioners respectively. The public availability of a building performance analysis tools and its training resources as well as having a platform possible to be easily shared with other design/BIM tools such as Revit could be a main reason for the professionals' higher interest in using Autodesk simulation tools.

Table 5.20 Tools that educators use for analyzing the feasibility of passive systems on their projects

Tools	%Count	Count
Climate Consultant	10.4%	24
Sefaira	7.4%	17
Manual tables, charts, and protractors	7.0%	16
Diva for Rhino	6.5%	15
Energy Plus	6.1%	14
Ladybug/Honeybee plugins for Rhino	6.1%	14
Spreadsheets	6.1%	14
Radiance	4.3%	10
WUFI	3.9%	9
Therm	3.9%	9
Revit Tools/Plugins	3.5%	8
eQuest/DOE2	3.0%	7
HEED	3.0%	7
OpenStudio	3.0%	7
COMFEN	3.0%	7
Daysim	3.0%	7
DesignBuilder	3.0%	7
Autodesk Flow	1.7%	4
IES VE	1.7%	4
BeOpt	1.3%	3
Autodesk CFD	0.9%	2
HAP	0.9%	2
PHPP (Passive House Planning Package)	0.9%	2
TRNSYS	0.9%	2
Personal or In-house software	0.9%	2
Archsim	0.9%	2
F-Chart	0.4%	1
Ansys Flow	0.4%	1
Trane Trace	0.4%	1
SWL Tools Excel workbook	0.4%	1
Students software selection	0.4%	1
REM/Rate	0.4%	1
LBNL Optics 6	0.4%	1
HTflux	0.4%	1
Elum tools	0.4%	1
Licaso	0.4%	1
Velux Daylight Visualizer	0.4%	1
CoolVent	0.4%	1
35 foot Boundary Layer Wind Tunnel	0.4%	1
Physical model daylight modeling	0.4%	1
None	0.4%	1
Solidwork Flow Plugins	0.0%	0
TAS	0.0%	0
Total	100%	230

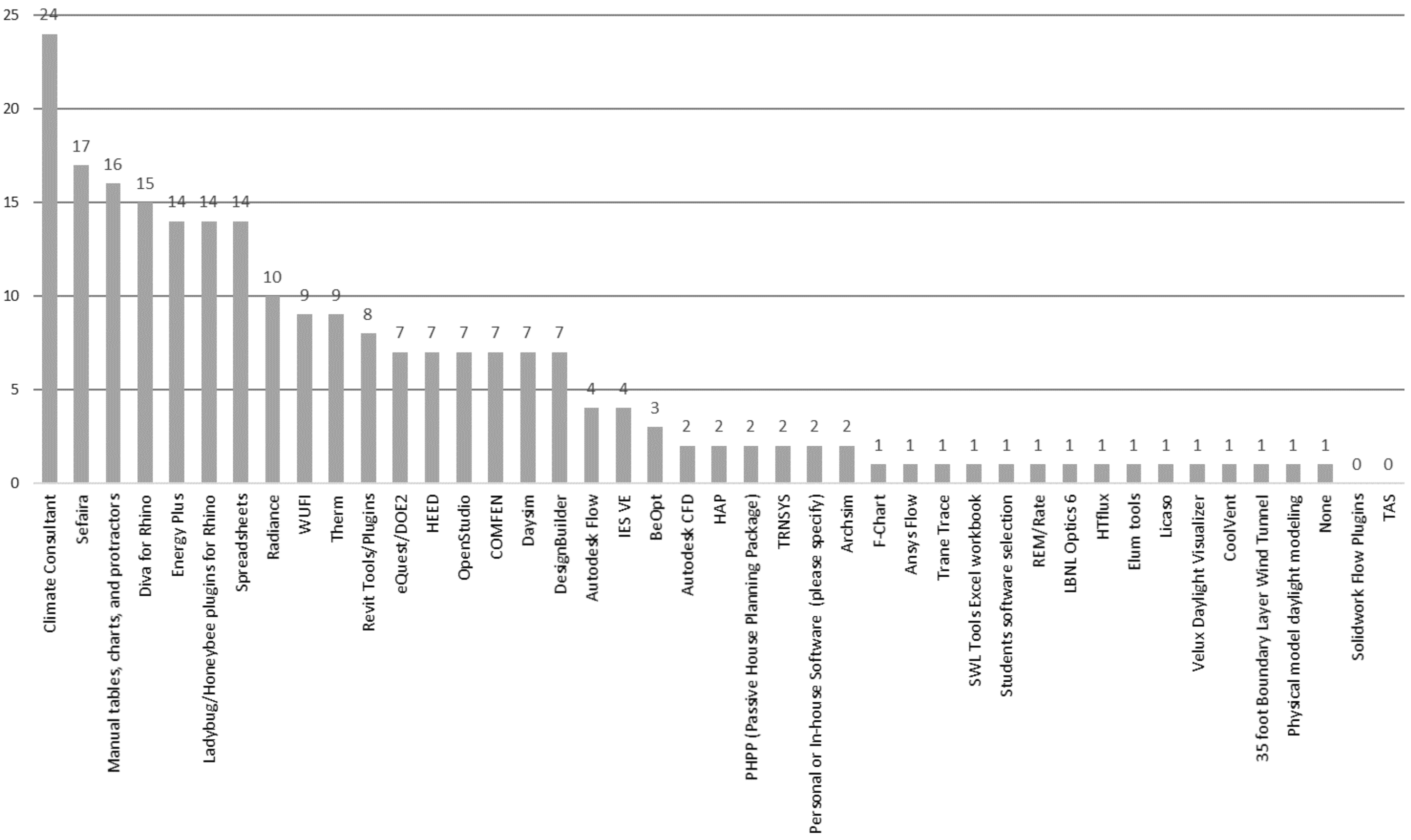


Figure 5.24 Tools that educators use for analyzing the feasibility of passive systems on their projects

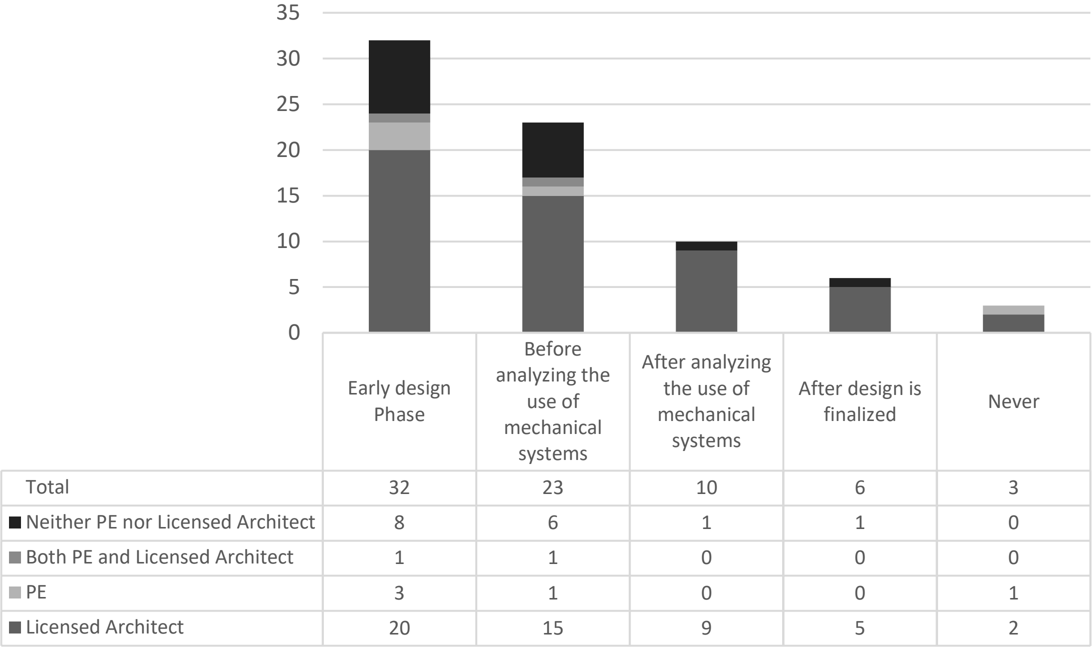
5.7. Phase of the Calculation of Passive Strategies' Savings (Educators)

Only 8.1% of the educators (1 engineer and 2 architects) did not calculate savings of the use of passive systems in their class projects (Table 5.21). This is considerably lower compared with practitioners' survey in which 28.3% of professionals (24 architects,7 engineers, and 8 without professional registrations) mentioned that they never calculate the savings from passive systems.

Table 5.21 Phase of calculating passive systems savings broken out by professional registration of educators

Analysis Phase	**%Count**	**Count**	**% Educators**
Early design Phase	43.2%	32	86.5%
Before analyzing the use of mechanical systems	31.1%	23	62.2%
After analyzing the use of mechanical systems	13.5%	10	27.0%
After design is finalized	8.1%	6	16.2%
Never	4.1%	3	8.1%
Total	100%	**74**	

Most of the educators (86.5%) calculate the savings of passive systems in the early design phase. Based on the survey results, this claim is true for both engineers and architects. Such a calculation is reduced as we move toward the final phases of design (Figure 5.25). None of the educators with PE registration (4 counts) responded that they would calculate passive systems savings after analyzing the use of mechanical system. This finding is different from practitioners' responses in which mostly passive calculation by PE practitioners were conducted (15 counts) after rather than before analyzing mechanical systems applications (14). The percentage of educators calculating passive savings of their class projects include early design phase (86.5%), before analyzing the use of mechanical systems (62.2%), after using mechanical systems (27%), and after design is finalized (16.2%).



	Early design Phase	Before analyzing the use of mechanical systems	After analyzing the use of mechanical systems	After design is finalized	Never
Total	32	23	10	6	3
■ Neither PE nor Licensed Architect	8	6	1	1	0
■ Both PE and Licensed Architect	1	1	0	0	0
■ PE	3	1	0	0	1
■ Licensed Architect	20	15	9	5	2

Figure 5.25 Phase of calculating passive systems' savings categorized by professional registration of educators

Educators' responses to earlier questions of the survey showed low percentages of the calculation level of teaching passive systems, as discussed in Section 5.4.1 through Section 5.4.5 of this dissertation. However, it should be kept in mind that in those questions "design" calculation of passive systems was asked, which is different from passive systems' "saving" calculations.

5.8. Factors Influencing the Use of Passive/Natural Systems (Educators)

To find out the top three challenges/opportunities that can increase the use of passive systems in buildings educators were asked to select three choices from a proposed list of eleven challenges/opportunities in the application/implementation of passive systems. The educators' top three choices (Table 5.22) included "simulation tools with capabilities for analyzing passive systems" (16.7%) "building codes and rating systems such as those from USGBC (LEED), ASHRAE, Passive House, and ICC" (15.7%), and "experience of the project team in the design, implementation, and integration of passive systems" (10.2%). Another choice sharing the third place was "clients desire and collaboration to include passive systems" with 10.2% selection. A major difference between educators and practitioners is that clients desire and collaboration choice, previously ranked first by practitioners, has being selected as the third choice by educators who give the first priority to simulation tools.

The next eight items ranked based on the counts of selections included: fourth, avoiding complexity and simplifying the implementation of passive system strategies (9.3%) fifth as shared between three choices, "knowledge integrating mechanical and passive systems performance" (7.4%) "climate of the location where a passive system should be designed" (7.4%), and "knowledge of the modeling and simulation of passive system strategies" (7.4%), sixth "architect-engineer collaboration" (6.5%), seventh, cost of the "material and construction of passive systems" (5.6%), and eighth "occupants' training for the use and maintenance of the passive systems" (3.7%).

Table 5.22 Items ranked based on the educators' top three choices to increase the use of passive systems in the US

Rank	Influential Factor	Count	%Count	% Educators
1	Simulation tools with capabilities for analyzing passive systems	18	16.7%	48.6%
2	Building codes and rating systems such as those from USGBC (LEED), ASHRAE, Passive House, and ICC	17	15.7%	45.9%
3	Experience of the project team in the design, implementation, and integration of passive systems	11	10.2%	29.7%
3	Client's desire and collaboration to include passive systems	11	10.2%	29.7%
4	Avoiding complexity and simplifying the implementation of passive system strategies	10	9.3%	27.0%
5	Knowledge integrating mechanical and passive systems performance	8	7.4%	21.6%
5	Climate of the location where a passive system should be designed	8	7.4%	21.6%
5	Knowledge of the modeling and simulation of passive system strategies	8	7.4%	21.6%
6	Architect-engineer collaboration	7	6.5%	18.9%
7	Cost of material and construction of passive systems	6	5.6%	16.2%
8	Occupants' training for the use and maintenance of the passive systems	4	3.7%	10.8%
NA	**Total**	108	100%	

While the first rank (client's desire) and second rank choices have only 1% difference in selection, there is a sharp reduction of about 5.5% from selecting the second choice (i.e. building codes) to the third choice (i.e. implementation experience) by practitioners. The reduction after the third choice to the end is gradual with minor differences of about

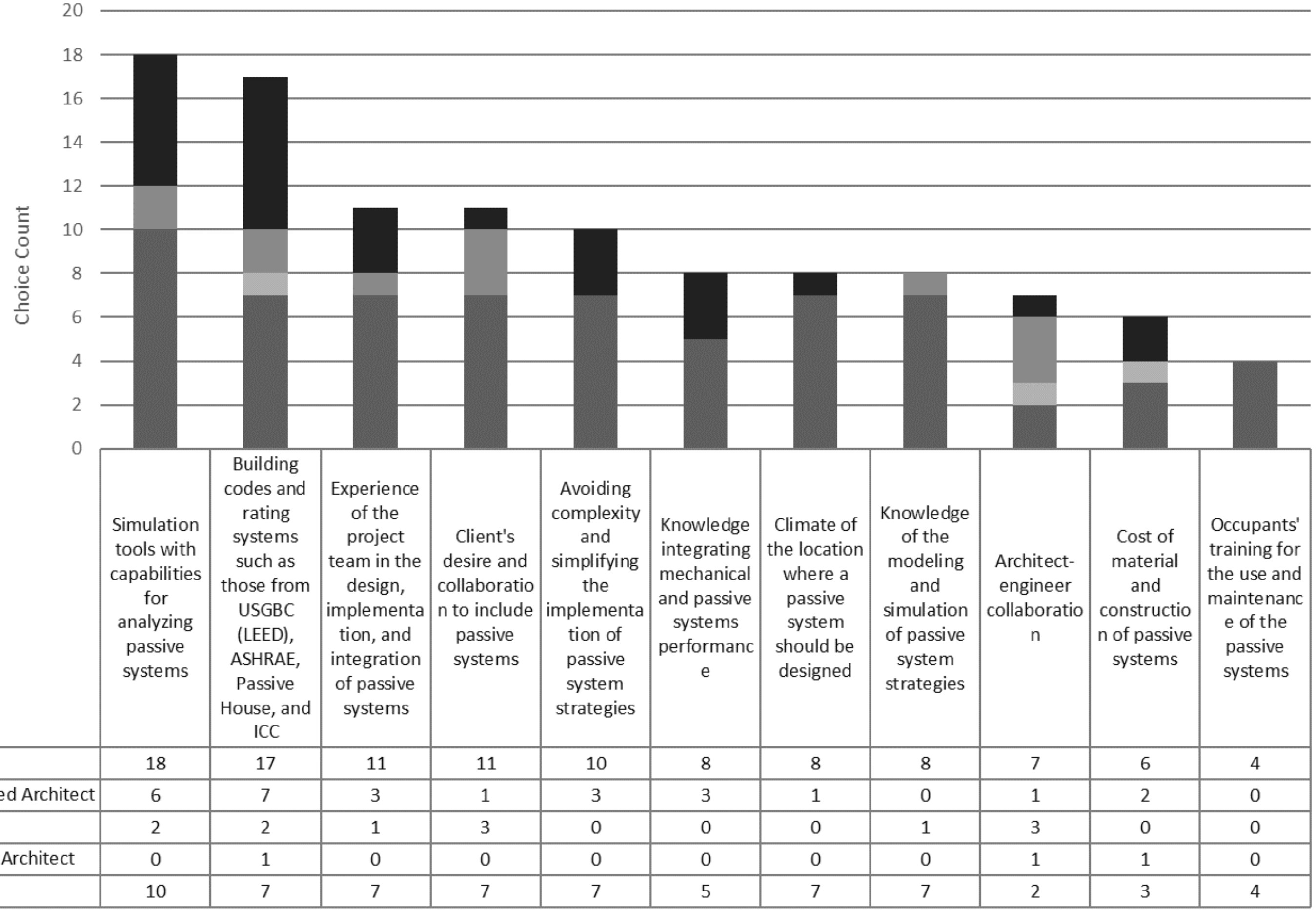
1% to 2%. Therefore, it is more logical to claim that the first and second items (i.e. simulation tools and building code) are of the same importance, next comes the importance of the experience of the project team as well as the client's desire in implementing passive systems, and on a lower importance comes simplification, knowledge for integrating mechanical and passive systems, climate, passive systems simulation knowledge, architect-engineer collaboration, cost, and occupants training. The least important item (i.e. occupants training) is as same as the least selected item by practitioners in the previous survey. Therefore, it seems logical to consider occupants training of the lowest importance by architects and engineers. However, as mentioned earlier, the role of occupants training in increasing the use of passive systems needs further analysis to be inclusive of more than only designers' opinions. In particular, a survey should focus on occupants rather than designers and also post occupancy evaluations to ask how important the role of training and designers could be in the use of passive systems.

Figure 5.26. Shows all the eleven factors in a chart with a breakout based on the respondents' professional registration. A comparison of the registered architects' and engineers' choices reveals several points. First, engineers consider architect-engineer collaboration to be the most important factor in increasing the use of passive systems, but this item has the least selection choice among other factors by the architects. Second, while engineers do not consider occupants training to be important in the use of passive systems, architects consider it to be the fourth important item in the list. Third, after the

importance of simulation tools for architects as the first item, other items are of almost the same importance for architects. In this case, except for cost, occupants training, integrating mechanical and passive systems, and architect-engineer collaboration have the same selection percentage for architects.

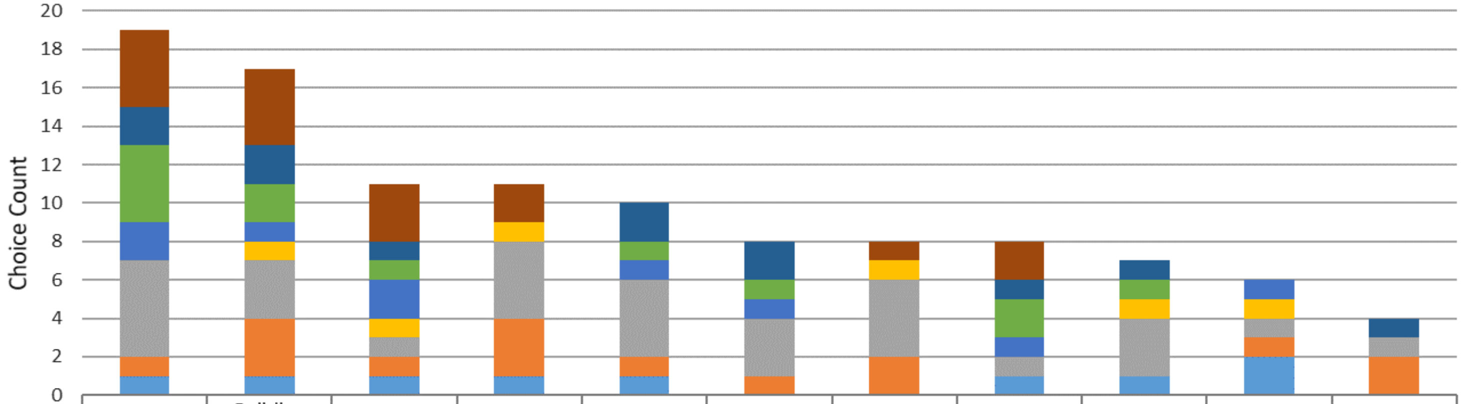
The number of years of teaching experience could also be an important factor in selecting the most influential factor in increasing the application of passive systems as shown in Figure 5.27. For example, those with over 34 years of teaching experience do not consider the simplification of passive systems to be important at all. This indicates that educators who have been trained in schools in the 1980s have probably dealt with the implementation of such systems and therefore, due to their higher chance of being involved in teaching, learning, or implementing passive systems, do not consider them to be complicated.

Finally, similar to practitioners' survey results and despite the general belief, climate does not play the key role in using or not using passive design strategies in the US. This claim is evidenced by ranking the importance of climate fifth among the eleven items in the survey questionnaire.



	Simulation tools with capabilities for analyzing passive systems	Building codes and rating systems such as those from USGBC (LEED), ASHRAE, Passive House, and ICC	Experience of the project team in the design, implementation, and integration of passive systems	Client's desire and collaboration to include passive systems	Avoiding complexity and simplifying the implementation of passive system strategies	Knowledge integrating mechanical and passive systems performance	Climate of the location where a passive system should be designed	Knowledge of the modeling and simulation of passive system strategies	Architect-engineer collaboration	Cost of material and construction of passive systems	Occupants' training for the use and maintenance of the passive systems
Total Counts	18	17	11	11	10	8	8	8	7	6	4
■ Neither PE nor Licensed Architect	6	7	3	1	3	3	1	0	1	2	0
■ PE	2	2	1	3	0	0	0	1	3	0	0
■ Both PE and Licensed Architect	0	1	0	0	0	0	0	0	1	1	0
■ Licensed Architect	10	7	7	7	7	5	7	7	2	3	4

Figure 5.26 Factors influential in the use of passive/natural systems categorized by professional registrations of the educators



	Simulation tools with capabilities for analyzing passive systems	Building codes and rating systems such as those from USGBC (LEED), ASHRAE, Passive House, and ICC	Experience of the project team in the design, implementation, and integration of passive systems	Client's desire and collaboration to include passive systems	Avoiding complexity and simplifying the implementation of passive system strategies	Knowledge integrating mechanical and passive systems performance	Climate of the location where a passive system should be designed	Knowledge of the modeling and simulation of passive system strategies	Architect-engineer collaboration	Cost of material and construction of passive systems	Occupants' training for the use and maintenance of the passive systems
Total	18	17	11	11	10	8	8	8	7	6	4
■ Over 34 years	4	4	3	2	0	0	1	2	0	0	0
■ 30 to 34 years	2	2	1	0	2	2	0	1	1	0	1
■ 25 to 29 years	4	2	1	0	1	1	0	2	1	0	0
■ 20 to 24 years	2	1	2	0	1	1	0	1	0	1	0
■ 15 to 19 years	0	1	1	1	0	0	1	0	1	1	0
■ 10 to 14 years	5	3	1	4	4	3	4	1	3	1	1
■ 5 to 9 years	1	3	1	3	1	1	2	0	0	1	2
■ Under 5 years	1	1	1	1	1	0	0	1	1	2	0

Figure 5.27 Factors influential in increasing the use of passive/natural systems in buildings categorized by educators' years of teaching experience

5.9. Open-ended Question (Educators)

In order to find out about other factors that can reduce or increase the contribution of passive systems into the design of buildings in the US an open ended text question was included in the survey. This question asked educators to write their comments or notes if there is anything not addressed in the survey about the education/application of passive/natural systems in buildings. A content analysis approach, similar to the approach taken for the analysis of practitioners' responses, was adopted. The results included several findings about educators' opinions on the education and application of passive systems, which will be summarized through the following themes

In order to find out about other factors that can reduce or increase the contribution of passive systems into the design of buildings in the US an open ended text question was included in the survey. This question asked educators to write their comments or notes if there is anything not addressed in the survey about the education/application of passive/natural systems in buildings. A content analysis approach, similar to the approach taken for the analysis of practitioners' responses, was adopted. The results included several findings about educators' opinions on the education and application of passive systems, which will be summarized through the following themes

- Level of teaching:

Some of the educators believe that learning the concepts, in comparison to calculation and simulation, is the key in teaching passive systems to architecture students. Some other educators added to this by expressing that learning/teaching basic rules of thumb for various passive design strategies with respect to overall limits on the size, massing, scale, and other features of a building or its zones is a critical first step in seriously implementing many passive design strategies.

- Design studio and passive systems:

A majority of educators' responses dealt with the scope of architectural design studio and its relation or impact on teaching passive design strategies. Some of the educators mentioned that while their teaching focus has varied considerably over the years, but in recent years they have covered the scope of the passive systems primarily in their design studios. Some other educators mentioned that because students are very preoccupied with design studios it is difficult to implement any sort of intensive calculation or simulation methods unless it directly relates to their studio projects. Even in dealing with this issue in the context of a design studio class, educators believe there needs to be a greater opportunity for a nimble analysis of design options as student designs rapidly evolve in a design studio.

- Courses focused on passive systems:

In addition to the limited time in a studio class for a deep immersion in the application of passive/natural systems in buildings, even the class time for other courses seems to be insufficient. Some educators mentioned that very little time exists to delve into details about any particular passive system. In other words, in just 15 weeks the class time for an environmental technology course is taken by the need to cover topics such as site design, HVAC, plumbing, fire protection and detection, electrical, lighting, vertical transportation, acoustics, and life cycle cost analysis.

- Role of the architects in practice:

Some of the answers had a focus on the perception of the responsibility expected from architects and clients in regards to the design of passive systems. The results of this group's responses can be explained in two themes. First, in general, architects seem not to feel comfortable to include substantive passive systems in their projects. The respondents believe that architects' lack of the application of passive systems is probably due to lack of actionable design knowledge, which is partly due to lack of readily accessible analysis tools and lack of appreciation for the carbon-reduction potential of even part-season use of passive systems.

Second, some of the respondents mentioned that it should be kept in mind that architects, with some rare exceptions, are responsible to design and integrate systems, but not to calculate their performance. This group maintained that, generally, engineers are responsible for calculations regarding the heating and cooling of buildings. They extended that the use of passive systems is driven partly by the client's responsiveness to include these systems, such as sunshades, since they all come with cost premiums. Therefore, the client's responsiveness is also tied to the proven effectiveness of the systems, which is generally evaluated through the consulting engineer's energy models.

In this case, as mentioned by some of the educators, simulations need to consider the lifecycle costing associated with energy benefits to find the value over a client's interested period of time. This cost usually must pay back in less than maximum five to seven years, and if it is less than two years it will be adopted.

- Perception/definition of passive systems and its importance:

Some of the responses raised concerns about the way passive systems are defined by professionals and from what view we should approach the scope of passive system design issues. One of the respondents mentioned that the survey seems to take a technological approach to the problem, but non-technological issues should also receive the same significance. Narrow comfort standards and the drift in modern expectations are part of a cultural issue which needs attention. Passive design can run across the architectural curriculum, but it is rarely addressed in a theory or history class. Department of Energy funding rarely engages passive design issues, because of investment interests in commercialization products and not embodied intelligent architectural configuration. The respondent continued that Passive House claiming the term passive is also a problem in defining and designing passive systems. This vagueness in defining passive systems in the field has been addressed also in some of other responses in the survey: **"**It's not clear what's included or not included, and how it differs from existing terms like high-performance buildings."

Therefore, by considering the educators' responses, who also may have practiced in passive design, there is a need for further work on several themes including: level of teaching, incorporation of passive design course modules in design studios, assigning course modules to learning about passive systems, better understanding of the role of architects in practice and in relation to clients, and a more inclusive perception and definition of passive systems and its importance.

5.10. Major Findings (Educators)

The major findings of the survey with respect to the education of passive design strategies can be summarized through Table 5.23.

Table 5.23 Major findings from educators' survey results

Theme	**Findings**
Educators' Background	About 78% of the educators are either architects, architectural engineers, or sustainability experts. This high percentage of educators who also practiced indicates that there is a great potential to inform the building industry through educators who practiced in the building industry and vice versa. However, the results show architecture schools still hire architects rather than engineers/architectural engineers as evidenced by 50% of the educators having architecture as their current and previous professional roles. Considering the number of engineers and architects there is a 3 to 1 ratio in terms of the educators' background being an architect versus an engineer. This finding implies that very few architectural engineers are teaching at architecture schools.
Teaching and Professional Practice	About 76.5 % of the total educators had professional registration in the US, which is only about 6% less than the total number of registered practitioners found from the practitioners' survey results (81.2%). This number indicates that the majority of educators are informed with the building industry's practice regarding passive systems. Therefore, this same majority can also have an influence with their educational practice on the building industry.

Table 5.23 Continued

Theme	Findings
Teaching Experience	The results showed that the combination of old educators who had over 34 years teaching experience with young educators who had 5-14 years teaching experiences define the majority of the educators in the top 50 architecture school. Therefore, there seems to be a large experience gap between those who are about to retire and those who are starting their career as educators in higher education. On the other hand, the shift toward new passive concepts in higher education, such as adaptive facades or biomimetic design of building envelope components, could be the result of the replacement of the retiring educators with younger educators. Additionally, about 51.4% of the educators are more than 55 years old, which implies that they had the opportunity of developing their educational or professional experience during the peak periods of passive design in the 1980s and the 1970s.
Educators' Degrees	Given the third rank for educators with PhD degrees in the survey results, there is a potential to increase the number of faculty members in higher education who have PhD degrees related to the field of passive/natural systems if research for updating and promotion the old passive literature is desirable.
Educators Projects' Typology	While the highest ranked projects for practitioners were educational, single family buildings define the highest ranked type of designed or constructed buildings for educators. Another finding is that the majority of the educators have both designed and constructed buildings. This feature can contribute to fostering the content of course curriculums on passive/natural systems through design-build courses and programs in schools which is feasible because of educators' involvement in practice.

Table 5.23 Continued

Theme	**Findings**
Teaching Renewable Systems	Except for photovoltaics, the majority of teaching level selections remain in the conceptual level. One reason for such a large difference could be the availability of many simulation tools exclusively tuned for the design of PV systems. Most of these tools are accessible online or in cloud-based formats. Additionally, the concept of PV panels seems to be more familiar for architecture students, and probably educators, due to its currently widespread application as well as easier installation procedures. The breakout of the total percentage in each level of teaching clearly shows a sharp drop from conceptual teaching level to calculation and simulation levels for renewable systems other than photovoltaics. Two other major finding of the survey is that, first, educators with PE registration do not teach the simulation level of renewable systems, however, licensed architects teach in all three levels of concept, simulation, and calculation. Second, the drop from conceptual level of teaching to calculation level is much lower for PE professionals compared with licensed architects. In reading both of these findings it should be kept in mind that a total number of respondents with PE registration is much less than educators with architectural licensure. For both educators and practitioners, the selection frequency shows that PV systems, DHW solar thermal collectors, geothermal, space heating solar thermal collectors, and wind turbines are the most selected renewable systems in order.
Teaching Passive Cooling	External shading devices (9.5%), cross ventilation (7.6%), and stack ventilation (6.9%) are the educators top three teaching topics in passive cooling strategies. External shading devices and stack ventilation were also among the top three choices of practitioners' survey which indicate that there is an overlap between practitioners and educators' interests in the case of passive cooling strategies. Overall, the survey result shows that calculation and simulation of passive cooling strategies, except for shading devices and cross ventilation, are receiving a low level of attention in education.
Teaching Passive Heating	Overall, based on the survey results, with exception for direct solar gain systems, calculation and simulation of passive heating systems are rarely being taught at architecture schools.
Teaching Daylighting	The top choices of educators for teaching daylighting systems included skylights (12.9%), light shelves (12.9%), clerestory windows (12.2%), sidelights (12%), and atriums (9.8%). This selection, excluding the light shelves, is similar to practitioners' top choices for the use of daylighting systems. Compared with other daylighting systems The teaching of skylights, light shelves, clerestory windows, and sidelights are better expanded in all three levels of concept, calculation, and simulation in architectural schools. Overall, the survey results show a low level of teaching for the calculation of daylighting systems in architectural education. Compared with the education of other passive systems, calculation and simulation of daylighting systems has been more considered to be taught in architecture schools. Concepts such as light pipes and dynamic daylighting systems are the least taught concepts in terms of calculation and simulation.

Table 5.23 Continued

Themes	Findings
Advanced Passive Building Envelope Systems	Among these topics, use of phase change materials is the most taught strategy in the calculation level and the double skin facade system is the most taught strategy in the simulation level. Non-motorized kinetic façade is the least taught topic in all three levels of concept, calculation, and simulation. The selection priority of teaching topics in building envelope systems by educators reflects the same priority of practitioners' choice of passive building envelopes in their related survey. In this case, the only difference is that educators by large are teaching these topics in their academic institutions, however, practitioners by large (77.5% of practitioners) are not using any of these systems.
Teaching Passive Systems for Different Phases of a Project	The low to zero percentage of teaching about passive systems in the phases of construction documents preparation, hiring the contractor, construction administration, and project close-out indicates that students before graduation will not learn about the required analysis and administration for the implementation of passive/natural systems or their related post occupancy evaluation.
Level of Teaching for Passive Systems	Overall passive systems in architecture schools are being taught only in conceptual level, to some extent at the simulation level, and rarely at the level of calculation.
Tools for Passive Design in Education	Climate Consultant (10.4%), Sefaira (7.4%), Manual tables, charts, and protractors (7.0%) were the top three choices mostly used by educators in their class projects. Such a selection only shares Climate Consultant with the three top tool choices of practitioners (i.e. Revit Tools/Plugins, Climate Consultant, and eQuest/DOE2) based on the practitioners' survey results. Therefore, there is a considerable difference between the design tools students learn about at school and the tools being applied in the actual architectural profession. Additionally, some of the practitioners' top ten tools, such as IES VE, are not being used by educators frequently. The high frequency of using Climate Consultant and Sefaira by educators could be due to their friendly fast grasping interface as well as the possibility of integrating them with modeling software such as SketchUP which are easier for students to learn. The high use of manual tools by educators in class shows that the majority of educators consider it a requirement for students to learn manual tools. The additional time required for instructors/students to learn a new software could be another reason for the inclusion of manual tools among the educators' top three tools. Also, this lack of tool application or low application could be the result of educators' and students' unfamiliarity with the tools due to difficult accessibility to open source tutorials and comprehensive training resources. Availability of Autodesk performance analysis tools, their publicly available training resources, and their possible integration with other design/BIM tools such as Revit could be a main reason for their higher selection by educators for exclusive CFD analysis. However, due to the expertise required for using the interface of these CFD exclusive software packages, it seems that students and educators use mostly plugin tools such as those for Rhino for natural ventilation simulations.

Table 5.23 Continued

Themes	Findings
Calculating Savings from Passive Systems in Class Projects	Only 8.1% of the educators do not calculate savings of the use of passive systems in their class projects. This is considerably lower compared with practitioners' (28.3%). Most of the educators (86.5%) calculate the savings of passive systems in the early design phase and this calculation reduces towards "after design is finalized."
Courses Related/Connected to Passive Systems	The majority of the educators have a specialty in courses focused on sustainable building technologies (8.5%), which shows growing interests in sustainability in architecture programs. The same can be said for courses in environmental control for passive systems (7.3%), building envelope (7%), and environmental control for active systems (6.7%). The fact that environmental control for passive systems is the second most selected area of specialty reflects the current interests in architecture schools for passive design. A major finding of the survey is the areas of specialty that needs further attention in architecture schools: Building energy optimization (5.6%), Building simulation (5%), Building physics (4.7%), Building performance optimization (4.4%), Building performance measurement (3.8%), Green building design studios (3.8%), Energy systems (3.8%), Building services (3.2%), Building rating systems (2.6%), and Design engineering studios (0.6%). It seems that these cases, the low percentage is due to two issues in architecture curriculums: • First, for example, the LEED AP affiliation was among the top three choices of educators' affiliations, however, courses focused on building rating systems did not receive a high response rate in the survey. This low response rate indicates that most of the educators are not integrating their professional experience with their teaching practice. However, based on the survey results, there is a potential for them to incorporate their professional experience, such as building rating systems, into their education. • Second, some of the courses are not directly related to passive/natural systems, but they are important for the integration of passive systems with other design considerations. However, the majority of them are rarely being taught at architecture schools. For example, courses focused on post-occupancy evaluation such as commissioning can considerably promote the students' learning to a professional level and make them familiar with the real measured performance of buildings and its evaluation. This finding suggests that there is a need for a stronger emphasis in architecture schools on courses related to passive systems as well as integrated courses with respect to passive systems, active systems, and design studios, rather than pursuing each of these courses only in isolation

Table 5.23 Continued

Themes	**Findings**
Factors Influential in Increasing or Reducing the Use of Passive Systems in the US From the of Perspective Educators	The factors ranked by educators in increasing/reducing the use of passive systems in buildings, in order, included: 1. Simulation tools with capabilities for analyzing passive systems; 2. Building codes and rating systems such as those from USGBC (LEED), ASHRAE, Passive House, and ICC; 3. Experience of the project team in the design, implementation, and integration of passive systems; 4. Client's desire and collaboration to include passive systems; 5. Avoiding complexity and simplifying the implementation of passive system strategies; 6. Knowledge integrating mechanical and passive systems performance; 7. Climate of the location where a passive system should be designed; 8. Knowledge of the modeling and simulation of passive system strategies; 9. Architect-engineer collaboration; 10. Cost of material and construction of passive systems; 11. Occupants' training for the use and maintenance of the passive systems
Influential Factors in Passive Design From the Perspective of Educators with Engineering Background Versus Architectural Background	In this case, there are two major findings. First, educators with engineering background consider architect-engineer collaboration to be the most important factor in increasing the use of passive systems, but this item has the least selection choice among other factors by the architects. Second, while engineers do not consider occupants training to be important in the use of passive systems, architects consider it to be the fourth important item in the list. Third, after the importance of simulation tools for architects as the first item, other items are of almost the same importance for architects. In this case, except for cost, occupant training, integrating mechanical and passive systems, and architect-engineer collaboration have the same selection percentage for architects.
Impact of Teaching Experience in Selecting the Influential Factors in Passive Design	Educators' years of teaching experience can impact the selection of the factors influential in passive design. For example, those with over 34 years of teaching experience do not consider the simplification of passive systems to be important at all. This indicates that educators who have been trained in schools in the 1980s have probably dealt with the implementation of such systems and therefore, due to their higher chance of being involved in teaching, learning, or implementing passive systems, do not consider them to be complicated.
Climate and Passive Design	Finally, similar to practitioners' survey results and despite the general belief, climate does not play the key role in using or not using passive design strategies in the US. This claim is evidenced by ranking the importance of climate fifth among the eleven items in the survey questionnaire.
Opportunities for Further Work in Education	By considering the educators' responses, who also may have practiced in passive design, there is a need for further work on several areas including: level of teaching, incorporation of passive design course modules in design studios, assigning course modules to learning about passive systems, better understanding of the role of architects in practice and in relation to clients, and a more inclusive perception/definition of passive systems and its importance.

6. SUMMARY AND CONCLUSION

6.1. Scope of the Section

This section contains a summary of the research, recommendations, discussion of the research limitations, and providing a path for the future research.

6.2. Summary

This research was an examination of the level of practice and education of passive/natural systems in the US to find the opportunities and challenges for promoting the application/education of these systems. To perform this research a survey questionnaire was used to collect data from practitioners and educators, which was also supported through the findings of a content analysis and case study methodologies. The case studies of AIA COTE Top Ten Awards indicated that the majority of the well-documented add-on or legacy passive systems have not been used in the US in the last ten years. If we move further backward in time (i.e. about ten years), as in the case of earlier AIA COTE TOP 10 Awards, more of the legacy passive systems have been applied by designers.

The case study results showed that projects related to the 2017 AIA COTE TOP Ten Awards mainly applied the following passive/natural system strategies:

- *Daylighting* such as solar tubes, atriums, reflective light louvers, skylights, light wells, and light shelves;

- *Building envelope strategies* such as super insulated and air-tight building envelopes as well as double-skin facades;
- *Natural cooling and heating* through stack/cross ventilation with operable windows in double skin facades and clerestory windows, appropriate orientation for direct solar gain with fixed shading devices to prevent overheating, and superinsulation measures, which are integrated in some cases with green roofs; and
- Renewable systems including mainly PV systems, solar thermal collectors geo-exchange systems, and in some cases wind turbines.

In the earlier examples associated with AIA COTE Top Ten Awards 2010, in addition to the above approaches, other strategies were applied. These strategies included: natural cooling through fixed or operable shading devices and night-flushing, and natural heating through direct gain systems with appropriate building orientation and thermal mass. This broader range of passive system strategies for the AIA 2010 Awards showed that design teams were more successful and interested in the implementation of such passive/natural systems in earlier projects (i.e. 2004-2010) versus the more recently awarded projects (i.e. 2014-2017).

The case study analysis showed that buildings designed by US firms or their branches outside the country have been more successful regarding the application of passive systems. The two cases that were studied included the King Abdullah University of

Science and Technology (KAUST) in KSA, which uses two large solar chimneys on the university campus among many other applied passive cooling strategies, and the Ng Teng Fong General Hospital (NTFGH) in Singapore where 70% of the hospital is naturally ventilated.

In contrast, the AIA 2017 Awards it was only the NOAA Daniel K. Inouye Regional Center (built in 2014) that applied passive/natural systems including a passive downdraft cooling system and a partially passive geo-thermal system.

The findings of the survey of building practitioners in the US supported the same findings from different case studies. This survey was designed to address the issues that are summarized through the following constructs with their findings:

- The factors influencing the increase/reduction of the use of passive/natural systems in buildings, which included “client’s desire and collaboration” and “building codes and building rating systems” were the first and second most important items with considerably higher votes (almost two times their next item, which was “simulation tools”). Other influential factors, almost of equal importance, included: experience of the project team in design, implementation, and integration of passive systems; material and construction cost; avoiding complexity and simplifying the implementation of passive systems; climate; architect-engineer collaboration; passive systems’ modeling and simulation knowledge; knowledge integrating mechanical and passive systems; and occupant training.

- The design tools that were currently used for the application of passive design, in descending order included: Revit tools/plugins, Climate Consultant, eQuest/DOE2, No Tools at all, Spreadsheets, EnergyPlus, Sefaira, Manual tables and charts/protractors, Radiance, Wufi, IES VE, OpenStudio, Therm, Autodesk CFD, HAP, Ladybug/Honey bee plugins for Rhino, Daysim, Diva for Rhino, Personal/In-house Software, DesignBuilder, Trane Trace, Autodesk Flow, PHPP, Specialty Consultant, BeOpt, TRNSYS, COMFEN, F-Chart, HEED, Ansys Flow, Solidwork Flow Plugins, CONTAM, and RET Screen. The tools used for daylighting analysis in descending order included: Radiance, Daysim, and Diva for Rhino. The most popular CFD tools in descending order were Autodesk CFD, Autodesk Flow, Ansys Flow, and Solidwork Flow Plugins.

- The most and least recurring types of passive/natural system strategies, which included the followings for each type of systems:
    - *Renewables*: PV panels and geothermal were the most frequent types and wind turbine was the least frequently used renewable system. About 23% of the practitioners did not use renewable systems in their projects.
    - *Passive cooling systems*: external shading devices, green roofs, and cross ventilation were the top three cooling systems used. Earth tubes, double roofs for shading, and roof ponds were the three least used systems. About 15% of the practitioners do not use passive cooling systems in their projects.

    - *Passive heating systems:* Direct solar gain, deciduous plants, and isolated solar gain systems were the most frequently used natural heating systems, and roof pound and stack ventilation were the least recurring types. The majority of practitioners do not use any passive heating systems (48%).
    - *Daylighting*: skylights, clerestory windows, and sidelights were the three most used systems. Light duct, external reflector, and dynamic daylighting systems were the least recurring types of daylighting systems.
    - *Advanced building envelope systems*: with the exception of super-insulation and airtightness measures, the most frequent system was double skin facades and the least frequent system was non-motorized kinetic facades. The majority of practitioners did not apply any of the advanced building envelope systems in their projects (77.5%).

- The importance of incorporating passive/natural system strategies in a practical design process with respect to the integration with mechanical systems:
    - Only about 33% of the practitioners calculated the energy savings from passive systems after they analyzed the use of mechanical systems. About 16% of the practitioners took this step and also analyzed the savings from passive systems' integration with mechanical systems

  after design was finalized. About 28% of the practitioners never calculated the saving from passive systems.

  - The phases of analyzing passive systems by practitioners included mostly schematic design, design development, and programming. In most architectural designs this analysis falls short of the steps in which mechanical systems' operation are being considered for a project (e.g., construction documents and project close-out). About 14% of the practitioners never analyze the use of passive systems in their projects.

- Additionally, the findings from the content analysis of the open-ended question in the practitioners' survey showed five criteria should be considered in order to increase the use of passive design:
    1. *Usefulness of passive system strategies*. This is influenced by different perceptions of passive design including the perception of new practitioners and the perception of older practitioners
    2. *Usefulness of design tools for passive design*
    3. *The importance of an integrated design* such as the economic justification and the function of a building to allow the integration of passive systems with mechanical systems
    4. *The role of building typology in using passive systems*, such as the size of the building or difficulty in incorporating passive systems to healthcare facilities

5. *The drawbacks of using passive systems*, such as the lack of occupant training and climate incompatibility

The findings from educators indicated that there is a great opportunity to promote the quality of education about passive/natural systems in the US architecture schools:

- The factors influencing the increase/reduction of the use of passive/natural systems in buildings, which included “simulation tools with capabilities for analyzing passive systems” and “building codes and rating systems” were the top two influential factors (with almost 1.5 times more votes compared with the third voted items, which were clients’ collaboration and experience of the project team). The following items have equal importance, among which there is only minor voting differences:
    - Experience of the project team in the design, implementation, and integration of passive systems;
    - Client's desire and collaboration to include passive systems;
    - Avoiding complexity and simplifying the implementation of passive system strategies;
    - Knowledge integrating mechanical and passive systems performance;
    - Climate of the location where a passive system should be designed;
    - Knowledge of the modeling and simulation of passive system strategies; and
    - Architect-engineer collaboration.
- Accordingly, client desire and collaboration which was of the highest importance to practitioners is not considered important by educators. Cost of the material and

construction of passive systems and occupant training are of lowest importance to educators for promoting the use of passive systems.

- The top three design tools used by educators in their class projects for analyzing the application of passive design, in descending order included: Climate Consultant, Sefaira, and Manual tables or charts/protractors.

- The educators' top three tools for class projects only shares Climate Consultant with the three top tools of practitioners (i.e. Revit Tools/Plugins, Climate Consultant, and eQuest/DOE2). Therefore, there is a considerable difference between the design tools students learn about at school and the tools being applied in the actual architectural profession. Additionally, some of the practitioners' top ten tools, such as IES VE, were not being used by educators.

- The most and least taught types of passive/natural system strategies and their level of teaching in architecture schools included the followings for each type of systems:
    - *Renewables*: except for photovoltaics, the majority of the teaching of renewable systems remained at the conceptual level. One reason for such a large difference could be the availability of simulation tools capable of analyzing PV systems. Also, architecture students and educators were more familiar with PV systems. In addition, except for photovoltaics, there was a sharp drop from conceptual level of teaching to the calculation and

simulation of renewable systems. The least taught renewable system concept was wind turbines.

- *Passive cooling systems*: external shading devices, cross ventilation, and stack ventilation were the educators top three teaching topics in passive cooling strategies. External shading devices and stack ventilation were also among the top three choices of practitioner's cooling strategies indicating an overlap between practitioner's and educator's interests. Overall, the calculation and simulation of passive cooling strategies, except for shading devices and cross ventilation, received a low level of attention in education.
- *Passive Heating systems:* with exception of direct solar gain systems, the calculation and simulation of passive heating systems are rarely being taught at architecture schools. In combination of all the three levels of teaching (i.e., conceptual, simulation, and calculation) direct solar gain system with a considerable difference is the first most taught passive system, followed by isolated solar gain systems (i.e., sunspace and greenhouses) and indirect solar gain systems (i.e., Trombe' wall including water walls and their variations). Other concepts, of almost equal importance, included: indirect solar gain (Trombe' wall without water and its variations), solar chimney, deciduous plants (that shed their leaves in the fall), earth contact, and earth tube. Transpired solar wall systems were the least taught passive heating systems in architecture schools.

- The importance of incorporating passive/natural system strategies in a practical design process with respect to their integration with mechanical systems:
    - Only 8.1% of the educators did not calculate savings of the use of passive systems in their class projects. This is considerably lower compared with practitioners (28.3%). Therefore, although educators rarely taught the "design" calculation of passive systems in their classes (e.g., thermal mass area/volume needed or cooling towers' design features), they had a better focus on teaching the passive systems saving calculations. However, most of the educators (86.5%) only calculate the savings of passive systems in the early design phase, which would not consider the integration of passive and active systems.

    - Some of the courses were not directly related to passive/natural systems, but they were important for the integration of passive systems with other design considerations including mechanical systems. However, the majority of these courses were rarely being taught at architecture schools. Courses focused on post-occupancy evaluation, such as commissioning, can considerably promote the students' learning to a professional level with the teaching of methods that use real measured performance of passive and active building systems and their integration. Therefore, there is a need for a stronger emphasis in architecture schools on courses related to passive systems as well as integrated courses with respect to passive systems, active systems, and design studios.

  - The low to zero percentage of the teaching of passive systems in the phases of "construction documents preparation," "hiring the contractor," "construction administration," and "project close-out" indicates that students will not learn about the required analysis and administration needed for the implementation of passive/natural systems or their related post occupancy evaluation.

- Additionally, the findings of the content analysis of the open-ended question in the educators' survey suggested that several areas in education need further work, which include:
  - Increasing the level of teaching to include simulation and, in some cases, design calculation and saving calculation for passive systems,
  - Incorporation of passive design course modules in design studios,
  - Assigning course modules to learning about passive systems,
  - Better understanding of the role of architects in practice and in relation to clients, and
  - Promoting an inclusive perception/definition of passive systems and its importance.

6.3. Recommendations

To integrate the findings of this mixed-method research, several strategies are recommended to increase the application of passive systems by practitioners and to promote its level of education in architecture schools.

1. Building codes and building rating systems need to provide specific incentives and credits for the incorporation of these systems in buildings. As it was reviewed in Section 2.4.1. building standards and rating systems in the US are considerably behind comparable global rating systems for the inclusion of passive systems in their codes or rating criteria. This inclusion of passive systems in codes/rating systems requires funding by US organizations for research to find opportunities for the promotion of the use of these systems, which can bring both financial and health benefits to the community.

2. Practitioners, particularly architects are eagerly looking for user-friendly tools to analyze the use of passive systems in their projects. Certainly, these tools need to be simple, but need to have strong simulation capabilities, to avoid time consuming simulations that are not usually paid for by the clients. In this case, the integration of such simulation tools with BIM platforms could be a strategy to consider, which also facilitates the path for the integration of passive systems with mechanical systems due the integrated design nature of BIM tools.

3. ASHRAE Standard 90.1-2016 and IECC 2018 both use performance-based analysis of new designs for buildings to meet the code/standard requirements. Such an analysis can be performed by a number of different simulation programs. ASHRAE developed Standard 140-2017 which specifies a standard test method for evaluating the capabilities of software tools used for calculating the performance of buildings and their HVAC systems. Currently, this standard does not cover test methods for evaluating the simulation of passive systems. Therefore, ASHRAE Standard 140 needs to be expanded to include the evaluation procedure of the tools used for analyzing the performance of passive systems as well.

4. Climate, although it is an important factor for passive design, should not become an excuse for avoiding the use of passive systems. As evidenced by case studies and the survey findings, climate does not play the key role of passive design. However, it can limit the choices, for example, in a hot humid climate versus a hot dry climate. Meanwhile, consideration of auxiliary systems in a passive design is a necessity. In this case, better collaborations between architects and engineers are required to avoid issues such as oversized/undersized active systems for auxiliary heating/cooling or passive design issues such as over-heated/under-heated buildings. Such issues show that there is a need for further investment on the promotion of integrated design in both practice and education.

5. As the survey results showed, in most cases the passive systems that are most frequently taught in architecture schools are also most frequently used by practitioners and vice versa. Therefore, this would imply that promoting the education of passive systems in architecture schools can also promote their use in practice. In this case, beyond conceptual education, the calculation and simulation of passive systems needs to be taught through both individual course modules and courses integrated with topics of active systems. Passive systems should also be taught as a part of integrated design studios. Teaching the calculation and simulation of passive systems to architecture students needs to be through simple methods to be easily understood. Therefore, the teaching approaches used should avoid asking architecture students to calculate the complicated equations of these systems, which can be better conducted by engineers. In this case, simple tools such as SLR methods (explained as LCR in Section 2.3) or the PHPP can make considerable contributions if they become available to architecture students similar to Autodesk tools.

6. The calculation of the savings from passive systems is important, since it can show the clients a way of justifying the additional one-time cost of the incorporation of a passive system. Almost one-third of the professionals surveyed never calculated the savings from passive systems, and in architecture schools for more than eighty percent of the educators this calculation is limited to the schematic phase of a class project (also about eighty percent of the professionals

conduct this calculation in the schematic design phase). Therefore, to improve this situation, there can be incentives or requirements in building codes and rating systems to ask exclusively for the calculation of such energy savings from passive systems.

7. Based on the survey results, the majority of educators practiced architecture before or are still practicing in architecture and engineering firms. Therefore, educators need to bring more of their professional work experience in passive design to their classroom environments to reinforce the link between education and practice, which might also include the role of building codes and building rating systems in passive design.

8. The survey results showed that educators holding PhD degrees were ranked third compared with educators holding other level of degrees (i.e., Bachelors and Maters). Therefore, there is also a potential to increase the number of educators in higher education who both have PhD degrees in the field of building/environmental technologies and have practiced in the field of passive/natural systems. Such a recruitment can also open new opportunities for research on updating the old literature and software used to analyze passive systems.

9. In recruiting new faculty members in architecture schools, it should be kept in mind that based on the survey results a wide age/experience gap currently exist between new faculty members and retiring faculty in the field of sustainable design. Therefore, a proper conduit of transferring the knowledge of passive design from retiring faculty to the new faculty should be considered in architecture schools to reinforce the concept of institutional memory.

10. In the case of advanced building envelope systems, there is a need to better connect academic institutions with the building industry. Almost eighty percent of the practitioners are not using any of the advanced building envelope systems (i.e. kinetic facades, double skin facades, and PCMs). It seems that architecture schools currently have a great passion for including such topics in their design studios and digital design tools are becoming more user-friendly for the inclusion of such themes in architectural projects. However, without a connection to the building industry to receive support or to inform its general design trends advanced building envelope systems may take a long time to become popular in practice.

11. In the case of renewable systems, there are factors other than education and practice which more strongly can influence the use of these systems. For example, PV systems are being used on a larger utility scale compared with other types of renewable systems, not only because of the variety of available open

source tools to study their implementation, but also because of their lower cost and easier implementation/maintenance. However, it should be kept in mind that PV systems several years ago were offered at a much higher prices compared to their price today.[45] Therefore, there is the same opportunity for other renewable systems if they can be installed at a lower price and their maintenance be kept at a reasonable level (e.g. wind turbines). One way to promote renewable systems, which are not currently designed, is to provide the required calculation and simulation tools in architecture schools. Therefore, students will become familiar with their application, which should accelerate the inclusion of such systems in practice, thereby reducing their cost in long term.

Overall, the followings are recommended as the major strategies to map a better future for the use of passive systems in buildings in the US.

- better educational focus on the calculation and simulation of passive systems;
- stronger connection between the academic and the building industry with a focus on passive design;
- providing user-friendly tools for the design of passive systems;
- better collaboration between architects, clients, and engineers;

---

[45] For example, the cost of silicon PV cells from $76.67 per watt in 1977 reduced to $0.36 per watt in 2014. For further information please see https://avc.com/2015/07/the-bull-case-for-solar/, accessed January 2019.

- reducing the work experience/ age gap between retiring faulty and new faculty by reinforcing the institutional memory;
- better focus on passive design in integrated design studios; and
- strong inclusion of passive systems in building codes/rating systems

6.4. Discussion of the Research Limitations

Similar to all research studies, this study had some limitations. This study was focused on the US, and therefore, the findings cannot be immediately generalized beyond the US boundaries. Despite the researcher's consistent efforts, some of the AIA and ASHRAE chapters in the US preferred not to participate in the survey. However, the number of the states with no AIA or ASHRAE chapter representatives in the survey were less than 5 and the lack of response in certain regions was compensated by the responses of the participants who were registered architects and/or engineers in these regions. Therefore, at least a minimum sample of the respondents was provided for these regions.

Furthermore, the increase of the number of survey responses (educators' number=36, practitioners' number=138) could provide a more accurate perception of the practice and education of passive/natural systems. The same can be said in the case of content analysis of the limited number of responses to the last text question in the two survey questionnaires (i.e. the last text question in the survey for educators and in the survey for practitioners had 11 responses out of 37 participants for educators and 25 responses out of 138 participants for practitioners). In the case of having more participants answering this open-ended text question, the result of the content analysis could be more accurate. Having the required budget and time for conducting face-to-face interviews could also add to the findings of the three research methodologies already applied (i.e. case study, survey questionnaire, and content analysis).

Additionally, this research had a focus on passive systems in the original definition of legacy passive systems, in which building envelope features such as insulation R-value, air-tightness, and free thermal-bridge envelopes were not necessarily considered as passive design. Therefore, the findings of the current research do not address the use of these systems and their current level of practice. A separate study is needed to focus on these aspects of building envelope design.

Confounding variables imposed some limitations on the findings of the research. Examples include the size and scale of the participants' projects in addition to their projects' typologies. While some of these confounding variables such as the extent of the education, professional background, and affiliation of the respondents were controlled through the survey questions, controlling all of these variables in some cases was outside the control of the researcher. However, measures can be adopted to reduce these variables impact on the findings. One example, was the tool that participants would use to answer the survey questions. In this case, the survey questionnaire and its display on both small and large screens of digital devices such as smartphones and desktop computer was evaluated. This evaluation resulted in redesigning the tabular format questions and the appearance of the answer choices to the participants for better display and readability on smartphone screens.

The case study of the AIA COTE TOP Ten Award buildings also had some limitations for accessibility to the resources related to buildings’ performance measurements both before and after their construction. In this case, in addition to the available database of the AIA Awards, other online sources such as the design firms’ websites and library resources were also investigated. This investigation could unfold qualitative and quantitative building performance data such as energy production through renewable energy systems or daylighting design features. Meanwhile, a review of green buildings other than those awarded by AIA could better reflect the best practices of passive design in the US.

Some of the research limitations come from the number of the questions in the survey questionnaires. To increase the response rate, the survey questionnaire was kept brief and short, which did not allow the inclusion of many detailed questions in the questionnaire. Even in this case, the survey went beyond the usually accepted range of ten questions and reached 26 and 22 questions for educators and practitioners respectively. One example is the question about the practitioners’ types of projects and their percentage in each category in the last ten years (e.g. educational, office, residential, etc.). Certainly, the inclusion of more detailed questions about the square footage of each project category, the level of involvement, and the distribution of the type of projects within a ten-year span of time would better help the analysis of the final results.

Lastly, in this research the survey questionnaire asked respondents about the use of passive design strategies without considering the suitability of these strategies for different climates. For example, a respondent who usually practices in a cold and dry climate and a respondent who practices in a hot and humid climate both were asked the same questions about the types of passive strategies they have applied. It should be kept in mind that almost all of the passive systems from cooling to heating in most of the US climates are applicable, since most of these systems can have a double function. For example, a trombe wall can heat a building in winter and, if provided with a vent on the top, in summer can also cool a building with a function similar to the function of a solar chimney. However, it is either the heating function or the cooling function of a passive system that defines its main purpose depending on the length of the cold or hot season (i.e. heating degree days or cooling degree days). Therefore, in the future instead of one survey for the whole US, several surveys can each focus individually on a selected number of similar climates in the US to gain a better perception of the frequently used passive systems appropriate in each set of similar climates.

6.5. Path for the Future Research

The limitations of the current study and the findings of this study provides a path for a future research to conduct a more comprehensive study by addressing these limitations.

Therefore, future research should focus on several areas to expand the findings of this study. These research areas include:

- A survey that covers non-legacy passive design measures and practitioners' approaches for their application
- Interviews with experts of passive design to find out more about the practitioners' approaches in their application and the areas in need of more work
- The role of building codes, building rating systems, and building institutions that define the meaning of passive design and its application
- Developing simulation and modeling tools that are simple and user-friendly for passive designers, particularly architects, or incorporating such features into existing tools
- Exploring methods for incorporating the education of passive design in architecture school course curriculums particularly with a focus on passive design simulation and calculation
- Exploring the level of architectural education with a focus on passive design in integrated design studios
- Exploring new approaches for promoting collaboration between project team members including architects, engineers, and clients, with a focus on passive design
- Incorporating new design methods and technologies such as nature-inspired architecture into the existing legacy passive design systems

- Developing better methods for distributing the knowledge of passive design or its implementation among designers and clients as well as educators

6.6. Conclusion

This study showed that a majority of legacy passive heating/cooling systems are not used by practitioners in the US, although they are still taught by educators in architecture schools. Therefore, there is a potential for better research collaborations between the academia and the building industry to fill this gap. Even within the academia the teaching of passive systems at the simulation and calculation levels needs to be improved. Developing user-friendly design tools with passive simulation/calculation capabilities and updating the legacy passive systems with today technologies can facilitate this process.

Building codes and building rating systems can play a key role in promoting the use of passive/natural systems by directing the interests of practitioners and clients in the building industry for the inclusion of passive systems in their projects. Educating clients and designers about these systems for better collaborations can accelerate the impact of these potential building codes and rating systems on passive design. Otherwise, much of the valuable information about the legacy passive systems, which can significantly contribute to energy saving and human well-being, will remain unutilized. Therefore, further investment and research in the area of passive design is needed in order to fully realize these potential contributions. The research areas proposed in Section 6.5 outlined this path of investment for future research about passive/natural systems.

REFERENCES

Abel, C. (2004). *Architecture, technology and process*. Oxford: Architectural Press c/o Elsevier.

Abou-Houly, H. (2010). *Investigation of flow through and around the Macrotermes michaelseni termite mound skin*, Loughborough University Institutional Repository. Retrieved April 24, 2016, from https://dspace.lboro.ac.uk/dspace-jspui/handle/2134/8466

Aeleneia, D., Aeleneic, L., Catarina, P. V. (2016). Adaptive façade: concept, applications, research questions, International Conference on Solar Heating and Cooling for Buildings and Industry, *Energy Procedia* 91: 269-275.

AIA (2012). *An architect's guide to integrating energy modeling in the design process.* Retrieved January 2018 from *http://aiad8.prod.acquia-sites.com/sites/default/files/2016-04/Energy-Modeling-Design-Process-Guide.pdf*

AIA (2017). *The habits of high-performance firm*s. Retrieved from https://www.aia.org/resources/72031-thehabits-of-high-performance-firms

AIA (2018), AIA Committee on the Environment (COTE) Top Ten Toolkit accessed July 2018 from https://network.aia.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=3b309447-1472-66d9-f689-283d66865779

Alexander, C. M. (2009), Early Modern Architecture in Lincoln, Massachusetts, Retrieved February 9, 2019, from https://www.oldhouseonline.com/web-exclusives/early-modern-architecture-in-lincoln-massachusetts

Allyn and Bacon Crawley, D. B., et al. 2008. Contrasting the capabilities of building energy performance simulation programs. *Building and Environment*, 43(4), 661-673.

Alzubaidi, S., Roaf, B., Talib, R., Al-Ansari, A. (2013). *Survey of Hospitals Lighting: Daylight and Staff Preferences*. 10.5923/j.ijee.20130306.02.

Anagnostopoulos, G. (2009) *A companion to Aristotle*, Hoboken: Wiley-Blackwell.

Anderson, B. (1990). *Solar Building Architecture*, edited by Bruce Anderson. Cambridge, Mass.: MIT Press

Anderson, K. (2014) *Design Energy Simulation for Architects: Guide to 3D Graphics*, New York: Routledge.

Antretter, F, Klingenberg, K, and Pazold M. (2013), ASHRAE Conference Proceedings 2013, Retrieved March 2018 from https://www.techstreet.com/ashrae/standards/all-in-one-design-tool-solution-for-passive-houses-and-buildings-monthly-energy-balance-and-hygrothermal-simulation?gateway_code=ashrae&product_id=1868089#product

ArchDaily (2013). *CH2 Melbourne city council house 2.* Design Inc., Retrieved June 20, 2017, from http://www.archdaily.com/395131/ch2-melbourne-city-council-house-2-designinc

ArchDaily (2017). *five passive cooling alternatives using robotics and smart materials*. Retrieved September 15, 2017 from http://www.archdaily.com/877693/iaac-developsfive-passive-coolingalternatives-using-robotics-and-smart materials?utm_medium=email&utm_source=ArchDaily%20List

ArchDaily, (2011). *Interview: Michael Pawlyn on Biomimicry.* (2011, November 17). Retrieved April 25, 2016, from http://www.archdaily.com/185128/interview-michael-pawlyn-on-biomimicry

Architect 50 (2017) Retrieved April 25, 2017, from https://www.architectmagazine.com/practice/architect-50/2017-architect-50-top-50-firms-in-sustainability_o

Architectural Record (2017). Retrieved June 20, 2017, from http://www.architecturalrecord.com/Top300/2017-Top-300-Architecture-Firms-1

Architecture Challenge 2030 (2015). Retrieved February 2017 from http://architecture2030.org/2030_challenges/2030-challenge/

ASHRAE (1989). *ASHRAE Standard 90.1-1989*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers. Atlanta, Georgia.

ASHRAE (2010). *ASHRAE green guide: The design, construction, and operation of sustainable buildings*, J.M. Swift and T. Lawrence (eds.).

ASHRAE (2013) *2013 ASHRAE Handbook of Fundamentals. SI edition*. (2013). Atlanta, GA: ASHRAE.

ASHRAE 189 (2014). *ANSI/ASHRAE/IES Standard 189-2014: Standard for the design of high performance buildings,* ASHRAE.

ASHRAE 189 (2014). *ANSI/ASHRAE/IES Standard 189-2014: Standard for the design of high performance buildings,* ASHRAE.

ASHRAE 90.1 (2013). *ANSI/ASHRAE/IES Standard 90.1-2013: Energy standard for buildings except low-rise residential buildings*, ASHRAE.

ASHRAE 90.1 (2016). *ANSI/ASHRAE/IES Standard 90.1-2016: Energy standard for buildings except low-rise residential buildings*, ASHRAE.

ASHRAE Handbook of Fundamentals (2013), ASHRAE, Atlanta, Georgia U.S.A.

ASHRAE Standard 140. (2007) *Standard method of test for the evaluation of building energy analysis computer programs*. ASHRAE.

ASME AG-1a–2004, American Society of Mechanical Engineers, ASME AG-1a–2004, Addenda to ASME AG-1–2003 Code on Nuclear Air and Gas Treatment, 2004

Athienitis, A. and O'Brien, W. (2015) *Modeling, Design, and Optimization of Net-Zero Energy Buildings*, Wilhelm Ernst & Sohn Verlag fur Architektur und Technische.

Athienitis, A. K. and Santamouris, M. (2013) *Thermal Analysis and Design of Passive Solar Buildings*, Routledge/earthscan.

Athienitis, A. Torcellini, P, Hirsch, A., O'Brien, W., Cellura, M., Klein, R., Delisle, V., Attia, S., Bourdoukan, P., Carlucci, S. (2010). *Design, Optimization, and Modelling Issues of Net-Zero Energy Solar Buildings*. 1-8.

Atkins (2017) *Passive & Active Design of CIBSE Building Simulations Group*. Retrieved September 17, 2017 from http://www.cibse.org/getmedia/22be4d3b-2b5f-410d-bda4-79ce098baf66/Peter-Brown-(Atkins)-Passive-and-Active-Design(1).pdf.aspx

Attia, S., Beltrán, L., De Herde, A., and Hensen, J. (2009) Architect Friendly: A comparison of ten different building performance simulation tools. *11th International IBPSA Conference*, Glasgow, Scotland.

Attia, S., Hensen, J., Beltrán, L. & DeHerde, A. (2012) Selection criteria for building performance simulation tools: contrasting architects' and engineers' needs, *Journal of Building Performance Simulation*, 5:3, 155-169, doi: 10.1080/19401493.2010.549573

Badarnah, L. and Kadri, U. (2015) A methodology for the generation of biomimetic design concepts, *Architectural Science Review*, 58(2), 120-133. doi:10.1080/00038628.2014.922458

Badarnah, L. and Knaack, U. (2008). Shading/energy generating skin inspired from natural systems. Proceedings of the 2008 World Sustainable Building Conference: SB08, eds. G. Floiente and P. Paevere, pp. 305-312.

Badarnah, L., Kadri, U., and Knaack, U. (2008) A bio-inspired ventilating envelope optimized by airflow simulations. *Proceedings of the World Sustainable Building Conference*: SB08, eds. G. Floiente and P. Paevere, pp. 230-237.

Badarnah, L., Nachman, F. Y., and Knaack, U. (2010) Solutions from nature for building envelope thermoregulation Proc. of the fifth Design & Nature Conference: Comparing Design and Nature with Science and Engineering Carpi, A. and Brebbia, C.A. (eds) Southampton: WIT Press.

Bailes, A. A. (2014). The Principles, uses, and limitations of WUFI. Retrieved August 10, 2017, from http://www.greenbuildingadvisor.com/blogs/dept/building-science/principles-uses-and-limitations-wufi

Balcomb (1987): Solar Energy Research Institute, SERIIRR-254-3059 UC Categories: 59, 59a, 59c DE87001136 Passive Solar in the United States: 1976-1986 J. Douglas Balcomb Los Alamos National Laboratory, January 1987 Prepared under Task No.

3050.10 FTP No. 623 Solar Energy Research Institute A Division of Midwest Research Institute. Retrieved May 2018 from https://www.nrel.gov/docs/legosti/old/3059.pdf

Balcomb, J. D. (1992). *Passive solar buildings*, edited by J. Douglas Balcomb. Cambridge, Mass.: MIT Press.

Balcomb, J. D., Barley, D., McFarland, R. J., Perry, Jr., and Wray, W. (1980). *Passive Solar Design Handbook, Vol.2, Passive Solar Design Analysis*. U.S. Department of Energy. Washington, DC.

Balcomb, J. D., Jones R., McFarland, R., and Wray., W. (1984). *Passive Solar Heating Analysis.* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.

Barbosa and Ip, (2014). Barbosa S, Ip K. Perspectives of double skin façades for naturally ventilated buildings: a review. Renew Sustain Energy Rev 2014; 40:1019–29.

Barbosa, R., Loomans, M.G.L.C., Hensen, J.L.M. and Barták, M. (2015) The impact of increased airflow rates on indoor temperatures of passive house in the Netherlands, *Healthy Buildings Europe Conference Proceedings* May 2015

Baumeister, D. (2012). *Biomimicry Resource Handbook: A Seed Bank of Knowledge and Best Practices*. Missoula: Biomimicry 3.8.

BDC (2015). *Building Design + Construction: 10 megatrends shaping the future of green building*. Retrieved February 2017 from https://www.bdcnetwork.com/10-megatrends-shaping-future-green-building

Beauchemin, K.M., & Hays, P. (1996). Sunny hospital rooms expedite recovery from severe and refractory depression. *Journal of Affective Disorders (40):* pp. 49-51.

Bejan, A. (1997). *Advanced engineering thermodynamics* (2nd ed.), New York: Wiley.

Bejan, A. (2016) Life and evolution as physics, *Communicative & Integrative Biology,* 9:3, e1172159, doi: 10.1080/19420889.2016.1172159

Bejan, A. and Lorente, S. (2008) *Design with constructal theory,* Hoboken: Wiley.

Beltrán, L., Lee, E., Papamichael K., Selkowitz, S. (1994). The design and evaluation of three advanced daylighting systems: light shelves, light pipes, and skylights. *Proceedings of the Solar 94*, 19th National Passive Solar Conference, San Jose, California, pp. 229-234 (June).

Benyus, J. (2002) *Biomimicry: innovation inspired by nature*, Morrow, New York.

Bessoudo, M. (2017) *Health, wellness, and experience in the built environment: from green buildings to Conscious Cities*. Retrieved October, 2018 from https://www.ccities.org/health-wellness-experience-built-environment-green-buildings-conscious-cities/

Bhushan B. (2009). Review Biomimetics: lessons from nature--an overview, *Philosophical Transactions of Royal Society a Mathematical Physical Engineering Sciences.* 367(1893):1445-86.

Biomimicry 3.8. (2010). Retrieved September 2016 from http://biomimicry.net/

Bliss, R. W. (1959). The derivations of several plate efficiency factors useful in the design of flat plate solar heat collectors, Solar energy 3, 55-63

Bogatyreva, O., Pahl, A.K., Bowyer, A., and Vincent J. F. V. (2003). Data gathering for putting biology in TRIZ. Proceedings of TRIZcon 2003, Altshuller Institute, USA, 16–18 March.

BOMA (2006). Retrieved June 20, 2017, from http://www.mlgw.com/images/content/files/pdf/greenstarts.pdf

Boyce, R. (1993). Keck & Keck: The Poetics of Comfort. Princeton, NJ: Princeton Architectural Press.

Bradshaw, V. (2006) *The Building Environment Active and Passive Control Systems.* 3rd edition. New York: McGraw-Hill.

Bradshaw, V. (2006). *The building environment: active and passive control systems*. 3rd ed. Hoboken, N.J.: Wiley

Braham, W. (2005) Biotechniques: Remarks on the intensity of conditioning in *Performative Architecture: Beyond instrumentality*. New York: Spon Press.

BREAM (2018). *Building research establishment environmental assessment methodology*. Retrieved January 2018 from https://www.breeam.com

Brinkworth, B.J., Cross, B. M., Marshall, R. H., Yang, H. (1997). Thermal regulation of photovoltaic cladding. *Solar Energy* 1997;61(3):169–78.

Brooks W.A. (1918). The open air treatment of influenza*. American Journal of Public Health (8*): pp. 746-750.

Brown, L. (2009). *Future at risk on a hotter planet*, New York: W.W. Norton & Company.

Buchbinder, L. (1942). The bactericidal effects of daylight and sunlight on chained Grampositive cocci in simulated room environment: theoretical and practical considerations. In Moulton FR (Ed). Washington, DC: *American Association for the Advancement of Science, Smithsonian Institute*. pp. 267-270.

Bullough. D., Rea, M. S., Figueriro, M. G. (2006). Of mice and women: light as a circadian stimulus in breast cancer research. *Cancer Causes and Control 17(4):* pp. 375-383.

Busby Perkins+Will and Stantec Consulting (2007), Roadmap for The Integrated Design Process, BC Green Building Roundtable.

Kutscher, C.F. (1994). Heat Exchange Effectiveness and Pressure Drop for Air Flow Through Perforated Plates with and without Crosswind", *Journal of Heat Transfer*, vol. 116, pp. 391-399.

Caperna A., Serafini S. (2015). Biourbanism as new epistemological perspective between Science, Design and Nature. *Architecture & Sustainability: Critical Perspectives,* Belgium: KU Leuven, Faculty of Engineering.

Carpi, A., and Brebbia, C. A. (eds.) (2010) *Design and nature: comparing design in nature with science and engineering, Volume V* (pp. 251-262). Southampton: WIT.

CASBEE (2018). *Comprehensive Assessment System for Built Environment Efficiency.* Retrieved January 2018 from http://www.ibec.or.jp/CASBEE/english

CASEY, A. (2016) Retrieved February 2017 from https://www.energy.gov/energysaver/articles/how-much-can-you-really-save-energy-efficient-improvements

CBECS (2012). Retrieved June 20, 2017, from https://www.eia.gov/consumption/commercial/data/2012/

CBECS (2012a). https://www.eia.gov/todayinenergy/detail.php?id=31272

CEF (2018) Conserve Energy for Future, https://www.conserve-energy-future.com/difference-between-active-and-passive-solar-systems.php

CH2 (2017). CH2 design snapshot 11. Retrieved June 20, 2017, from https://www.melbourne.vic.gov.au/SiteCollectionDocuments/ch2-snapshot-11-biomimicry.pdf

Challenge 2030 Solution (2015). Retrieved February 2017 from http://architecture2030.org/buildings_problem_why/the-solution/

Chan, H. Y., Riffat, S. B., Zhu, J. (2010) Review of passive solar heating and cooling technologies, *Renewable and Sustainable Energy Reviews* 14, 781–789.

Chen, X., Yang, H., Lu, L. (2015). A comprehensive review on passive design approaches in green building rating tools, *Renewable and Sustainable Energy Reviews* 50: p1425–p1436.

Choi, J., Beltran, L. O., & Kim, H. (2012). Impacts of indoor daylight environments on patient average length of stay (ALOS) in a healthcare facility. *Building and Environment*, *50*, 6575. doi: 10.1016/j.buildenv.2011.10.010.

Chungloo, S., and Limmeechokchai, B. (2007). Application of passive cooling systems in the hot and humid climate: the case study of solar chimney and wetted roof in Thailand. *Building and Environment;* 42: 3341–3351.

Cohen, P. S., & Naginski, E. (2014). *The return of nature: sustaining architecture in the face of sustainability*. London: Routledge.

Collins, M. W., Atherton, M. A., & Bryant, J. A. (2005). *Nature and design*. Southampton; Boston: WIT.

Collins, P. (1959) The biological analogy, in W.W. Braham, J.S. Sadar and J. Hale, (eds.) (2007) *Rethinking technology: a reader in architectural theory, Routledge,* New York, 129-137.

Columbia University (2018). Content Analysis. Retrieved February 10, 2018, from https://www.mailman.columbia.edu/research/population-health-methods/content-analysis

CoM (2004). City of Melbourne website Retrieved June 20, 2016, from http://www.melbourne.vic.gov.au/info.cfm?top=171&pa=1943&pg=1934

Cook, J. (1984). *Award-Winning Passive Solar House Designs*, Garden Way Pub Co.

Cook, P., and Archigram (Group). (1999). *Archigram*. New York: Princeton Architectural Press.

Da Silva, F. J. (2015). Process simulation and optimization Technical articles, Process Ecology. Retrieved February, 2019, from http://processecology.com/articles/dynamic-process-simulation-when-do-we-really-need-it

DBSG (2017) *Sustainable Building Design Trends.* Retrieved January 2017 from http://www.dbsg.com/blog/sustainable-building-design-top-trends

Denzer, A. (2013) *The Solar House: Pioneering Sustainable Design.* New York: Rizzoli.

Design Intelligence (2017). Retrieved June 20, 2017, from http://www.di.net/almanac/stats/firm-statisticsarchitecture/

Dillman, D. A., Smyth, J. D., and Christian, L. M. (2014). *Internet, phone, mail, and mixed-mode surveys: the tailored design method.* Fourth edition. Hoboken, New Jersey: Wiley.

DODGE Data and Analytics (2016). World Green Building Trends report Retrieved February 2017 from http://fidic.org/sites/default/files/World%20Green%20Building%20Trends%202016%20SmartMarket%20Report%20FINAL.pdf

Dodge, D. (2014). *The Power of Passive Solar and Thermal Mass*. Retrieved February 9, 2019, from https://www.huffingtonpost.ca/david-dodge/passive-solar-heat_b_4809638.html

DOE (2017). *List of approved software for calculating the energy efficient home credit.* Retrieved September 2017 from https://energy.gov/eere/buildings/list-approved-software-calculating-energyefficient-home-credit

DOE (2017). List of approved software for calculating the energy efficient home credit. Retrieved September 2017 from https://energy.gov/eere/buildings/list-approved-software-calculating-energy-efficient-home-credit

DOH (2018). *Questions and Answers about Tuberculosis (TB)*, Department of Health, County of Albany, NY. Retrieved February 2019 from https://www.albanyschools.org/district/Programs/HealthServices/Docs/TB%20Q-A%202-08.pdf

Doucleff, M. (2013) *Medicines to Fight White Plague Are Losing Their Punch*, Health News From NPR. Retrieved Feb 2019 from https://www.npr.org/sections/health-shots/2013/06/05/188906912/tuberculosis-white-plague-doctors-modern-medicine

Duffie, J., Beckman, W., 2006. Solar Engineering of Thermal Processes. John Wiley and Sons, Inc.

Edwards, B., and Naboni, E. (2013). *Green buildings pay: design, productivity and ecology.* Third Edition. London; New York: Routledge.

EIA (2018). US Energy Information Administration Annual Energy Outlook 2018. Retrieved April 2018 from https://www.eia.gov/outlooks/aeo/pdf/AEO2018.pdf

ENR (2017). Retrieved June 20, 2017, from http://www.enr.com/toplists/2017-Top-500-Design-Firms1

EPA, 2005. Program needs from indoor environments research (PNIER). US EPA 420-B05-00. Retrieved February, 2018, from www.epa.gov/iaq/pdfs/pnier.pdf

Evans, M. (2018) 10 Steps to Design Climate-Responsive Architecture, Retrieved January 2019 from Sustainable Business from https://www.thebalancesmb.com/designing-climate-responsive-architecture-3157812

Ewing, R. A. (2006). *Power with nature: alternative energy solutions for homeowners.* Masonville, CO: PixyJack Press.

Ewing, R. A. (2006). *Power with nature: alternative energy solutions for homeowners.* Masonville, CO: PixyJack Press.

Federal Research and Development Agenda for net-zero energy high performance buildings. (2008), Retrieved January 2018 from https://www.wbdg.org/files/pdfs/fedird_netzero_energy_hp_green_buildings.pdf

Feenberg, A. and Hannay, A. (1995). *Technology and the politics of knowledge*. Bloomington: Indiana University Press.

Feist, W. (1992) Passivhäuser in Mitteleuropa. Dissertation, University of Kassel.

Feist, W., et.al. (2007). *PHPP Handbook*. Darmstadt, Germany: Passivhaus Institute.

Fernandeź-Galiano, L. (2000) *Fire and memory: on architecture and energy*, MIT Press, Cambridge.

Fislisbach P.G., and Zollikon, D.A. (1993) *Climate Responsive Building-Appropriate Building Construction in Tropical and Subtropical Regions.* SKAT: Swiss Centre for Development Cooperation in Technology and Management.

Franssen, M. (2009). Philosophy of Technology. Retrieved November 2014 from http://plato.stanford.edu/entries/technology/

Frostburg State University RMSC (2008). Retrieved January 2019 from https://www.frostburg.edu/fsu/assets/File/clife/mscenter/FinalPapers/2008/Heat.pdf

Gallowa, T. (2004). *Solar House: A Guide for the Solar Designer, Elsevier; Architectural Press.*

Galvin, R. (2014). Are passive houses economically viable? A reality-based, subjectivist approach to costbenefit analyses. *Energy & Buildings*, *80*149-157. doi: 10.1016/j.enbuild.2014.05.025

Gan, G. (1998). A parametric study of Trombe' walls for passive cooling of buildings. Energy and Building 27 (1998) 37-43.

Gardner J. (1996). Centers for disease control: guideline for isolation precautions in hospitals. *American Journal of Infection Control* 24:2–52.

GBIG (2018). *Green Building Labeling-Assessment Standard for Green Building.* Retrieved January 2018 from http://www.gbig.org/collections/14970

Gebeshuber, I. C., and Drack, M. (2008). An attempt to reveal synergies between biology and mechanical engineering. Proceedings of the IMECHE, Part C: *Journal of Mechanical Engineering Science* 222 (7): 1281–1287.

Givoni, B. (1994). Passive Low Energy Cooling of Buildings, John Wiley & Sons, 1994

Gonzalo, R., and Habermann, K. J. (2006). *Energy-efficient architecture: basics for planning and construction*. Basel; Boston: Birkhäuser-Publishers for Architecture.

Goudarzi, K., Asadi-Yousefabad, S. K., Shojaeizadeh, E., Hajipour, A. (2014). Experimental Investigation of Thermal Performance in an Advanced Solar Collector with Spiral Tube. *IJE Transactions* A: Basics Vol. 27, No. 7, 1149-1154.

Gralton, J., Tovey, E., McLaws, M.L., and Rawlinson, W.D. (2011). The role of particle size in aerosolized pathogen transmission: a review. *J Infect* 62:1-13.

Grange, L. (2016) *Impact of Office Daylighting & Fresh Air On Employee Productivity*. Retrieved October, 2018 from https://hammerandhand.com/field-notes/impact-of-office-daylighting-on-employee-productivity

Grondzik, W. T., and Kwok, A. G. (2015). *Mechanical and Electrical Equipment for Buildings*. 12th edition. Hoboken, New Jersey: John Wiley & Sons, Inc. eBook.

H.R.16276 — 93rd Congress (1973-1974) H.R.16276 - Solar Energy Research, Development and Demonstration Act. Retrieved February 2018 from https://www.congress.gov/bill/93rd-congress/house-bill/16276

Haight, F.A. (1967). *Handbook of the Poisson Distribution*. New York: John Wiley & Sons.

Hastings, R. (1999). *Passive solar commercial and institutional buildings: a sourcebook of examples and design insights. International Energy Agency,* S.R. Hastings (ed). Chichester; New York: Wiley.

Hawken, P., Lovins, A., Lovins, H. (1999). Natural Capitalism Boston, MA: Little, Brown, and Company

Hayter, S. J. and Torcellini, P. A. (2001). *The energy design process for designing and constructing high-performance buildings*. CLIMA 2000. Naples, Italy.

Hemsath, T., and AlagheBandhosseini, K. (2018). *Energy modeling in architectural design*. New York: Routledge.

Hirunlabh, J., Kongduang, W., Namprakai, P., Khedari, J. (1999). Study of natural ventilation of houses by a metallic solar wall under tropical climate, *Renewable Energy*; 18:109–19.

HKGBC (2018). Hong Kong Green Building Council (HKGBC). Retrieved January 2018 from https://www.hkgbc.org.hk/eng/

HKS (2013). *Convention Center in Xiamen, China*. Retrieved September 2015 from http://www.hksinc.com/insight/concept-of-balance-captures-aia-dallas-unbuilt-design-award/

Hobday, R., and Dancer, S. (2013). Roles of sunlight and natural ventilation for controlling infection: historical and current perspectives. *Journal of Hospital Infection, 84*(4), 271-282. doi: 10.1016/j.jhin.2013.04.011

Hordeski, M. F. (2011). *New technologies for energy efficiency*. New York. The Fairmont Press.

Hottel, H. C., and Willier, A. (1958). Evaluation of flat plate collector performance. Trans. of the conference on the use of solar energy, University of Arizona Press, 2, 1-74.

Hui, S. C. M. (1997) Overall thermal transfer value (OTTV): how to improve its control in Hong Kong, In Proc. of the One-day Symposium on Building, Energy and Environment, Hong Kong, pp. 12-1 to 1211.

Hyde, R. (2000). *Climate responsive design: a study of buildings in moderate and hot humid climates. Richard Hyde*. London; New York: E & FN Spon.

IBPSA Tools Directory (2017). Retrieved September 5 2017 from https://www.ibpsa.us/building-energysoftware-tools-best-directory

IBPSA Tools Directory (2017). Retrieved September 5 2017 from https://www.ibpsa.us/buildingenergy-software-tools-best-directory

Iddon, C. (2017). *Florence Nightingale: nurse and building engineer. CIBSE Journal.* Available Retrieved 2017 from https://www.cibsejournal.com/general/florence-nightingale-nurse-andbuilding-engineer

IECC (2012). *International Energy Conservation Code.* Washington, DC: International Code Council.

IECC (2018). *International Energy Conservation Code.* Washington, DC: International Code Council.

Jie, J., Hua, Y., Wei, H., Gang, P., Jianping, L., Bin, J. (2007). Modeling of a novel Trombe' wall with PV cells. *Building and Environment* 42 (2007) 1544–1552

Johnson, T. (1981). *Solar Architecture: The Direct Gain Approach*.

Kaplinsky, J. (2006). Biomimicry versus humanism. *Architectural Design, 76*(1), 66-71. doi:10.1002/ad.212

Kelland, P. (1992). Sick building syndrome, working environments and hospital staff. *Indoor Environment 1:335*-340.

Kellert, S. R., (2008). Dimensions, elements, and attributes of biophilic design. In J.H. Heerwagen, S. Kellert, & M. L. Mador (Ed.), *Biophilic design: the theory, science, and practice of bringing buildings to life*. (pp. 3-19). Hoboken, NJ: Wiley.

Kellert, S. R., Heerwagen, J. H., & Mador, M. L. (2011). *Biophilic design: the theory, science, and practice of bringing buildings to life*. Hoboken, NJ: Wiley.

Kiesler, F. (1939) On correalism and biotechnique: a definition and test of a new approach to building design, *The Architectural Record*, September, 60-75.

Klingenberg, K., Kernagis, M., and James, M. (2009). *Homes for a changing climate: passive houses in the U.S.* Chelsea Green Pub Co.

Koo, D. (2017). 5 Common Types of Air Purifiers. Retrieved May 2018, from https://learn.allergyandair.com/types-of-air-purifiers

Kubota, T., Hooi, C. and Toe, D. (2015) Application of passive cooling techniques in vernacular houses to modern urban houses: A case study of Malaysia. International

Conference Green Architecture for Sustainable Living and Environment, 29 November 2014, Social and Behavioural Sciences 179, 29–39

LBNL (1994). Lawrence Berkeley National Laboratory and Hirsch & Associates. *DOE-2 version 2.1e*. Lawrence Berkeley National Laboratory. Berkeley, California, U.S.A.

Lechner, N. (2009). *Heating, cooling, lighting: sustainable design methods for architects*. 3rd edition. Hoboken, New Jersey: Wiley.

Lechner, N. (2015). *Heating, Cooling, Lighting: Design Methods for Architects*. 2nd edition. New York: John Wiley & Sons, Inc. eBook Collection (EBSCOhost)

LEED BD+C (2017). LEED v4 for building design and construction, USGBC.

Leedy, P. D., & Ormrod, J. E. (2013). *Practical research: planning and design*. Boston: Pearson.

Lengsfeld, K., and Holm, A. (2007) Entwicklung und Validierungeiner hygrothermischen *Raumklima*-Simulationssoftware WUFI®-Plus. *Bauphysik* 29, Magazin 3.

Levy, B. (2016). *Sunrise on Vassar Street: the birth of the MIT solar research program*. Retrieved March 2018, from https://scopeweb.mit.edu/sunrise-on-vassar-street-the-birth-of-the-mit-solar-research-program-8d603e21e73b

Lewis, R. K. (1998). Architect-client collaboration is the foundation of great design. *The Washington Post.* Retrieved January 2018 from Nexis Uni.

Li, A., Jones, P., Zhao, P., and Wang, L. Heat transfer and natural ventilation airflow rates from single-sided heated solar chimney for buildings. *Journal of Asian Architecture and Building Engineering* 2004; 3:233–8.

Linstone, H. A., and Turoff, M. (1975). *The Delphi Method: Techniques and Applications*. Mass: Addison-Wesley.

LLNL (2016). *Estimated energy consumption in 2016*. Lawrence Livermore National Laboratory and DOE, Retrieved September 2018 from https://flowcharts.llnl.gov/content/assets/images/energy/us/Energy_US_2016.png

Loftness, V., and Snyder, M. (2011). Where windows become doors. In S. Kellert, J.H. in Heerwagen, & M. L. Mador (Ed.), *Biophilic design: the theory, science, and practice of bringing buildings to life*. (pp. 107-131). Hoboken, NJ: Wiley

Loonen, R., Rico-Martinez, J.M., Favoino, F., Brzezicki, M., Menezo, C., La Ferla, G., et al. (2015) Design for façade adaptability – towards a unified and systematic characterization. *Proc. 10th Energy Forum-Advance Building Skin*, Bern, Switzerland: 2015, p. 1274–84.

Lstiburek, J. W. (2011). Seeing red over green roofs, *ASHRAE Journal*, June 2011.

McHarg, I. L. (1969). *Design with nature*. New York: J. Wiley.

Mckinley, A. (1995). *Calumet Roots. Solar power has its own home in history*. Retrieved March 21, 2018, from http://www.nwitimes.com/uncategorized/calumet-roots-solar-power-has-its-own-home-in-history/article_185aed6f-3df1-52f7-b04a-5a1aad7b18b2.html

Megan Ray Nichols, 2017 : Top 5 Global Green Building Trends of 2017 https://interestingengineering.com/top-5-green-building-trends-2017

MIT (2017). MIT open courseware. Retrieved from https://ocw.mit.edu/courses/architecture/4-430daylighting-spring-2012/assignments/MIT4_430S12_hw4.pdf

MIT Solar History (2018). Retrieved April, 2018, from http://web.mit.edu/solardecathlon/history.html

Monsen, W.A., Klein, S.A., and Beckman, W.A. (1982). The Un-utilizability method for collector-storage walls. *Solar Energy*, Vol. 28, pp. 421-430, (1982)

Murgula, V., Vatina, N., and Zayats, I. (2015). The role of the solar light quantity in the architectural forming of buildings, International Scientific Conference Urban Civil Engineering and Municipal Facilities, *Procedia Engineering SPbUCEMF-2015*

Nagy, G., and Osam, N. (2016). Biomimicry, an approach for energy efficient building skin design. *Procedia Environmental Sciences, 34*, 178-189. doi: 10.1016/j.proenv.2016.04.017

NCARB (2018). *Education Guidelines*. Retrieved January 2019 from https://www.ncarb.org/sites/default/files/Main%20Website/Data%20%26%20Resources/Guidelines/EducationGuidelines.pdf

NEEA (2014). Retrieved June 2017, from https://neea.org/docs/default-source/reports/2014-cbsa-finalreport_05-dec-2014.pdf?sfvrsn=12

Nielsen P.V. (2009). Control of airborne infectious diseases in ventilated spaces. *J R Social Interface*; 6: pp.747-755.

Nightingale F. (1863). *Notes on hospitals*. 3rd ed. London: Longman, Roberts & Green.

NOAA-ESRL (2017). Daily CO2. Retrieved February 2017 from https://www.co2.earth/daily-co2

Norton, B., (2018) Solar Energy. Retrieved September 2018 from http://www.thermopedia.com/content/1136/ doi: 10.1615/AtoZ.s.solar_energy

NREL (2008) *A Methodology for Validating Building Energy Analysis Simulations*. (Ed.) R. *Judkoff*, D. Wortman, B. O'Doherty, and J. Burch. National Renewable Energy Laboratory.

NREL (2008). *A Methodology for Validating Building Energy Analysis Simulations*. (Ed.) R. Judkoff, D. Wortman, B. O'Doherty, and J. Burch. National Renewable Energy Laboratory.

NREL (2018). National Solar Radiation Data Base (NSRDB). Retrieved February, 2018, from http://rredc.nrel.gov/solar/old_data/nsrdb/

NREL (2019). *Transpired Solar Walls for Commercial Buildings.* Retrieved February 2019 from https://www.nrel.gov/docs/fy01osti/30176.pdf

Oh, S. & Haberl, J. (2015). Origins of analysis methods used to design high performance commercial buildings: Solar energy analysis. *Science and Technology for the Built Environment*. 22. 87-106. 10.1080/23744731.2015.1090277.

Olgyay, V. (*1963) Design with Climate: Bioclimatic Approach to Architectural Regionalism*. Princeton University Press.

Ong, K.S. and Chow, C. C. (2003), Performance of a solar chimney. *Solar Energy*; 74:1–17.

Oxtoby, B., McGuinness, T., and Morgan, R.E. (2002). Developing organizational change capability. *European Management Journal*, 20 (3), 310–320.

Palette 2030 (2018). A database of sustainable design tools and resources at your fingertips by AIA, Retrieved September 2018 from http://2030palette.org

Palmiter, L. (1984). *SUNCODE-PC Building Load Simulation Program*. Ecotope, Inc.

Perlin, J. (2013) *Let It Shine: The 6000 Year Story of Solar Energy*, New World Library; Revised edition.

PHIUS (2013). Certified PHIUS Projects. Passive House Institute US, Urbana, IL. www.passivehouse.us/projects.php

PHIUS Certification Overview (2017). Retrieved June 20, 2017, from http://www.phius.org/phiuscertification-for-buildings-products/phius-2015-project-certification/phius-certification-overview

PHIUS Certification Overview (2017). Retrieved June 20, 2017, from http://www.phius.org/phius-certificationfor-buildings-products/phius-2015-project-certification/phius-certification-overview

PHIUS History (2018), Retrieved May 2018 from http://www.phius.org/about/mission-history

PHIUS Mission (2018), About Passive House Institute US: Where we're going and where we've been Retrieved January 2018 from http://www.phius.org/about/mission-history

PHIUS Project Database (2017). Retrieved June 20, 2017, from http://www.phius.org/phiuscertification-for-buildings-products/certified-projects-database

PHIUS Project Database (2017). Retrieved June 20, 2017, from http://www.phius.org/phius-certification-forbuildings-products/certified-projects-database

PHIUS+ 2015 Certification Guidebook _v1.03 (2016). Retrieved June 20, 2017, from http://www.phius.org/PHIUSplusdocs/PHIUS+CertificationGuidebook_v1.03.pdf

PHIUS+ 2015 Certification Guidebook _v1.03 (2016). Retrieved June 20, 2017, from http://www.phius.org/PHIUSplusdocs/PHIUS+CertificationGuidebook_v1.03.pdf

PHIUSP (2018) http://www.phius.org/what-is-passive-building/passive-house-principles

Preziosi, P. (2004). Workplace air-conditioning and health services attendance among French middle-aged women: a prospective cohort study. *International Journal of Epidemiology*, 33(5), pp.1120-1123.

Qian, H. and Zheng, X. (2018). Ventilation control for airborne transmission of human exhaled bio-aerosols in buildings. *J Thorac Dis*. 2018 Jul; 10 (19): 2295–2304. doi: 10.21037/jtd.2018.01.24

Ralegaonkar, R.V., and Gupta, R. (2010) Review of intelligent building construction: a passive solar architecture approach, *Renewable and Sustainable Energy Reviews,* 14: p2238–p2242 2239.

Raman P., Mande S., and Kishore, V. V. N. (2001). A passive solar system for thermal comfort conditioning of buildings in composite climates. *Solar Energy*; 70:319–29.

Ransome, A., and Delepine. S. (1894) On the influence of certain natural agents on the virulence of the tubercle-bacillus. *Proc R Soc. Lond.*;56: pp.51-56.

Reardon, C., and Downton, P. (2016) Passive design: design for climate, in *Your Home: Australia's Guide to Environmentally Sustainable Homes,* Australia Department of the Environment and Energy, 5th edition, Australian Government-Department of Industry and Science. Retrieved September 2018 from http://www.yourhome.gov.au/passive-design/design-climate

Reinhart, C., and Stein, R. (2014). *Daylighting handbook. Volume I, Fundamentals, designing with the sun.* [Place of publication not identified]: [publisher not identified].

Riley, E. C., Murphy, G., and Riley, R. L. (1978) Airborne spread of measles in a suburban elementary-school. *American Journal Epidemiolology*,107:421-32. doi: 10.1093/oxfordjournals.aje.a112560

Rittelmann, P. R., and Ahmed, S. F. (1985) *Task 8 of International Energy Agency (IEA) for the Passive and Hybrid Solar Low-Energy Buildings.* Burt Hill Kosar Rittelmann Assoc. Butler, PA. Retrieved September 15, 2017 from http://task08.ieashc.org/data/sites/1/publications/Task%208Design%20Tool%20Survey%20Vol%201-May%201985.pdf

Robertson, A. S., Roberts, K. T., Burge, P., & Raw, G. (1990). The effect of change in building ventilation category on sickness absence rates and the prevalence of sick building syndrome. *Proceedings of Indoor Air 90*1: pp. 237-242.

Roth, L. M. (2003) *American Architecture: A History*, Westview Press, 2003, p. 361

Saadatian, O., Sopian, K., Lim, C.H., Asim, N., Sulaiman, M.Y., 2012. Trombe' walls: A review of opportunities and challenges in research and development. Renewable and Sustainable Energy Reviews.

Sadineni, S. B., Madala, S., and Boehm, R. F. (2011). Passive building energy savings: A review of building envelope components. *Renewable and Sustainable Energy Reviews*, *15*3617-3631. doi: 10.1016/j.rser.2011.07.014

Seppanen, O., and Fisk, W.J. (2002). Association of ventilation system type with SB symptoms in office workers. *Indoor Ail* 12 (2): pp. 98-112.

Sharifi, A., and Yamagata, Y. (2015). Roof ponds as passive heating and cooling systems: A systematic review, *Applied Energy*, Volume 160, 2015, Pages 336-357

Shurcliff, W. (1982). The Saunders-Shrewsbury House. Selfpublished.

Shurcliff, W. (1986). Superinsulated houses. *Annual Reviews Energy* 11:1-24.

Shurcliff, W. (1988). *Superinsulated Houses and Air-To-Air Heat Exchangers*. Andover, MA: Brickhouse Publishing Company.

Sonne, J. (2006) Evaluating Green Roof Energy Performance, American Society of Heating, Refrigerating and Air-Conditioning Engineerrs. *ASHRAE Journal*, Vol. 48.

Stein, B., and Reynolds, J. S. (2000) *Mechanical and Electrical Equipment for Buildings.* 9th edition, John Wiley and Sons, Inc., New York, 455-475.

Sterner, C. (2015) *Six Metrics Every Architect Should Know*. Retrieved 18 September 2017, from http://sefaira.com/resources/six-metrics-every-architect-should-know-and-how-to-use-them

Strong, D. & Burrows, V. (2017). *A whole-system approach to high-performance green buildings*. Boston: Artech House.

Strong, D., and Burrows, V. (2017). *A Whole-System Approach to High-Performance Green Buildings*. Boston: Artech House.

Struckmann, F. (2008). *Analysis of a Flat-plate Solar Collector*, Heat and Mass Transport Project Report, Department of Energy Sciences, Faculty of Engineering, Lund University, Sweden.

Stunkel, K. R. (2004). *Understanding Lewis Mumford: a guide for the perplexed*, Edwin Mellen Press, Lewiston.

Sun, W., Ji, J., Luo, C., and He, W. (2011). Performance of PV-Trombe' wall in winter correlated with south facade design. *Applied Energy* 2011; 88:224–31.

Syed, A. (2012). *Advanced building technologies for sustainability*. Hoboken: John Wiley & Sons.

Tittmann, J. (2018) AIA, Albert, Righter, Tittmann Architects. Retrieved April 2018 from http://www.artarchitects.com/sustainability/

Tsoroti, S. (2014). What's that building? Eastgate Mall. Retrieved June 20, 2017, from http://www.hararenews.co.zw/2014/05/whats-that-building-eastgate-mall/#comments

Tunc¸ M, Uysal M. Passive solar heating of buildings using a fluidized bed plus Trombe' wall system. *Applied Energy* 1991;38(3):199–213.

Turner, S. and Rupert, S. (2008). Beyond biomimicry. What termites can tell us about realizing the living building. First International Conference on Industrialized, Intelligent Construction (I3CON) Loughborough University, (14-16 May).

UNS (2016) Transforming our world: the 2030 agenda for sustainable development. Retrieved January 2018 from development http://ec.europa.eu/environment/sustainable-development/SDGs/index_en.htm

Ürge-Vorsatz, D., N. Eyre, P. Graham, D. Harvey, E. Hertwich, Y. Jiang, C. Kornevall, M. Majumdar, J. E. McMahon, S. Mirasgedis, S. Murakami and A. Novikova, (2012). *Global Energy Assessment - Toward a Sustainable Future*, Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 649-760. Retrieved May 2018 from http://www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/Chapte10.en.html

USGVMT, (1995) *Code of Federal Regulations 10 – Energy*. Office of the Federal Register National Archives and Records Administration. Washington, D.C. U.S.A.

Van Decker, G.W.E., Hollands, K.G.T. and A.P. Brunger, "Heat-Exchange Relations for Unglazed Transpired Solar Collectors with Circular Holes on a Square or Triangular Pitch", Solar Energy, 2001, vol. 71, No. 1, pp. 33-45.

Ventive (2018). *Facade integrated passive ventilation.* Retrieved September 2018 from https://www.ventive.co.uk/passive.html

Verrengia, J. (2010). *Smart windows: energy efficiency with a view*. Retrieved November 2016 from https://web.archive.org/web/20111017071503/https://www.nrel.gov/news/features/feature_detail.cfm/feature_id=1555

Vijayalaxmi, J. (2010) Concept of Overall Thermal Transfer Value (OTTV) in design of building envelope to achieve energy efficiency. *International Journal of Thermal & Environmental Engineering, 1 (2010) 75-80.*

WBDG (2017) Whole Building Design Guide. *Passive solar heating*. Retrieved September 22, 2017, from https://www.wbdg.org/resources/passive-solar-heating

WBDG. (2017.). Whole Building Design Guide. *Optimize energy use*. Retrieved June 28, 2017, from http://wbdg.org/design-objectives/sustainable/optimize-energy-use

Wei Chen, Wei Liu, 2004. Numerical analysis of heat transfers in a composite wall solar-collector system with a porous absorber. *Applied Energy* 78 (2004) 137–149.

Weinschenk, C. (2015). *LEED certification, energy efficiency increase property value*. Retrieved October, 2018, from https://www.energymanagertoday.com/leed-certification-increases-property-value-0115986/

Wells, W.F. (1948) On the mechanics of droplet nuclei infection: apparatus for the quantitative study of droplet nuclei infection of animals. *Am Journal of Hyg*iene 1948; 47:1-10.

Wennick, A., Lundqvist, A., & Hallstrom, I. (2009). Everyday experience of families three years after diagnosis of Type 1 diabetes in children: a research paper. *Journal of Pediatric Nursing*. 24. 222-230.

Wennick, A., Lundqvist, A., and Hallstrom, I. (2009). Everyday experience of families three years after diagnosis of Type 1 diabetes in children: A research paper. *Journal of Pediatric Nursing*. 24. 222-230.

WGBC (2018). Green Building Rating Tools. World Green Building Council Retrieved May 2018 from http://www.worldgbc.org/rating-tools

WHO (2002). Guidelines on prevention and control of hospital associated infections. New Delhi: WHO Regional Office for South-East Asia.

WHO. (2007) Infection prevention and control of epidemic- and pandemic-prone acute respiratory diseases in health care — *WHO interim guidelines*. Geneva, World Health Organization.

WHO. (2009) natural ventilation for infection control in health-care settings — *WHO interim guidelines*. Geneva, World Health Organization.

Willier, A. (1977). Prediction of Performance of solar collectors, in Application of Solar Energy for Heating and Cooling of Buildgins, ASHRAE, New York.

Wilson, E. O. (1984). *Biophilia: The Human Bond with Other Species.* Cambridge, MA: Harvard University Press.

Wong, I. L. (2017). A review of daylighting design and implementation in buildings, Renewable and Sustainable Energy Reviews, Volume 74, 2017: 959-968.

Woolley, T. (2016). *Building materials, health and indoor air quality: no breathing space*, CRC Press, 2016. ProQuest eBook Central.

Wright, G., and Klingenberg, K. (2015). Climate-Specific Passive Building Standards. Building America Report -1405 July 2015. Retrieved from https://buildingscience.com/sites/default/files/ba-1405_climatespecific_passive_building_standards.pdf

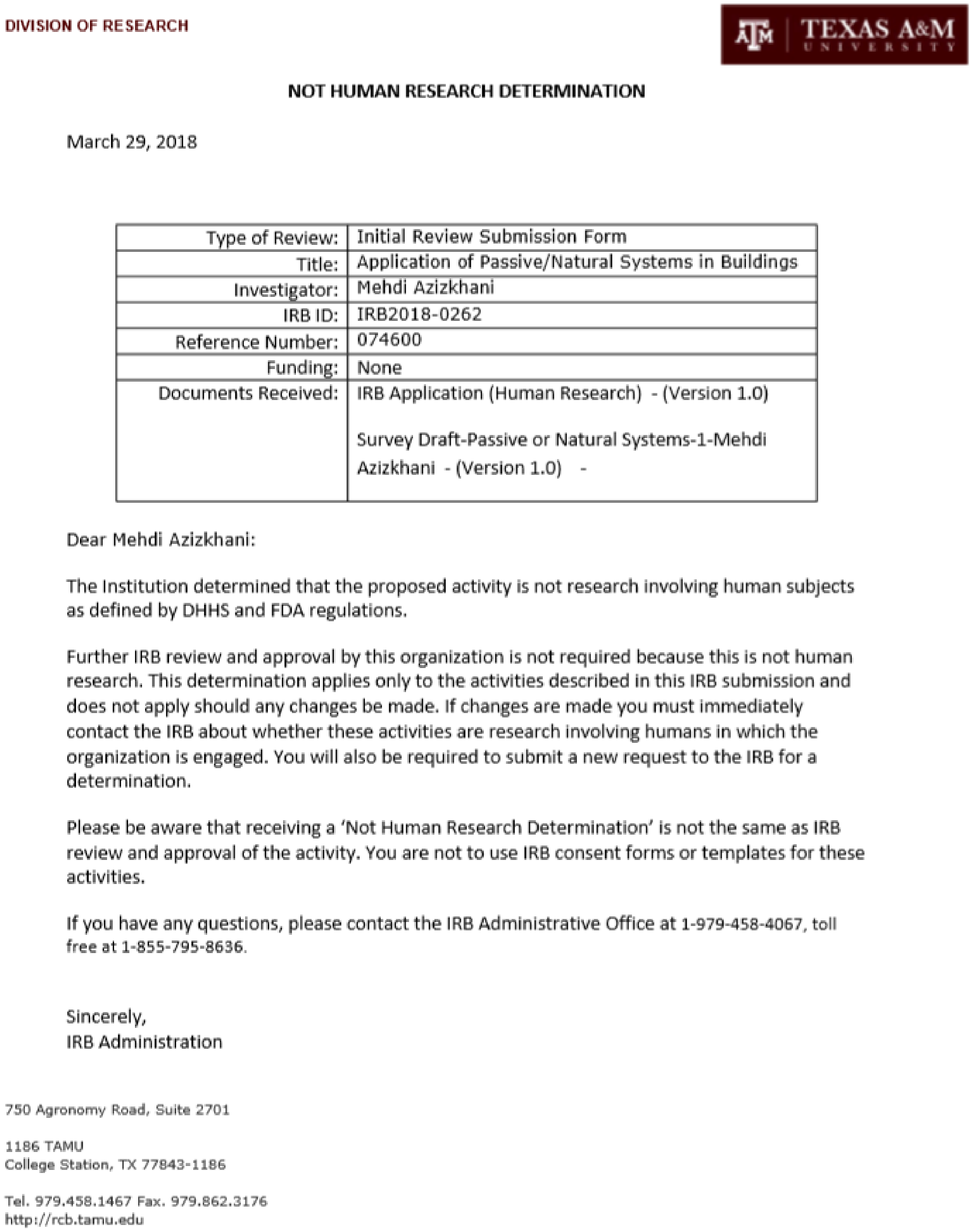
Zadeh, R. S., Shepley, M. M., Williams, G., and Chung, S. S. (2014). The impact of windows and daylight on acute-care nurses' physiological, psychological, and behavioral health. *HERD: Health Environments Research & Design Journal*, *7*(4), 35-61. doi:10.1177/193758671400700405

Zalewski, L., Joulin, A., Lassue, S., Dutil, Y., and Rousse, D. (2012). Experimental study of small-scale solar wall integrating phase change material. Solar Energy.

Zalewski, L., Lassue, S., Duthoit, B., Butez, M., Study of solar walls: validating a numerical simulation model, *International Review on Building and Environment* 37 (1) (2002) 109–121.

APPENDIX A

IRB REVIEW LETTER



DIVISION OF RESEARCH

TEXAS A&M UNIVERSITY

NOT HUMAN RESEARCH DETERMINATION

March 29, 2018

Type of Review:	Initial Review Submission Form
Title:	Application of Passive/Natural Systems in Buildings
Investigator:	Mehdi Azizkhani
IRB ID:	IRB2018-0262
Reference Number:	074600
Funding:	None
Documents Received:	IRB Application (Human Research) - (Version 1.0) Survey Draft-Passive or Natural Systems-1-Mehdi Azizkhani - (Version 1.0) -

Dear Mehdi Azizkhani:

The Institution determined that the proposed activity is not research involving human subjects as defined by DHHS and FDA regulations.

Further IRB review and approval by this organization is not required because this is not human research. This determination applies only to the activities described in this IRB submission and does not apply should any changes be made. If changes are made you must immediately contact the IRB about whether these activities are research involving humans in which the organization is engaged. You will also be required to submit a new request to the IRB for a determination.

Please be aware that receiving a 'Not Human Research Determination' is not the same as IRB review and approval of the activity. You are not to use IRB consent forms or templates for these activities.

If you have any questions, please contact the IRB Administrative Office at 1-979-458-4067, toll free at 1-855-795-8636.

Sincerely,
IRB Administration

750 Agronomy Road, Suite 2701

1186 TAMU
College Station, TX 77843-1186

Tel. 979.458.1467 Fax. 979.862.3176
http://rcb.tamu.edu

APPENDIX B

SURVEY INVITATION LETTER

Dear [Contact Name],

I hope this email finds you well. I am a PhD candidate at the Department of Architecture at Texas A&M University and I am conducting my dissertation research in collaboration with Professor Jeff Haberl on the education/application of passive/natural systems in buildings in the US. As a part of this research I am conducting a survey with 22 questions. It takes less than 15 minutes to answer the questions.

I greatly appreciate it if there is a possibility to take the survey and/or if you could suggest it to your colleagues interested in the education/application of passive/natural systems. **Below is a brief description of the research/survey along with the survey link at the end of the email.** This survey is anonymous and has been approved by Texas A&M Institutional Review Board (IRB ID: IRB2018-0262/ Ref. Number: 074600). Please let me know about the possibility of taking the survey or if you need any additional information.

Best regards,
Mehdi Azizkhani

PhD Candidate
Department of Architecture
College of Architecture
Texas A&M University
512.363.8056
m.azizkhani@tamu.edu

Please take the survey here:

https://tamu.qualtrics.com/jfe/form/SV_4ZRSlmU64RN9ipT

Dear Participant,

My name is Mehdi Azizkhani and I am a Doctoral Candidate and researcher at the College of Architecture at Texas A&M University. In collaboration with Professor Jeff Haberl I am conducting research on the application of passive/natural systems in buildings in the US to find opportunities/challenges that could increase/reduce the frequency of their use on a national scale in the US. The incorporation of natural/passive systems in buildings is in line with programs such as Architecture 2030

Challenge. Such programs can reduce the energy consumption of buildings, the associated cost, and preserve our natural resources for future generations.

As a part of the current study I am conducting a survey to find out about the education and application of passive/natural systems in addition to usual passive design strategies such as airtightness and continuous insulation. The intended target audience of this survey include professors/instructors who have taught or practiced in the US. The purpose of this survey is to obtain a more accurate perception of the education and practice of passive system design across different disciplines in academia and the building industry in the US to better measure the followings:

- The factors influencing the increase/reduction of the use of passive/natural systems in buildings
- The design tools being used for the education/application of passive design
- The most and least recurring types of passive/natural system strategies
- The importance of incorporating passive/natural system strategies in a practical design process with respect to their integration with mechanical systems

Your participation in this survey is greatly appreciated. The opinions of academics and professionals like you are an important component to better understand the current education and practice in universities and the building industry across the country.

The link below will direct you to a survey questionnaire which takes about 15 minutes to answer. This survey has been approved by Texas A&M Institutional Review Board (IRB ID: IRB2018-0262/ Ref. Number: 074600). If you have received the link from other organizations, please take the survey only once. The survey is anonymous and your responses to the survey questions will be kept confidential. The results of the survey will be sent back to you at the end of the research study.

Please take the survey here:

https://tamu.qualtrics.com/jfe/form/SV_4ZRSlmU64RN9ipT

Thank you in advance for your time.
Sincerely,

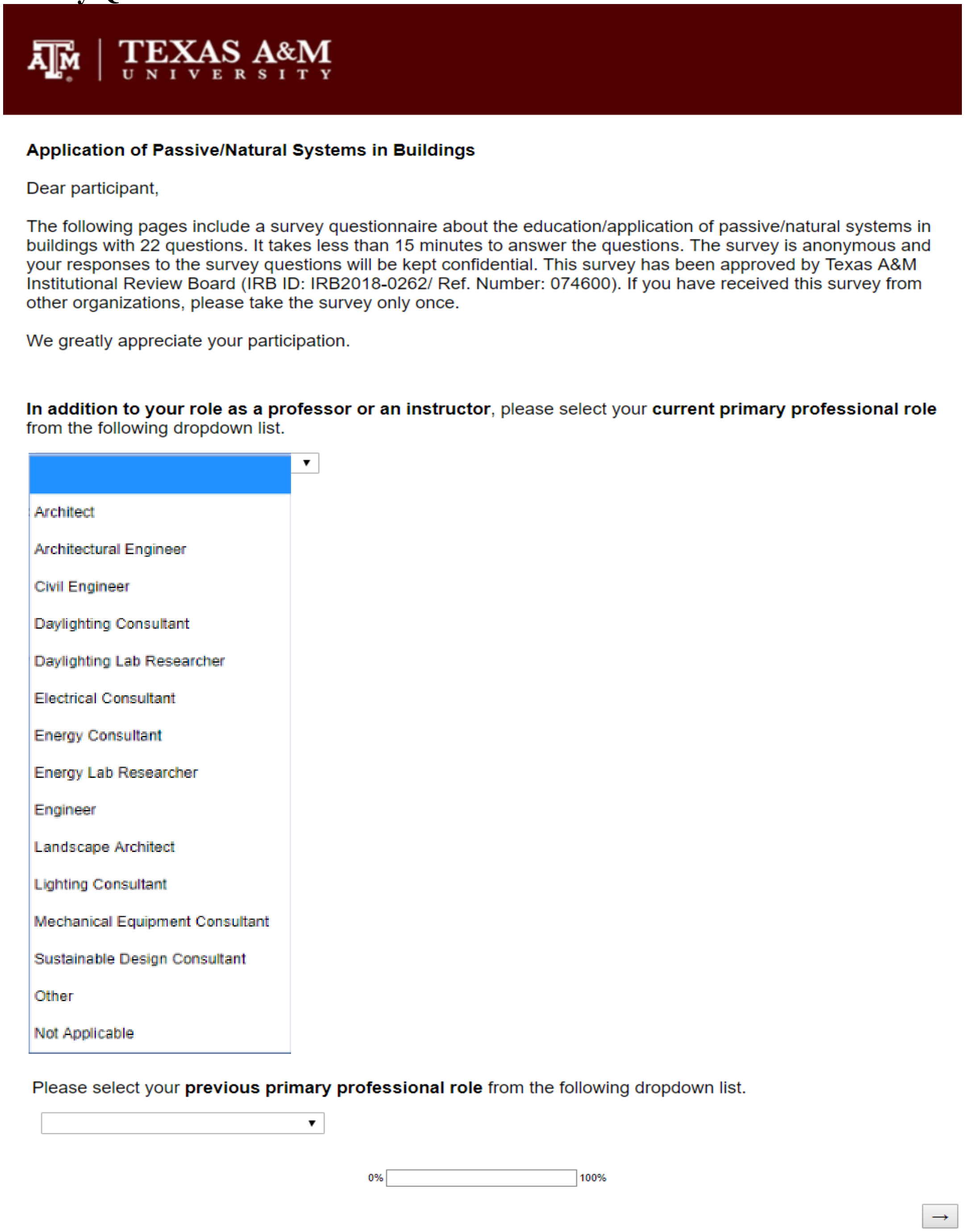
Mehdi Azizkhani	Dr. Jeff Haberl
PhD Candidate	Professor

Department of Architecture
College of Architecture
Texas A&M University
512.363.8056
m.azizkhani@tamu.edu

APPENDIX C

SURVEY QUESTIONNAIRE FOR EDUCATORS AND PRACTITIONERS

Survey Questionnaire for Educators



TEXAS A&M UNIVERSITY

Application of Passive/Natural Systems in Buildings

Dear participant,

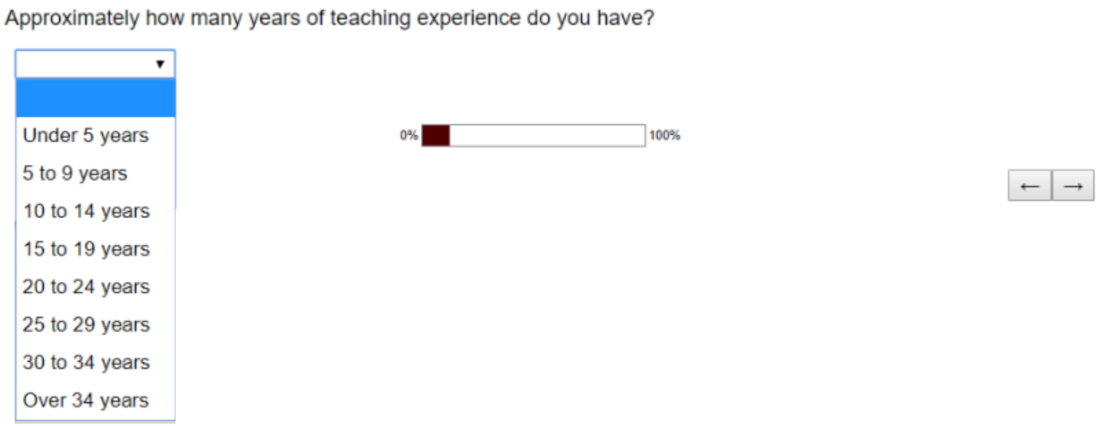
The following pages include a survey questionnaire about the education/application of passive/natural systems in buildings with 22 questions. It takes less than 15 minutes to answer the questions. The survey is anonymous and your responses to the survey questions will be kept confidential. This survey has been approved by Texas A&M Institutional Review Board (IRB ID: IRB2018-0262/ Ref. Number: 074600). If you have received this survey from other organizations, please take the survey only once.

We greatly appreciate your participation.

In addition to your role as a professor or an instructor, please select your **current primary professional role** from the following dropdown list.

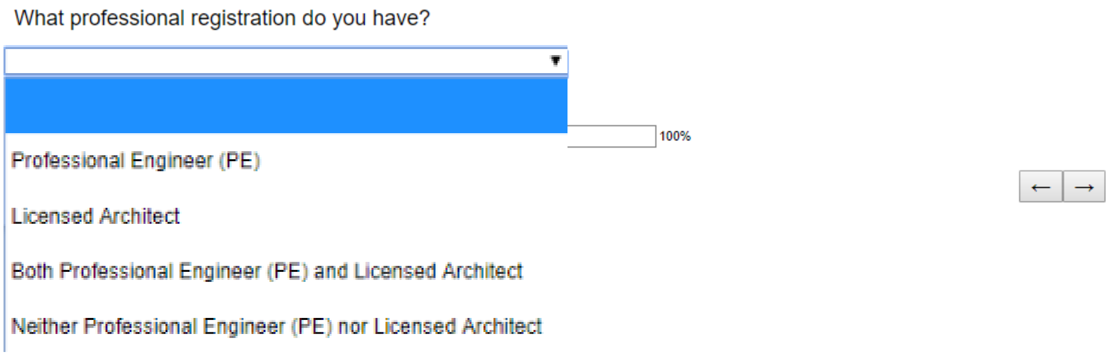
- Architect
- Architectural Engineer
- Civil Engineer
- Daylighting Consultant
- Daylighting Lab Researcher
- Electrical Consultant
- Energy Consultant
- Energy Lab Researcher
- Engineer
- Landscape Architect
- Lighting Consultant
- Mechanical Equipment Consultant
- Sustainable Design Consultant
- Other
- Not Applicable

Please select your **previous primary professional role** from the following dropdown list.



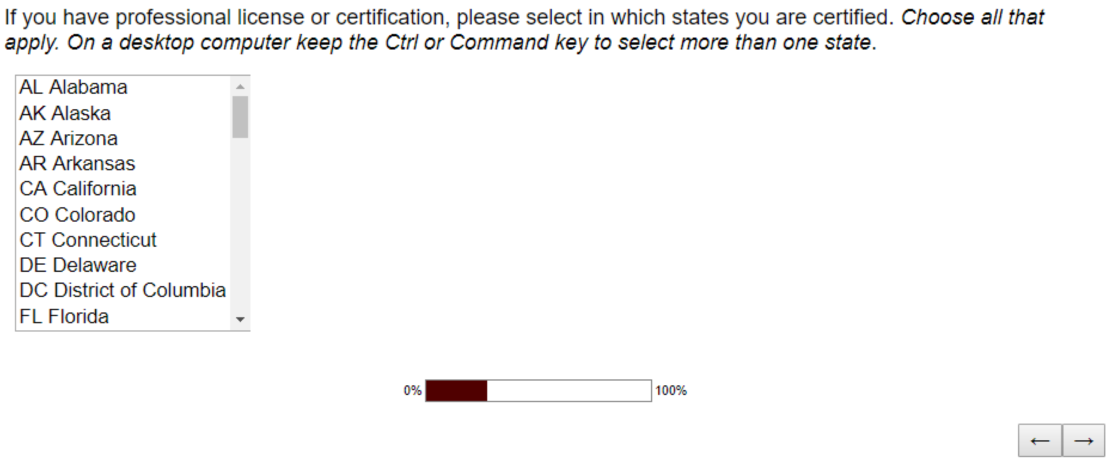
Approximately how many years of teaching experience do you have?

- Under 5 years
- 5 to 9 years
- 10 to 14 years
- 15 to 19 years
- 20 to 24 years
- 25 to 29 years
- 30 to 34 years
- Over 34 years



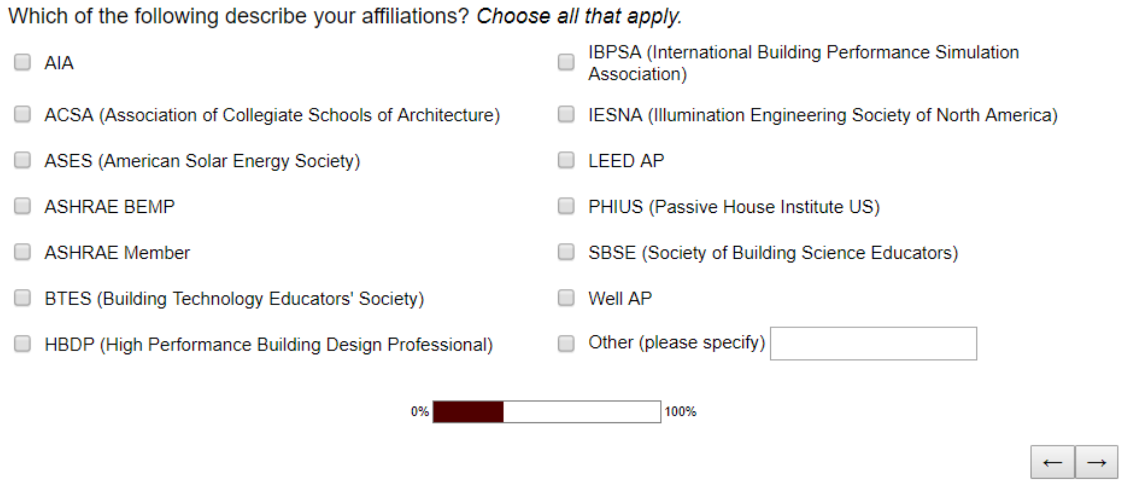
What professional registration do you have?

- Professional Engineer (PE)
- Licensed Architect
- Both Professional Engineer (PE) and Licensed Architect
- Neither Professional Engineer (PE) nor Licensed Architect



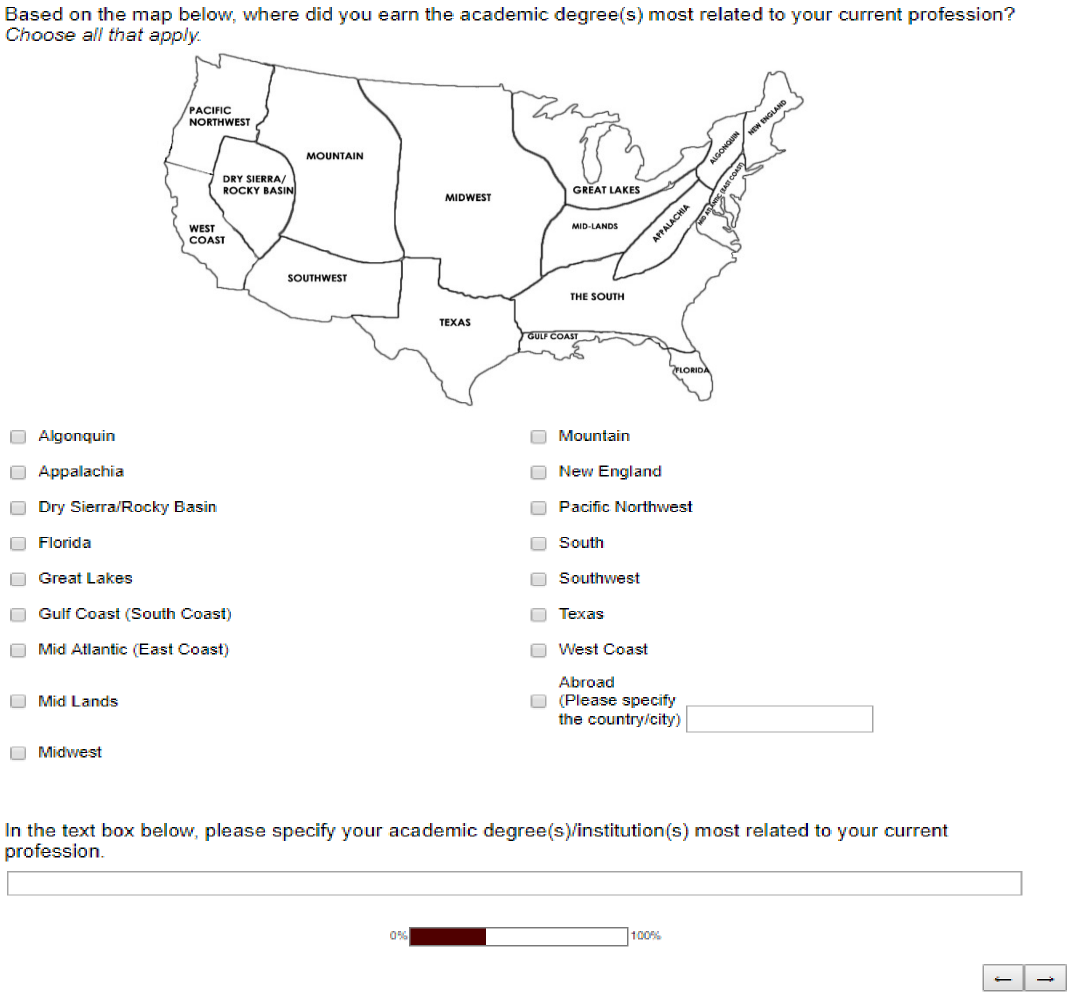
If you have professional license or certification, please select in which states you are certified. *Choose all that apply. On a desktop computer keep the Ctrl or Command key to select more than one state.*

- AL Alabama
- AK Alaska
- AZ Arizona
- AR Arkansas
- CA California
- CO Colorado
- CT Connecticut
- DE Delaware
- DC District of Columbia
- FL Florida



Which of the following describe your affiliations? *Choose all that apply.*

- ☐ AIA
- ☐ ACSA (Association of Collegiate Schools of Architecture)
- ☐ ASES (American Solar Energy Society)
- ☐ ASHRAE BEMP
- ☐ ASHRAE Member
- ☐ BTES (Building Technology Educators' Society)
- ☐ HBDP (High Performance Building Design Professional)
- ☐ IBPSA (International Building Performance Simulation Association)
- ☐ IESNA (Illumination Engineering Society of North America)
- ☐ LEED AP
- ☐ PHIUS (Passive House Institute US)
- ☐ SBSE (Society of Building Science Educators)
- ☐ Well AP
- ☐ Other (please specify) ____________

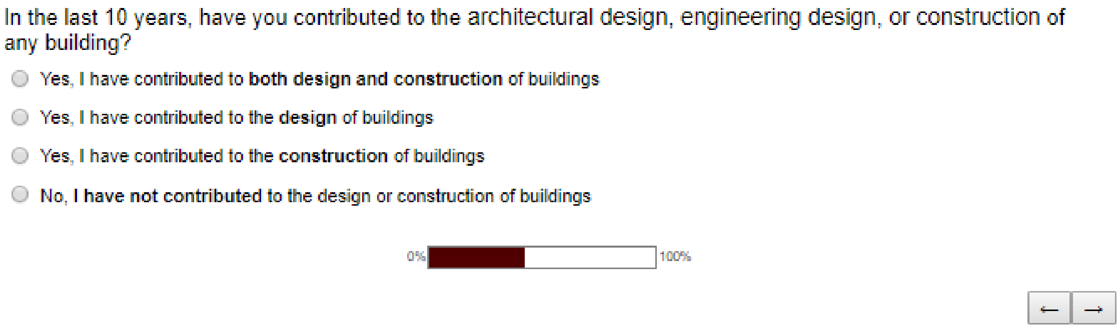


Based on the map below, where did you earn the academic degree(s) most related to your current profession? *Choose all that apply.*

- ☐ Algonquin
- ☐ Appalachia
- ☐ Dry Sierra/Rocky Basin
- ☐ Florida
- ☐ Great Lakes
- ☐ Gulf Coast (South Coast)
- ☐ Mid Atlantic (East Coast)
- ☐ Mid Lands
- ☐ Midwest
- ☐ Mountain
- ☐ New England
- ☐ Pacific Northwest
- ☐ South
- ☐ Southwest
- ☐ Texas
- ☐ West Coast
- ☐ Abroad (Please specify the country/city) ____________

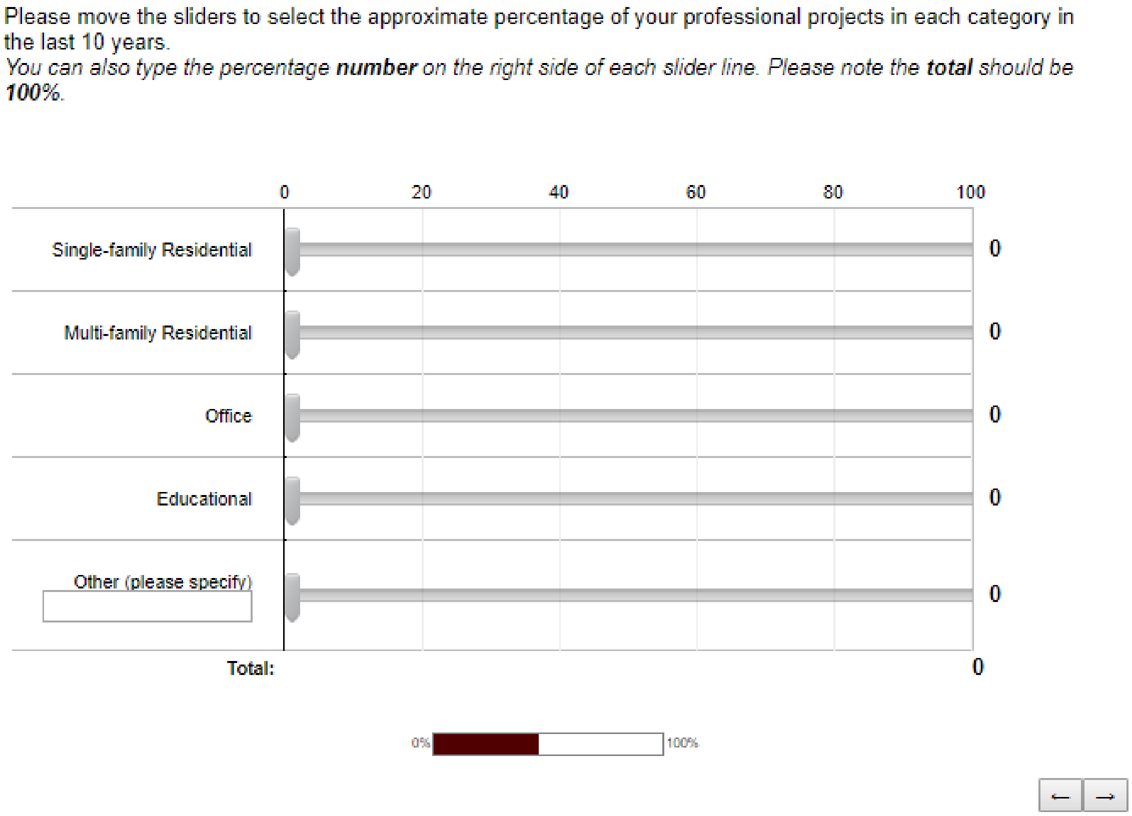
In the text box below, please specify your academic degree(s)/institution(s) most related to your current profession.

____



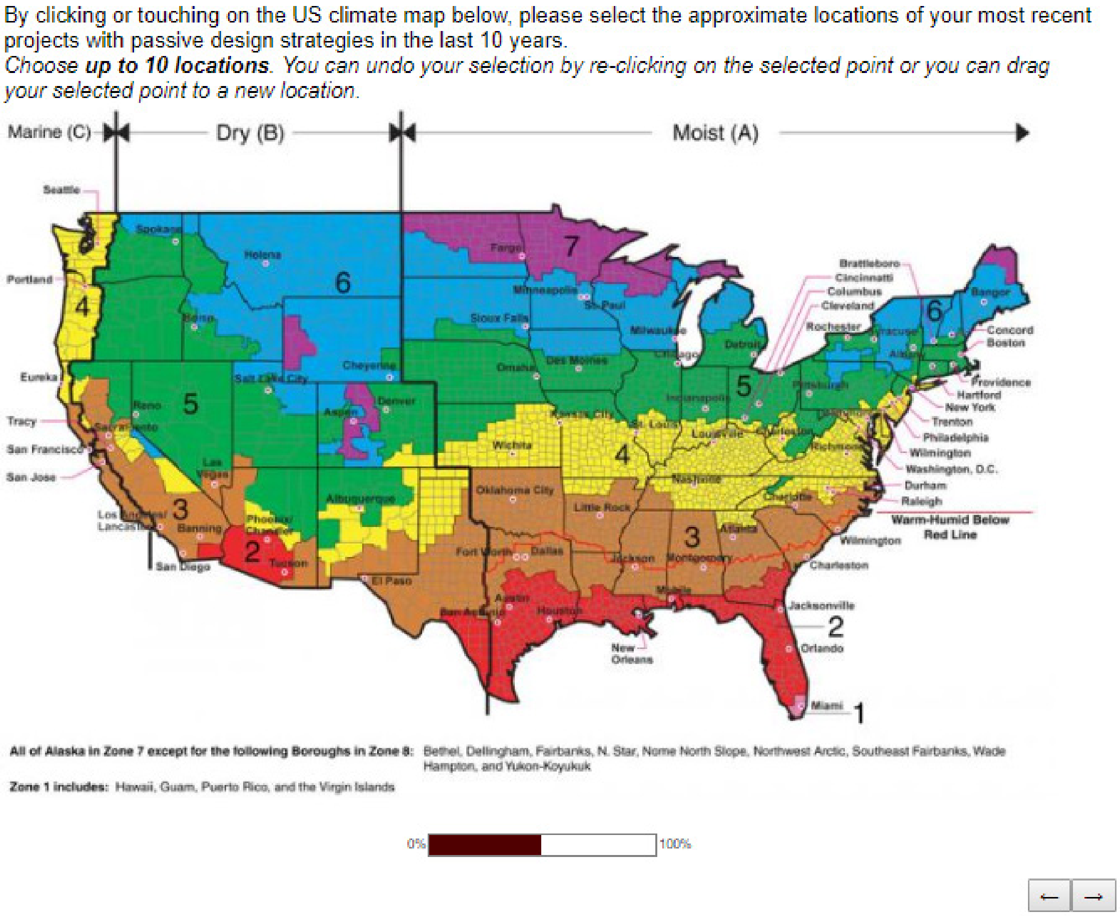
In the last 10 years, have you contributed to the architectural design, engineering design, or construction of any building?

- ○ Yes, I have contributed to **both design and construction** of buildings
- ○ Yes, I have contributed to the **design** of buildings
- ○ Yes, I have contributed to the **construction** of buildings
- ○ No, **I have not contributed** to the design or construction of buildings



Please move the sliders to select the approximate percentage of your professional projects in each category in the last 10 years.
*You can also type the percentage **number** on the right side of each slider line. Please note the **total** should be **100%**.*

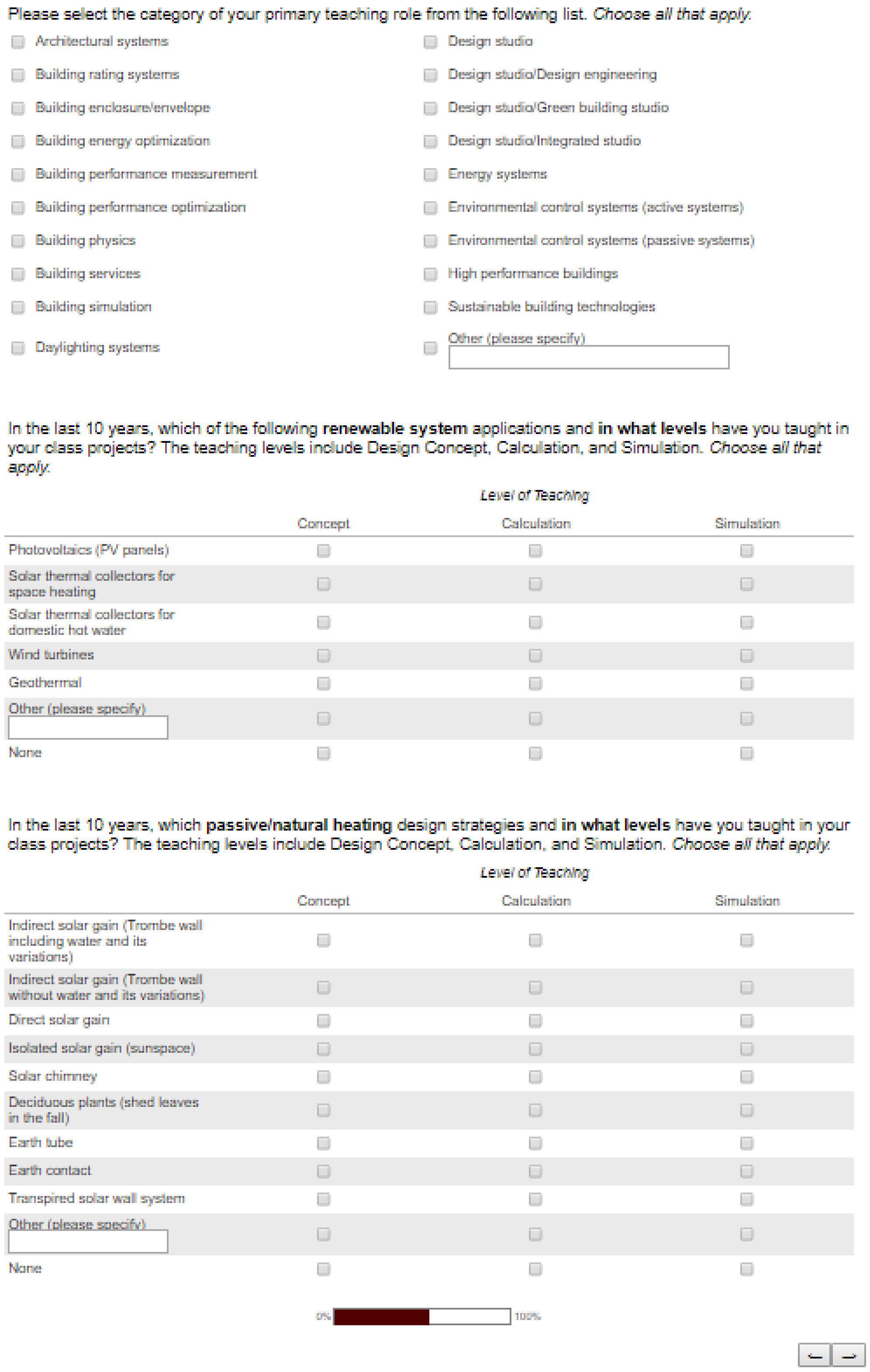
Single-family Residential	0
Multi-family Residential	0
Office	0
Educational	0
Other (please specify)	0
Total:	0



By clicking or touching on the US climate map below, please select the approximate locations of your most recent projects with passive design strategies in the last 10 years.
*Choose **up to 10 locations**. You can undo your selection by re-clicking on the selected point or you can drag your selected point to a new location.*

All of Alaska in Zone 7 except for the following Boroughs in Zone 8: Bethel, Dellingham, Fairbanks, N. Star, Nome North Slope, Northwest Arctic, Southeast Fairbanks, Wade Hampton, and Yukon-Koyukuk

Zone 1 includes: Hawaii, Guam, Puerto Rico, and the Virgin Islands



Please select the category of your primary teaching role from the following list. *Choose all that apply.*

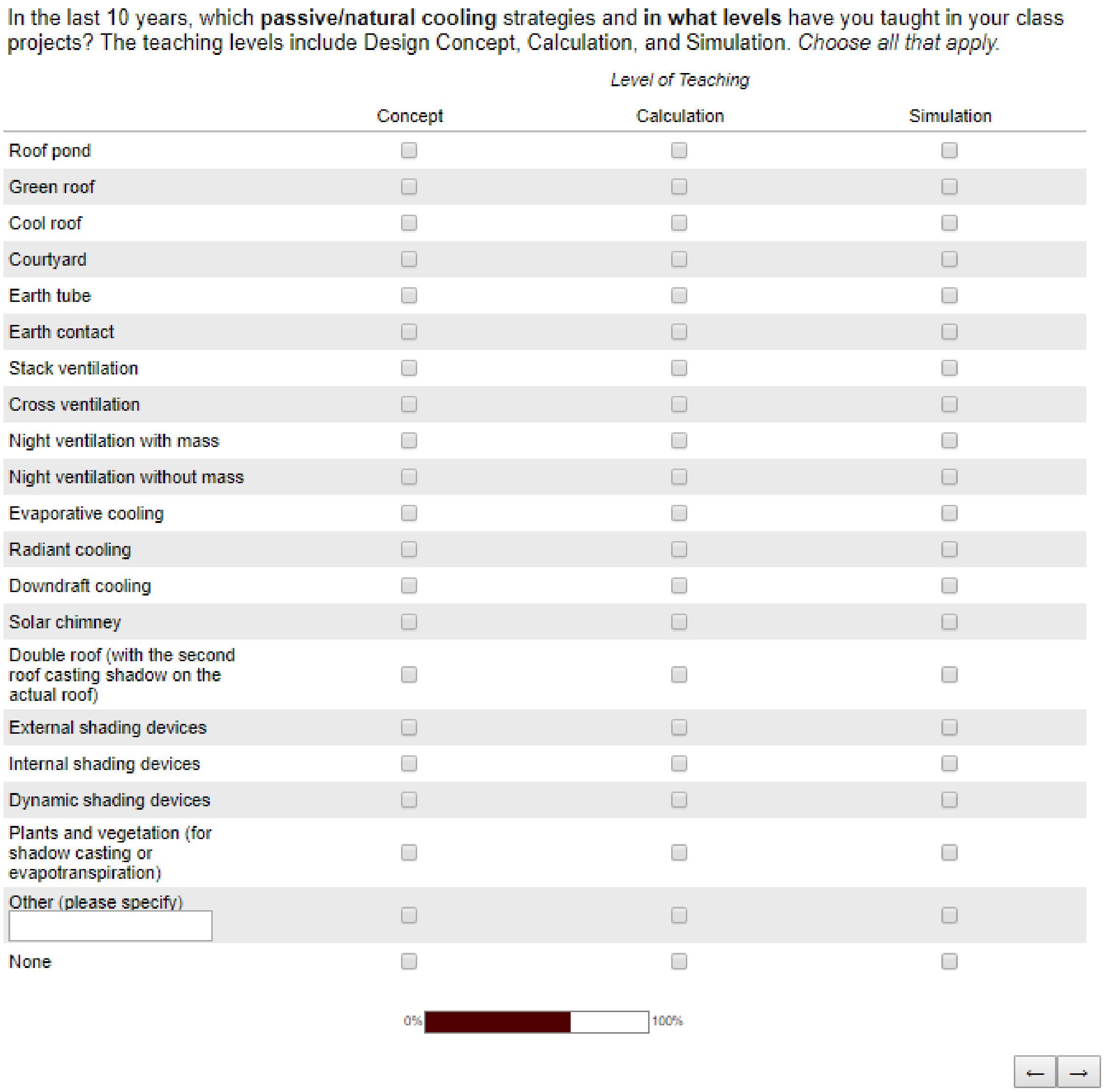
- ☐ Architectural systems
- ☐ Building rating systems
- ☐ Building enclosure/envelope
- ☐ Building energy optimization
- ☐ Building performance measurement
- ☐ Building performance optimization
- ☐ Building physics
- ☐ Building services
- ☐ Building simulation
- ☐ Daylighting systems
- ☐ Design studio
- ☐ Design studio/Design engineering
- ☐ Design studio/Green building studio
- ☐ Design studio/Integrated studio
- ☐ Energy systems
- ☐ Environmental control systems (active systems)
- ☐ Environmental control systems (passive systems)
- ☐ High performance buildings
- ☐ Sustainable building technologies
- ☐ Other (please specify)

In the last 10 years, which of the following **renewable system** applications and **in what levels** have you taught in your class projects? The teaching levels include Design Concept, Calculation, and Simulation. *Choose all that apply.*

	Level of Teaching		
	Concept	Calculation	Simulation
Photovoltaics (PV panels)	☐	☐	☐
Solar thermal collectors for space heating	☐	☐	☐
Solar thermal collectors for domestic hot water	☐	☐	☐
Wind turbines	☐	☐	☐
Geothermal	☐	☐	☐
Other (please specify)	☐	☐	☐
None	☐	☐	☐

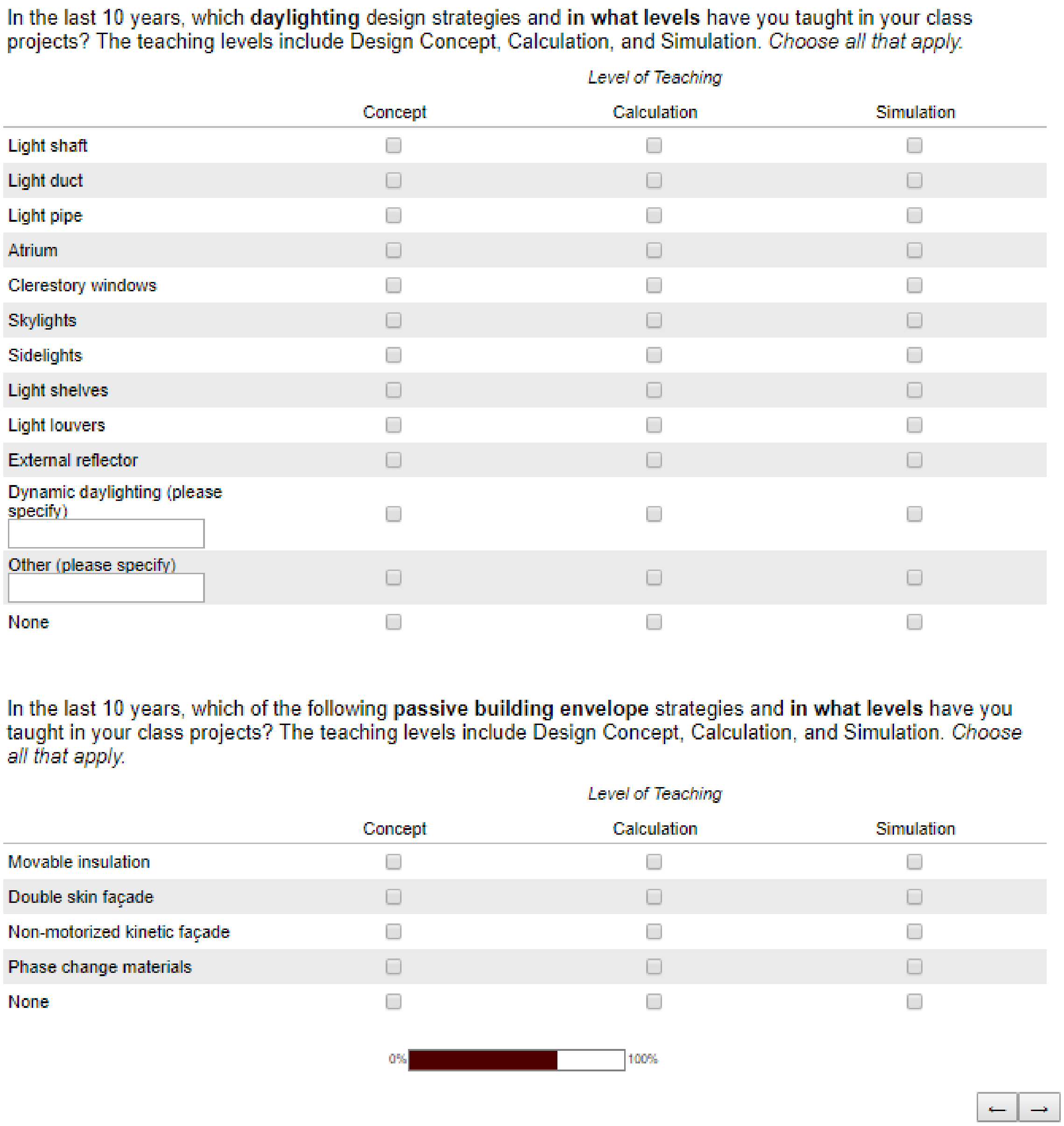
In the last 10 years, which **passive/natural heating** design strategies and **in what levels** have you taught in your class projects? The teaching levels include Design Concept, Calculation, and Simulation. *Choose all that apply.*

	Level of Teaching		
	Concept	Calculation	Simulation
Indirect solar gain (Trombe wall including water and its variations)	☐	☐	☐
Indirect solar gain (Trombe wall without water and its variations)	☐	☐	☐
Direct solar gain	☐	☐	☐
Isolated solar gain (sunspace)	☐	☐	☐
Solar chimney	☐	☐	☐
Deciduous plants (shed leaves in the fall)	☐	☐	☐
Earth tube	☐	☐	☐
Earth contact	☐	☐	☐
Transpired solar wall system	☐	☐	☐
Other (please specify)	☐	☐	☐
None	☐	☐	☐



In the last 10 years, which **passive/natural cooling** strategies and **in what levels** have you taught in your class projects? The teaching levels include Design Concept, Calculation, and Simulation. *Choose all that apply.*

	Level of Teaching		
	Concept	Calculation	Simulation
Roof pond	☐	☐	☐
Green roof	☐	☐	☐
Cool roof	☐	☐	☐
Courtyard	☐	☐	☐
Earth tube	☐	☐	☐
Earth contact	☐	☐	☐
Stack ventilation	☐	☐	☐
Cross ventilation	☐	☐	☐
Night ventilation with mass	☐	☐	☐
Night ventilation without mass	☐	☐	☐
Evaporative cooling	☐	☐	☐
Radiant cooling	☐	☐	☐
Downdraft cooling	☐	☐	☐
Solar chimney	☐	☐	☐
Double roof (with the second roof casting shadow on the actual roof)	☐	☐	☐
External shading devices	☐	☐	☐
Internal shading devices	☐	☐	☐
Dynamic shading devices	☐	☐	☐
Plants and vegetation (for shadow casting or evapotranspiration)	☐	☐	☐
Other (please specify)	☐	☐	☐
None	☐	☐	☐

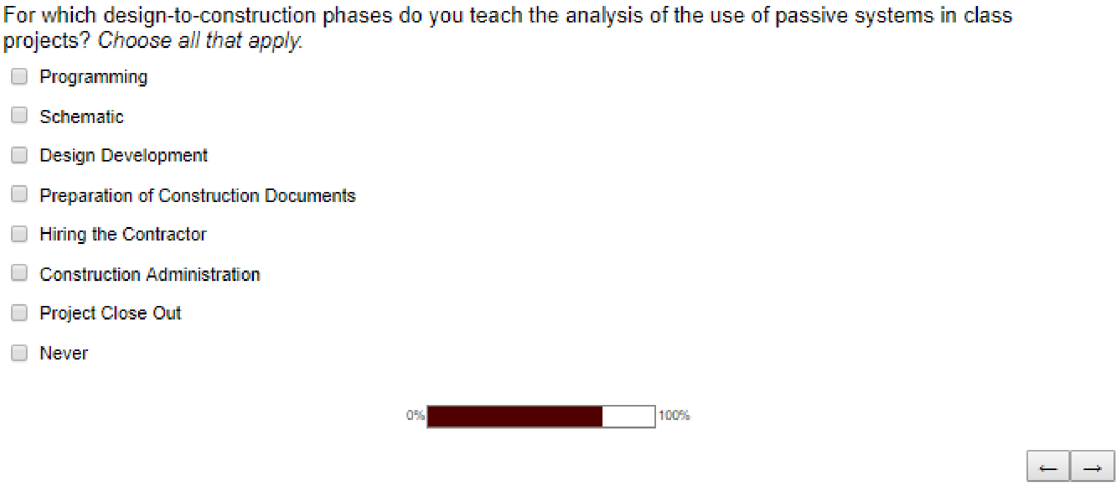


In the last 10 years, which **daylighting** design strategies and **in what levels** have you taught in your class projects? The teaching levels include Design Concept, Calculation, and Simulation. *Choose all that apply.*

		Level of Teaching	
	Concept	Calculation	Simulation
Light shaft	☐	☐	☐
Light duct	☐	☐	☐
Light pipe	☐	☐	☐
Atrium	☐	☐	☐
Clerestory windows	☐	☐	☐
Skylights	☐	☐	☐
Sidelights	☐	☐	☐
Light shelves	☐	☐	☐
Light louvers	☐	☐	☐
External reflector	☐	☐	☐
Dynamic daylighting (please specify) ☐	☐	☐	☐
Other (please specify) ☐	☐	☐	☐
None	☐	☐	☐

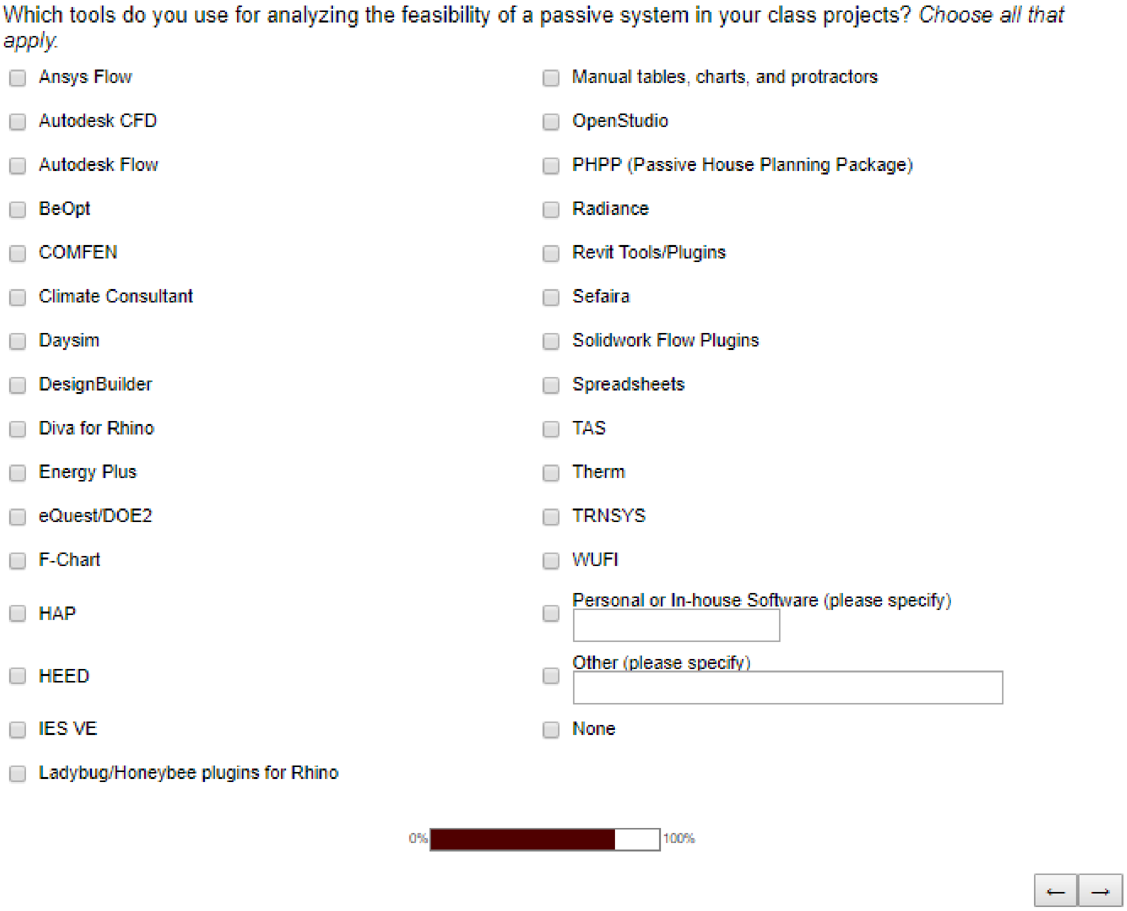
In the last 10 years, which of the following **passive building envelope** strategies and **in what levels** have you taught in your class projects? The teaching levels include Design Concept, Calculation, and Simulation. *Choose all that apply.*

		Level of Teaching	
	Concept	Calculation	Simulation
Movable insulation	☐	☐	☐
Double skin façade	☐	☐	☐
Non-motorized kinetic façade	☐	☐	☐
Phase change materials	☐	☐	☐
None	☐	☐	☐



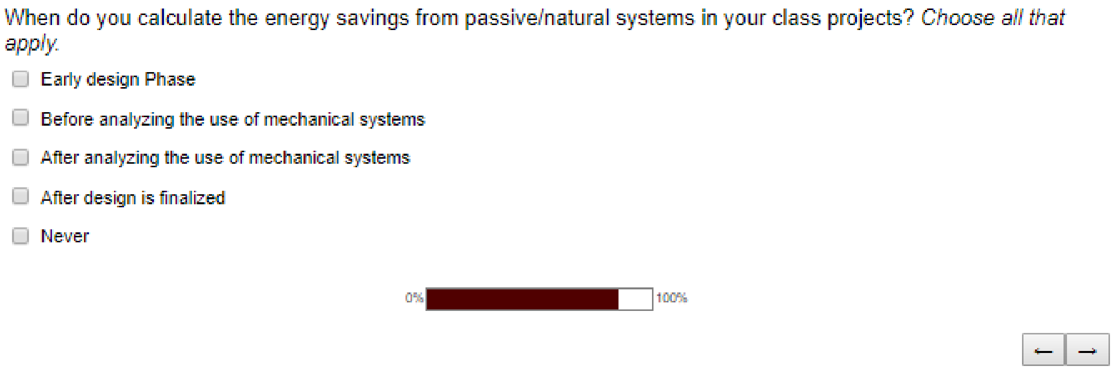
For which design-to-construction phases do you teach the analysis of the use of passive systems in class projects? *Choose all that apply.*

☐ Programming
☐ Schematic
☐ Design Development
☐ Preparation of Construction Documents
☐ Hiring the Contractor
☐ Construction Administration
☐ Project Close Out
☐ Never



Which tools do you use for analyzing the feasibility of a passive system in your class projects? *Choose all that apply.*

☐ Ansys Flow
☐ Autodesk CFD
☐ Autodesk Flow
☐ BeOpt
☐ COMFEN
☐ Climate Consultant
☐ Daysim
☐ DesignBuilder
☐ Diva for Rhino
☐ Energy Plus
☐ eQuest/DOE2
☐ F-Chart
☐ HAP
☐ HEED
☐ IES VE
☐ Ladybug/Honeybee plugins for Rhino
☐ Manual tables, charts, and protractors
☐ OpenStudio
☐ PHPP (Passive House Planning Package)
☐ Radiance
☐ Revit Tools/Plugins
☐ Sefaira
☐ Solidwork Flow Plugins
☐ Spreadsheets
☐ TAS
☐ Therm
☐ TRNSYS
☐ WUFI
☐ Personal or In-house Software (please specify)
☐ Other (please specify)
☐ None



When do you calculate the energy savings from passive/natural systems in your class projects? *Choose all that apply.*

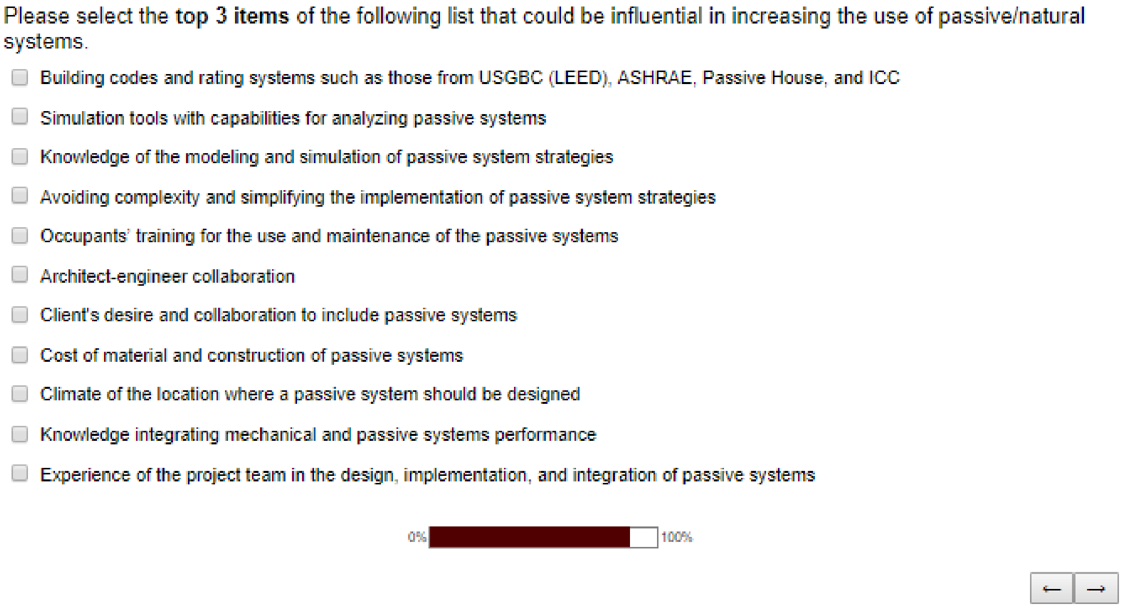
☐ Early design Phase

☐ Before analyzing the use of mechanical systems

☐ After analyzing the use of mechanical systems

☐ After design is finalized

☐ Never



Please select the **top 3 items** of the following list that could be influential in increasing the use of passive/natural systems.

☐ Building codes and rating systems such as those from USGBC (LEED), ASHRAE, Passive House, and ICC

☐ Simulation tools with capabilities for analyzing passive systems

☐ Knowledge of the modeling and simulation of passive system strategies

☐ Avoiding complexity and simplifying the implementation of passive system strategies

☐ Occupants' training for the use and maintenance of the passive systems

☐ Architect-engineer collaboration

☐ Client's desire and collaboration to include passive systems

☐ Cost of material and construction of passive systems

☐ Climate of the location where a passive system should be designed

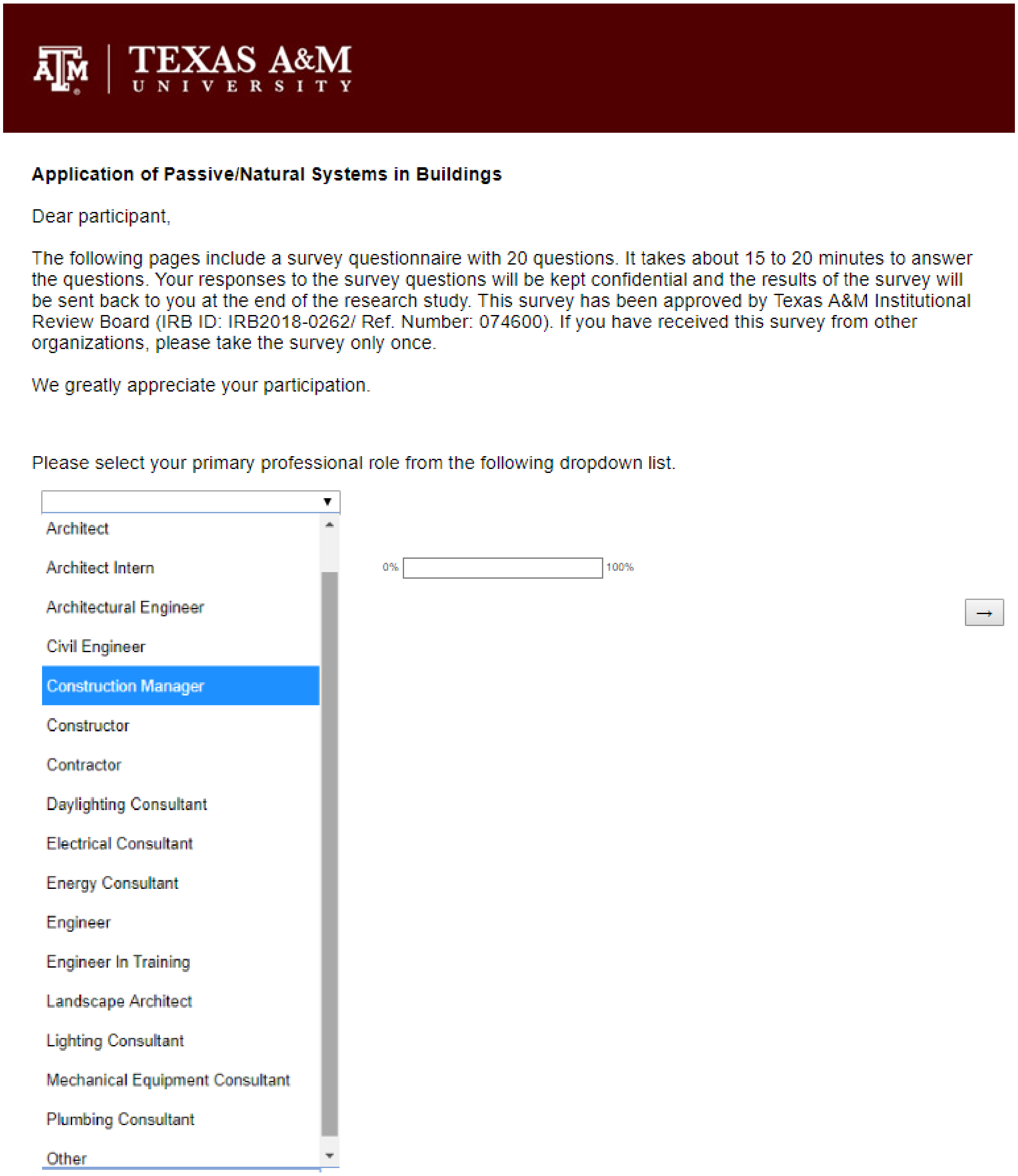
☐ Knowledge integrating mechanical and passive systems performance

☐ Experience of the project team in the design, implementation, and integration of passive systems

Please select your age.

If there are any additional notes/comments not addressed in this survey about the education/application of passive/natural systems in buildings, please respond in the text box below.

Survey Questionnaire for Practitioners



Application of Passive/Natural Systems in Buildings

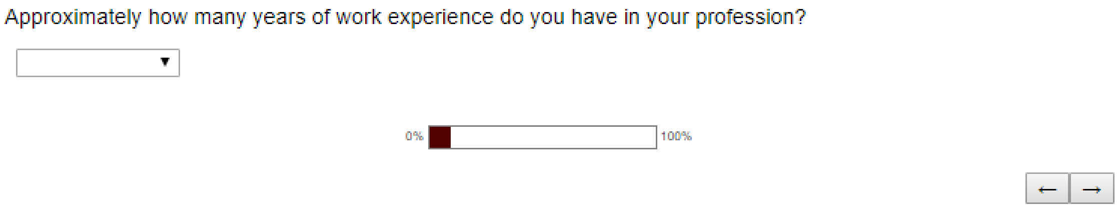
Dear participant,

The following pages include a survey questionnaire with 20 questions. It takes about 15 to 20 minutes to answer the questions. Your responses to the survey questions will be kept confidential and the results of the survey will be sent back to you at the end of the research study. This survey has been approved by Texas A&M Institutional Review Board (IRB ID: IRB2018-0262/ Ref. Number: 074600). If you have received this survey from other organizations, please take the survey only once.

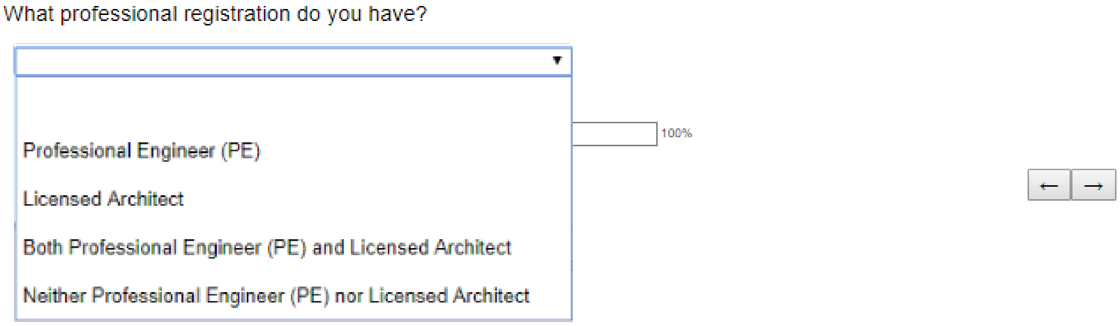
We greatly appreciate your participation.

Please select your primary professional role from the following dropdown list.

- Architect
- Architect Intern
- Architectural Engineer
- Civil Engineer
- Construction Manager
- Constructor
- Contractor
- Daylighting Consultant
- Electrical Consultant
- Energy Consultant
- Engineer
- Engineer In Training
- Landscape Architect
- Lighting Consultant
- Mechanical Equipment Consultant
- Plumbing Consultant
- Other



Approximately how many years of work experience do you have in your profession?



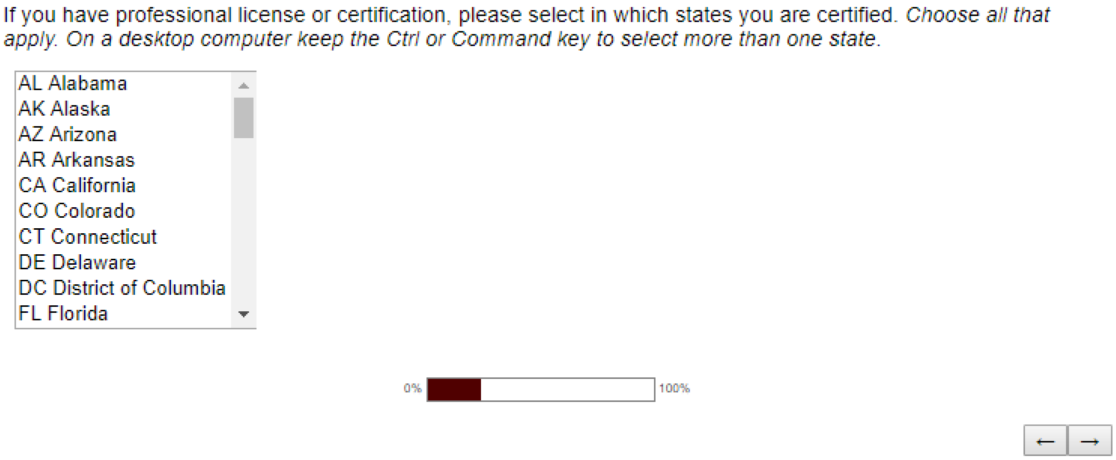
What professional registration do you have?

Professional Engineer (PE)

Licensed Architect

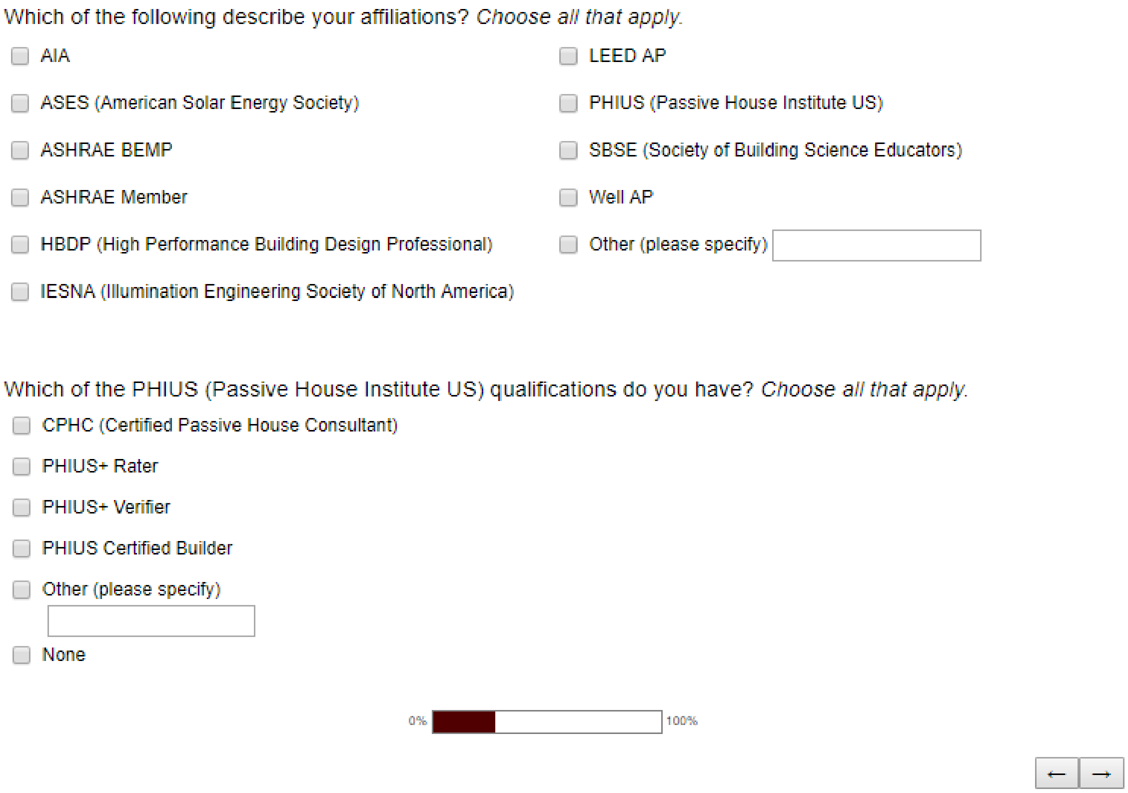
Both Professional Engineer (PE) and Licensed Architect

Neither Professional Engineer (PE) nor Licensed Architect



If you have professional license or certification, please select in which states you are certified. *Choose all that apply. On a desktop computer keep the Ctrl or Command key to select more than one state.*

AL Alabama
AK Alaska
AZ Arizona
AR Arkansas
CA California
CO Colorado
CT Connecticut
DE Delaware
DC District of Columbia
FL Florida



Which of the following describe your affiliations? *Choose all that apply.*

☐ AIA

☐ ASES (American Solar Energy Society)

☐ ASHRAE BEMP

☐ ASHRAE Member

☐ HBDP (High Performance Building Design Professional)

☐ IESNA (Illumination Engineering Society of North America)

☐ LEED AP

☐ PHIUS (Passive House Institute US)

☐ SBSE (Society of Building Science Educators)

☐ Well AP

☐ Other (please specify)

Which of the PHIUS (Passive House Institute US) qualifications do you have? *Choose all that apply.*

☐ CPHC (Certified Passive House Consultant)

☐ PHIUS+ Rater

☐ PHIUS+ Verifier

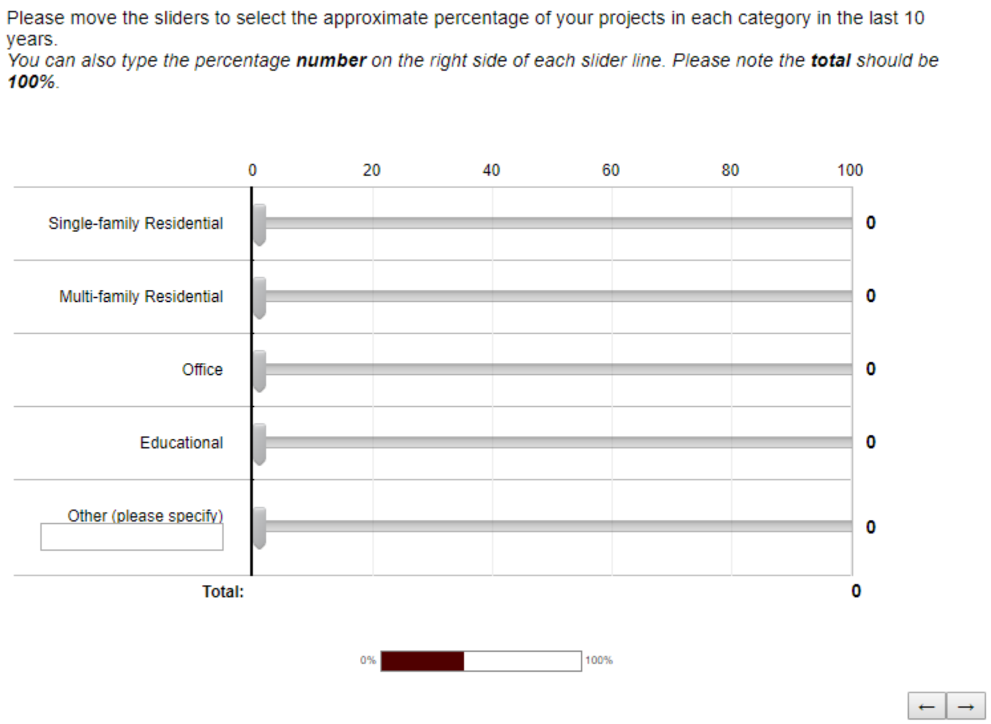
☐ PHIUS Certified Builder

☐ Other (please specify)

☐ None

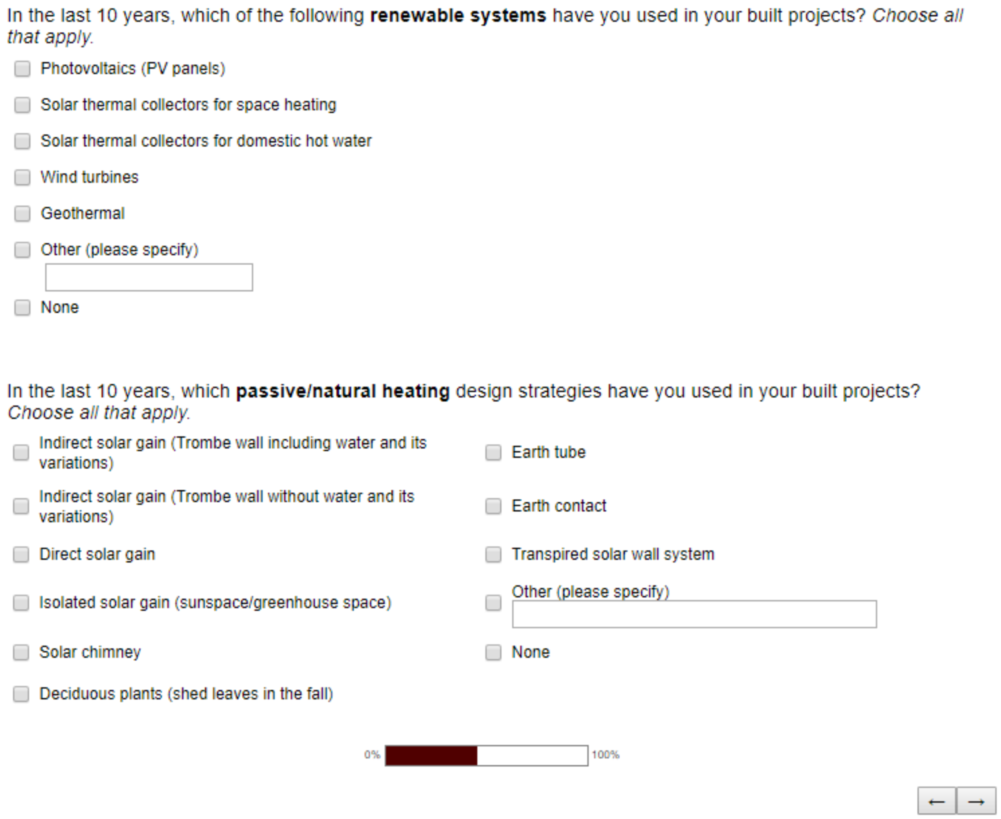
Based on the map below, where did you earn the academic degree(s) most related to your current profession? *Choose all that apply.*

- ☐ Algonquin
- ☐ Appalachia
- ☐ Dry Sierra/Rocky Basin
- ☐ Florida
- ☐ Great Lakes
- ☐ Gulf Coast (South Coast)
- ☐ Mid Atlantic (East Coast)
- ☐ Mid Lands
- ☐ Midwest
- ☐ Mountain
- ☐ New England
- ☐ Pacific Northwest
- ☐ South
- ☐ Southwest
- ☐ Texas
- ☐ West Coast
- ☐ Abroad (Please specify the country/city) ____



Please move the sliders to select the approximate percentage of your projects in each category in the last 10 years.
You can also type the percentage ***number*** *on the right side of each slider line. Please note the* ***total*** *should be* ***100%****.*

Single-family Residential	**0**
Multi-family Residential	**0**
Office	**0**
Educational	**0**
Other (please specify)	**0**
Total:	**0**

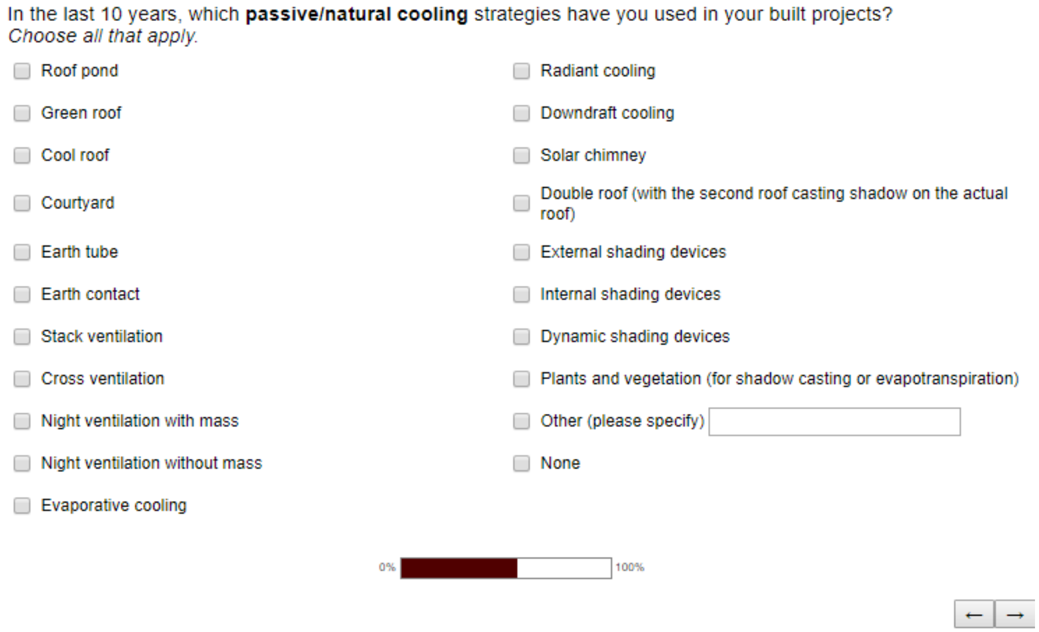


In the last 10 years, which of the following **renewable systems** have you used in your built projects? *Choose all that apply.*

☐ Photovoltaics (PV panels)
☐ Solar thermal collectors for space heating
☐ Solar thermal collectors for domestic hot water
☐ Wind turbines
☐ Geothermal
☐ Other (please specify)
☐ None

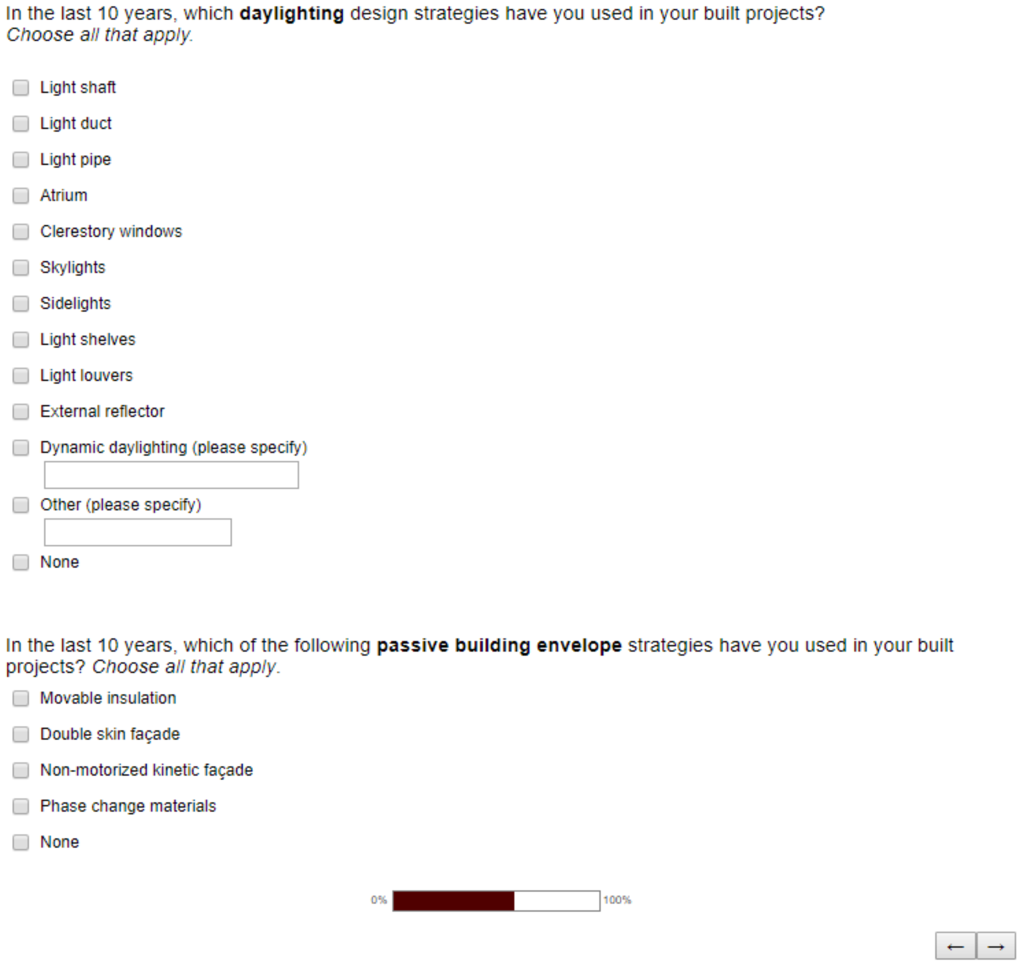
In the last 10 years, which **passive/natural heating** design strategies have you used in your built projects? *Choose all that apply.*

☐ Indirect solar gain (Trombe wall including water and its variations)
☐ Indirect solar gain (Trombe wall without water and its variations)
☐ Direct solar gain
☐ Isolated solar gain (sunspace/greenhouse space)
☐ Solar chimney
☐ Deciduous plants (shed leaves in the fall)
☐ Earth tube
☐ Earth contact
☐ Transpired solar wall system
☐ Other (please specify)
☐ None



In the last 10 years, which **passive/natural cooling** strategies have you used in your built projects? *Choose all that apply.*

- ☐ Roof pond
- ☐ Green roof
- ☐ Cool roof
- ☐ Courtyard
- ☐ Earth tube
- ☐ Earth contact
- ☐ Stack ventilation
- ☐ Cross ventilation
- ☐ Night ventilation with mass
- ☐ Night ventilation without mass
- ☐ Evaporative cooling
- ☐ Radiant cooling
- ☐ Downdraft cooling
- ☐ Solar chimney
- ☐ Double roof (with the second roof casting shadow on the actual roof)
- ☐ External shading devices
- ☐ Internal shading devices
- ☐ Dynamic shading devices
- ☐ Plants and vegetation (for shadow casting or evapotranspiration)
- ☐ Other (please specify) ____________
- ☐ None

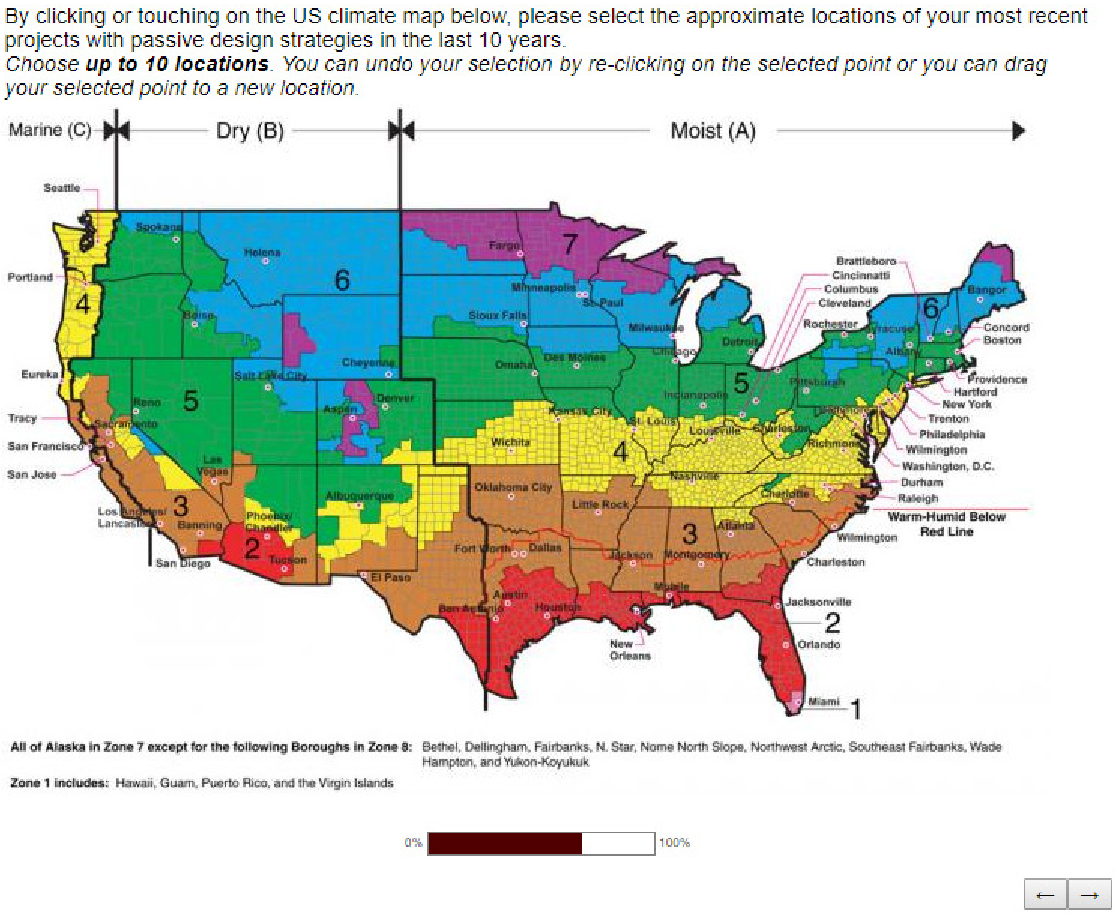


In the last 10 years, which **daylighting** design strategies have you used in your built projects? *Choose all that apply.*

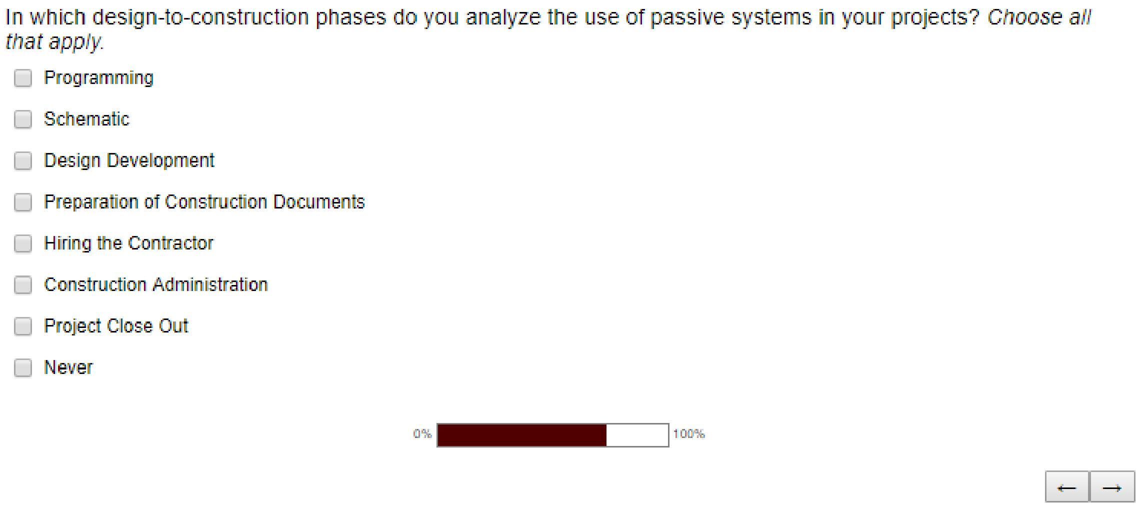
- ☐ Light shaft
- ☐ Light duct
- ☐ Light pipe
- ☐ Atrium
- ☐ Clerestory windows
- ☐ Skylights
- ☐ Sidelights
- ☐ Light shelves
- ☐ Light louvers
- ☐ External reflector
- ☐ Dynamic daylighting (please specify) ____________
- ☐ Other (please specify) ____________
- ☐ None

In the last 10 years, which of the following **passive building envelope** strategies have you used in your built projects? *Choose all that apply.*

- ☐ Movable insulation
- ☐ Double skin façade
- ☐ Non-motorized kinetic façade
- ☐ Phase change materials
- ☐ None



By clicking or touching on the US climate map below, please select the approximate locations of your most recent projects with passive design strategies in the last 10 years.
*Choose **up to 10 locations**. You can undo your selection by re-clicking on the selected point or you can drag your selected point to a new location.*



In which design-to-construction phases do you analyze the use of passive systems in your projects? *Choose all that apply.*

☐ Programming

☐ Schematic

☐ Design Development

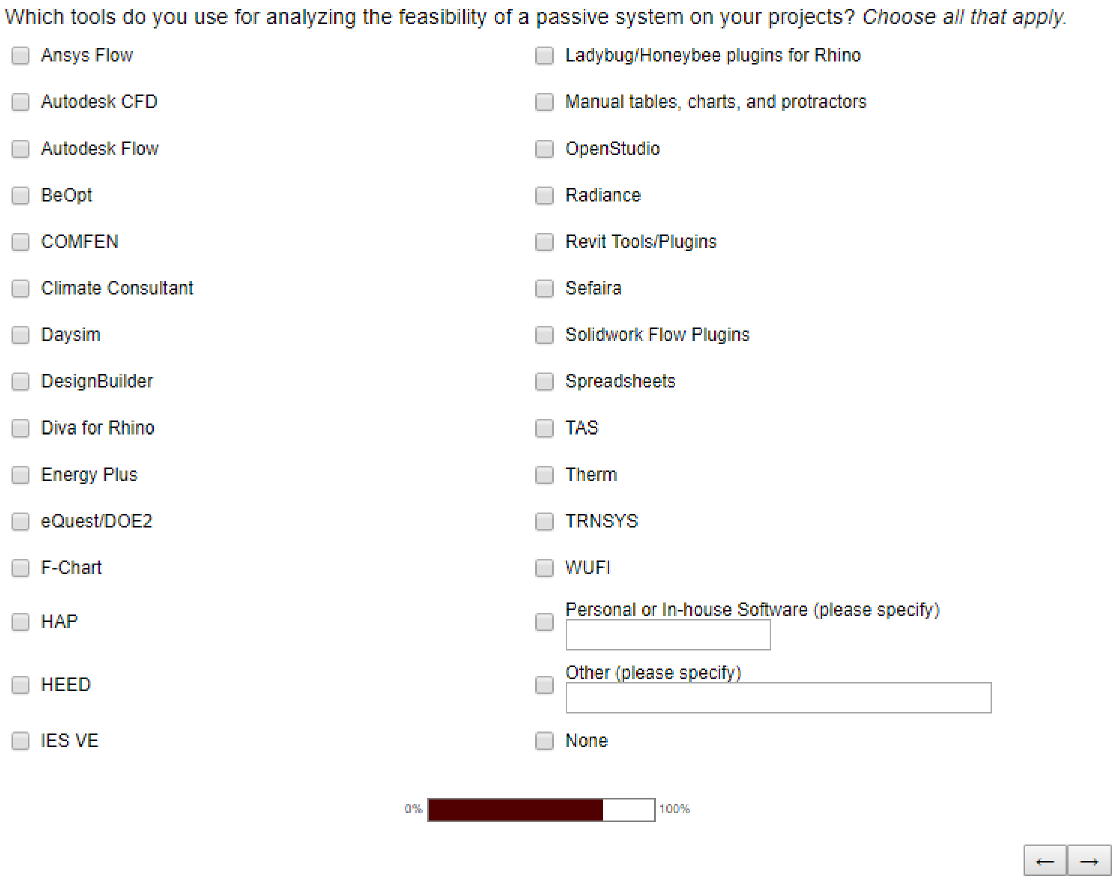
☐ Preparation of Construction Documents

☐ Hiring the Contractor

☐ Construction Administration

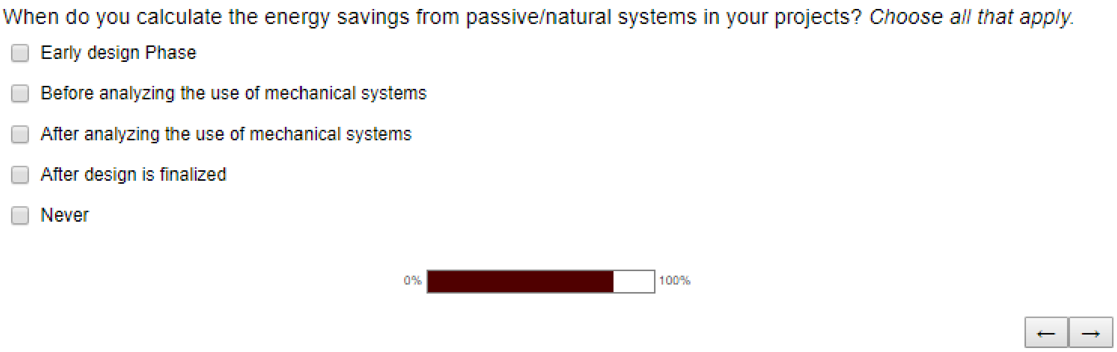
☐ Project Close Out

☐ Never



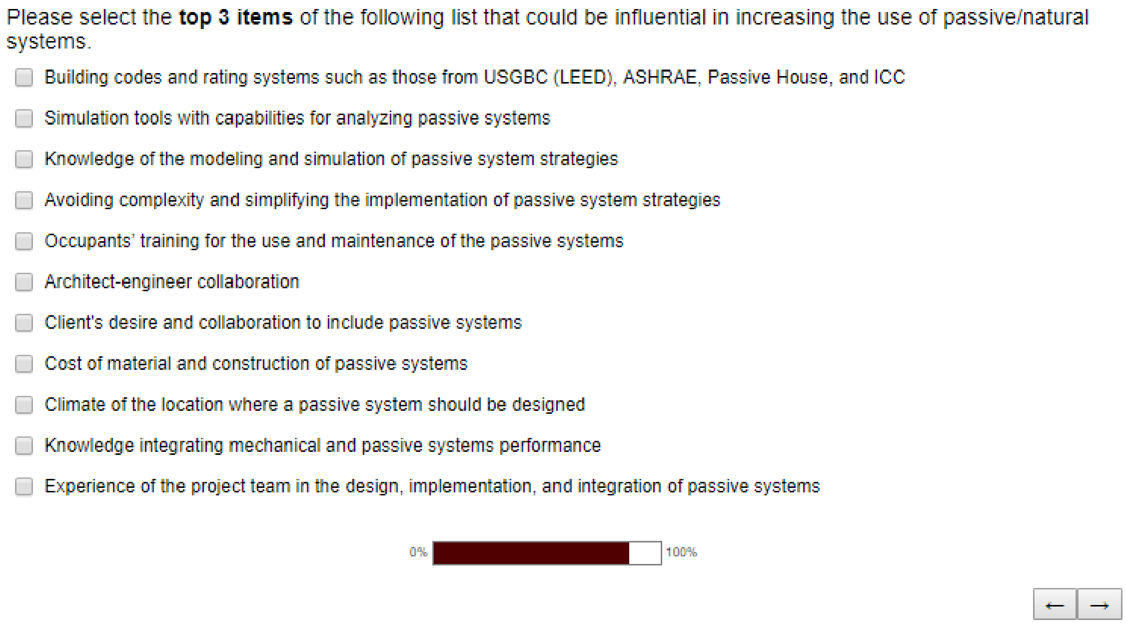
Which tools do you use for analyzing the feasibility of a passive system on your projects? *Choose all that apply.*

☐ Ansys Flow
☐ Autodesk CFD
☐ Autodesk Flow
☐ BeOpt
☐ COMFEN
☐ Climate Consultant
☐ Daysim
☐ DesignBuilder
☐ Diva for Rhino
☐ Energy Plus
☐ eQuest/DOE2
☐ F-Chart
☐ HAP
☐ HEED
☐ IES VE
☐ Ladybug/Honeybee plugins for Rhino
☐ Manual tables, charts, and protractors
☐ OpenStudio
☐ Radiance
☐ Revit Tools/Plugins
☐ Sefaira
☐ Solidwork Flow Plugins
☐ Spreadsheets
☐ TAS
☐ Therm
☐ TRNSYS
☐ WUFI
☐ Personal or In-house Software (please specify)
☐ Other (please specify)
☐ None



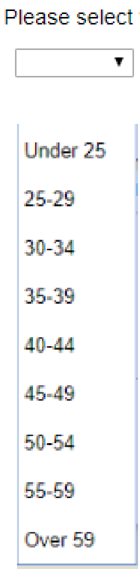
When do you calculate the energy savings from passive/natural systems in your projects? *Choose all that apply.*

☐ Early design Phase
☐ Before analyzing the use of mechanical systems
☐ After analyzing the use of mechanical systems
☐ After design is finalized
☐ Never



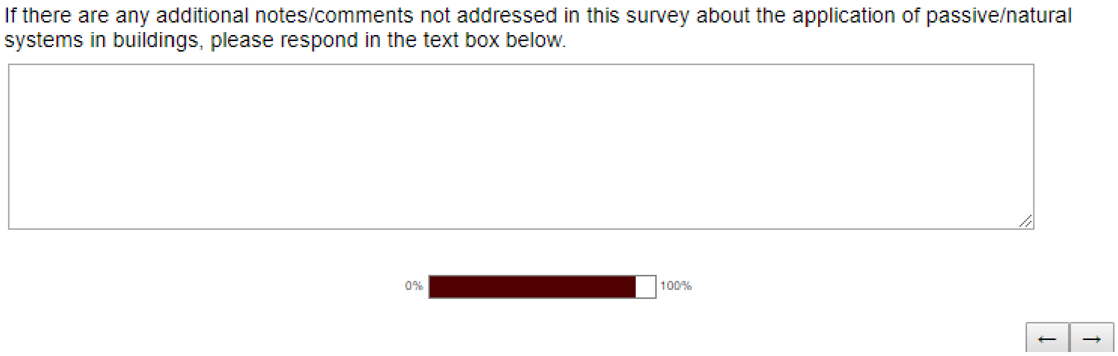
Please select the **top 3 items** of the following list that could be influential in increasing the use of passive/natural systems.

- ☐ Building codes and rating systems such as those from USGBC (LEED), ASHRAE, Passive House, and ICC
- ☐ Simulation tools with capabilities for analyzing passive systems
- ☐ Knowledge of the modeling and simulation of passive system strategies
- ☐ Avoiding complexity and simplifying the implementation of passive system strategies
- ☐ Occupants' training for the use and maintenance of the passive systems
- ☐ Architect-engineer collaboration
- ☐ Client's desire and collaboration to include passive systems
- ☐ Cost of material and construction of passive systems
- ☐ Climate of the location where a passive system should be designed
- ☐ Knowledge integrating mechanical and passive systems performance
- ☐ Experience of the project team in the design, implementation, and integration of passive systems



Please select your age.

- Under 25
- 25-29
- 30-34
- 35-39
- 40-44
- 45-49
- 50-54
- 55-59
- Over 59



If there are any additional notes/comments not addressed in this survey about the application of passive/natural systems in buildings, please respond in the text box below.

APPENDIX D

PARTICIPANTS' RESPONSES TO THE OPEN-ENDED TEXT QUESTION

Practitioners' open-ended text question and responses: **If there are any additional notes/comments not addressed in this survey about the application of passive/natural systems in buildings, please respond in the text box below.**
We evaluate passive systems frequently but almost never employ them. I have done some longer than 10 years ago, and practically none since. The usual problem is that passive systems don't do the whole annual job, and are not able to displace much of the required capacity of active systems. You have to buy two systems. If the building is well insulated, shaded and oriented, the active systems are not too expensive to deploy and operate, leaving little to save from passive systems. Note that insulation, proper use of glazing, orientation and building tightness are the real winners in passive construction.
Passive/natural systems are largely applicable to new buildings, and particularly buildings with substantial lots. More focus is needed on existing buildings and building compactly.
The negatives we have seen with passive systems are: 1 - Europeans pushing in in the USA when their summers have similar DB temperatures, but much lower WB temperatures and then our clients hate it

2 - Occupants who have no understanding of controlling operable windows in passive systems. It takes a fair amount of education to make a person understand weather, psychrometrics, and the effects on the building. One open window can humidify an entire building. Perhaps a RED/GREEN light to tell people they can open up or not is the best solution.
A majority of the strategies listed in this survey are simply not useful. The primary passive tactics to improve energy performance in a high heating climate are continuous insulation and exceptional air-tightness - neither of which are even mentioned. Plus, exterior shading is good for cooling (to avoid overheating). Notes below. -The factors influencing the increase/reduction of the use of passive/natural systems in buildings [building code] -The design tools being used for passive design [PHPP or WUFI Passive] -The most and least recurring types of passive/natural system strategies [continuous insulation + superinsulation and exceptional air-tightness] -The importance of incorporating passive/natural system strategies in a practical design process with respect to their integration with mechanical systems [building form, orientation, layout, and percentage of glazing are important. So during schematic design. Then insulation and window selections during design development. Then construction details for thermal bridging, continuous insulation, and air tightness.] Good luck!

I am mainly and R&D project manager. I do no specifying or managing of actual building projects.
This survey would benefit from better defining "passive/natural systems". It's not clear what's included or not included, and how it differs from existing terms like "high-performance buildings." Regarding the question "How can we increased use of good passive design?" The issue is not on the supply side. It's not an issue of knowledge or capabilities. The issue is demand (by owners / clients). Demand can increase (1) by legislation, i.e. if code requires it, (2) by incentivizing it (tax incentives; development incentives, etc.), or (3) by decreasing cost (even with good integrative design, high-performance buildings generally cost more).
Passive design is not commonly applied in healthcare facilities. However, from a resilience perspective, passive design is starting to pick up. How does a building react during an outage at various weather conditions? We're developing tools and protocols to simulate failures of mechanical systems and determine the impact on the occupied space. For some healthcare facilities, evacuation is not possible.
Much of the earliest energy analytical work done in residential passive systems is documented in the publications (e.g. Passive Solar Design Handbook, Jan. 1980) of Dr. Doug Balcomb et al. working at the Los Alamos National Lab. In my estimation, those publications are the most significant contributions in the current field of passive/natural system design. Additionally, I believe that DOE-2 is the most powerful building energy analysis tool to use when integrating passive and

mechanical system design in commercial and institutional buildings. I would hope that Dr. Haberl would agree with me.
Difficult to do in heavy commercial applications such as healthcare architecture.
It seems like there are built in assumptions about what the 'acceptable' strategies should be... There are a lot of passive strategies and systems that can be implemented beyond the traditional building strategies. For example, what happens in a building is important and often can present opportunities if those operational systems are integrated with the building systems - we do a lot of this with brewery projects.
Our office has designed passive systems since the earliest 1970s
I'm probably not the best example: I was educated in California but now practice in Connecticut and focus on healthcare projects where the environment is highly regulated and mechanical systems are not intended to include passive systems. Furthermore, healthcare projects tend to be hospitals with large footprints (limited perimeter) or developer projects where little thought goes into the core and shell.
Fear of potential Owner/user dissatisfaction with the comfort delivered by the HVAC system, and compliance with ASHRAE guidelines as now referenced in building codes, are a great disincentive in the use of passive systems in commercial/institutional projects.
apparently I am a luddite, the construction of energy efficient buildings need not be so over thought.

Most of our clients want buildings which include passive solar or active solar strategies. However, almost none of them want to pay for it.
You left off the most important single criteria for the adoption of Passive strategies in building design and construction: Beauty. For decades we have concentrated on the savings, cost benefits and justification of passive strategies when I reality the customer usually only wants a beautiful building and becomes suspicious when we begin justifying a design. They will even pay more for a beautiful design. That beauty should include at least four of the five senses. They should feel better, smell better, sound better, and look better. And they usually do. But above all they should look better, because that is what the public sees in magazines films and on the internet.
I have asked Autodesk for years to allow me to model the temperature swing in my buildings without taking into effect HVAC in an effort to judge efficacy of passive measures. Need a naked button, haven't seen it.
Finding out what incentive states are providing would also help. Getting the power company to be more collaborative, so we can show the financial benefit to the owner and also reviewing agency to learn about it.
Passive systems are actually part of indigenous design that existed prior to modern mechanical systems. The renewed interest in using passive heating and cooling as well as humidification strategies for buildings comes from the need for long term cost saving solutions as well as the aesthetic value of natural building modeling.

Certain states are behind the times in innovations and technology use. This drives the cost of new systems or construction styles way up, making it nearly impossible to get clients on board. Best of Luck with your studies.
I would like to specify that I believe CODES have a greater impact on the increase in use of passive systems than rating systems. Rating systems are not practical for smaller scale projects due to cost. They serve as great guidelines, but codes need to be more strict.
I trust that "passive systems" are any type of construction system for building enclosure and not just specialized systems that are proprietary or add-ons.

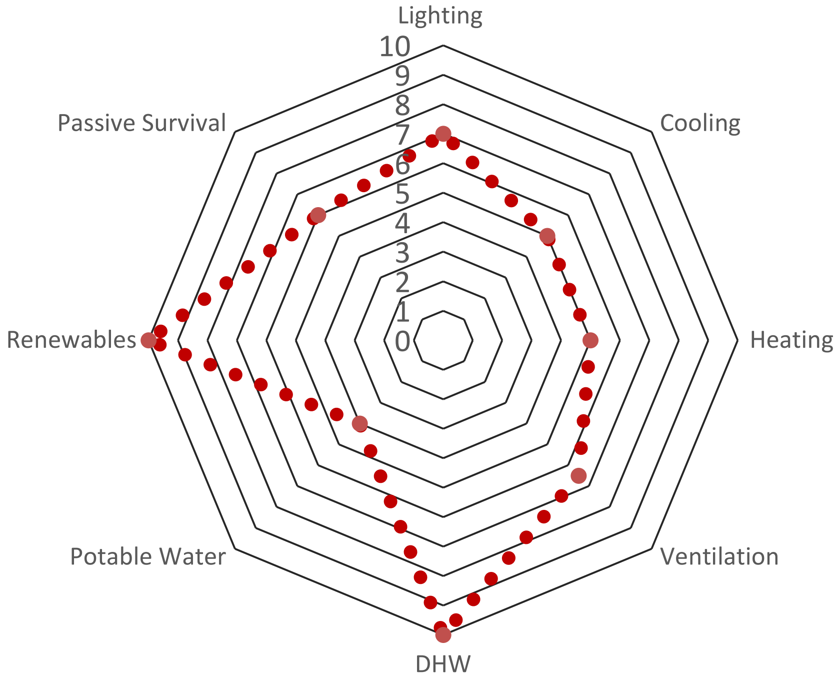
Educators' open-ended text question and responses **If there are any additional notes/comments not addressed in this survey about the education/application of passive/natural systems in buildings, please respond in the text box below.**
I teach a survey course to third year architecture students. Learning the concepts is key.
Very little time to delve into much detail about any particular system - need to cover site design, HVAC, plumbing, fire protection & detection, electrical, lighting, vertical transportation, acoustics and LCCA in 15 weeks
It is implied here, but learning and teaching basic rules of thumb for various passive design strategies with respect to overall limits on building or zone size/massing/scale, etc. is a critical first step in seriously implementing many passive design strategies. I would also like to see the results of this survey...looking forward to you sharing this with the participants.
The focus of my teaching has varied greatly over the years. In the last ten years this has meant that I have covered the issues of the survey primarily in the design studio.
Keep in mind that architects are generally responsible to design and integrate systems, but not to calculate their performance (with some rare exceptions). Generally, engineers are responsible for calculations regarding the heating & cooling of buildings. The use of passive systems are driven partly by the client's responsiveness to them (sunshades, etc. all come with cost premiums) and the

proven effectiveness of the systems (generally evaluated through the consulting engineer's energy model).
The students are so preoccupied with design studios that it's difficult to implement any sort of intensive calculation or simulation methods unless it directly relates to their studio projects.
Simulations need lifecycle costing associated with energy benefits to find the value over an owner interested period of time - usually it must pay back in less than 5-7 years max and if less than 2 years it will be adopted.
The survey seems to take a technological only approach to the problem. Narrow comfort standards and the drift in Modern expectations are part of a cultural issue. Passive design can run across the curriculum, but is rarely addressed as theory or in history classes. DOE funding almost never engages passive issues. They want commercialization products, not embodied intelligent architectural configuration. Passive House claiming the term passive is also a problem.
There is a long and rich history of passive solar design, both in the southwest but in other part of the country where the climate requires less obvious strategies. A retrospective survey of some of the earlier iconic passive solar buildings to see how they are performing now would be a great addition to the literature.
There needs to be a greater opportunity for a nimble analysis of design options as student designs rapidly evolve in the design studio.

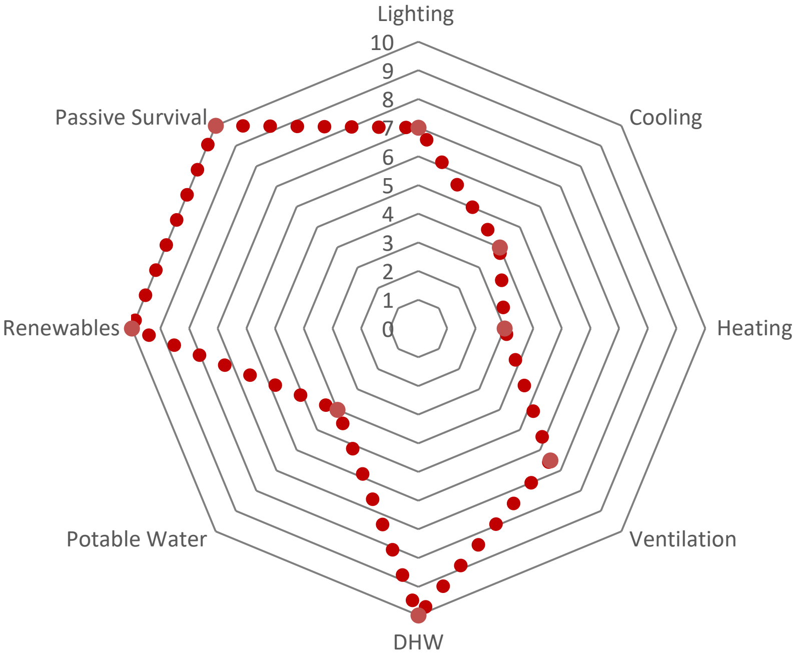
In general, architects seem to not feel comfortable including substantive passive systems in their projects. This is probably partly due to lack of actionable design knowledge, partly due to lack of readily accessible analysis tools, and partly due to lack of appreciation for the carbon-reduction potential of even part season use of passive systems.

APPENDIX E

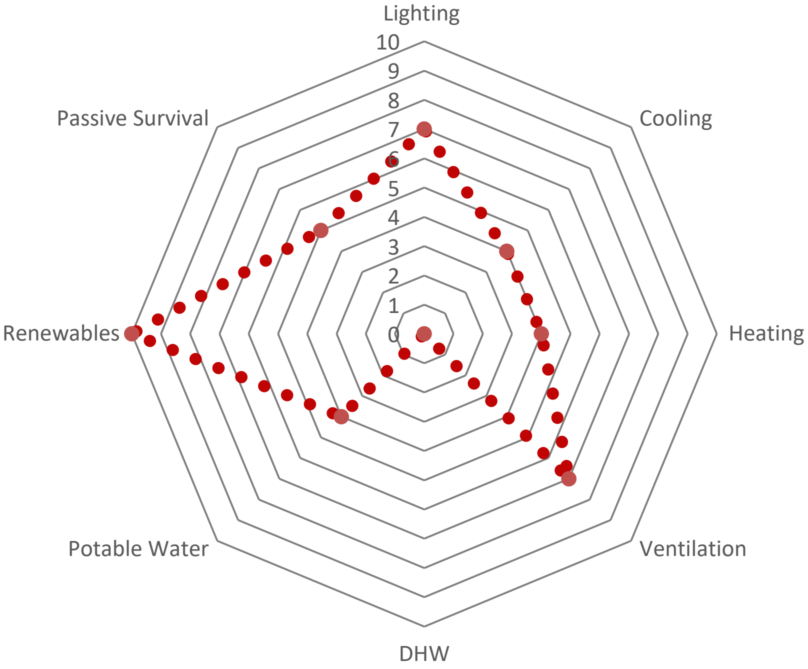
RADAR CHARTS FOR 2017 AIA COTE TOP TEN CASE STUDIES



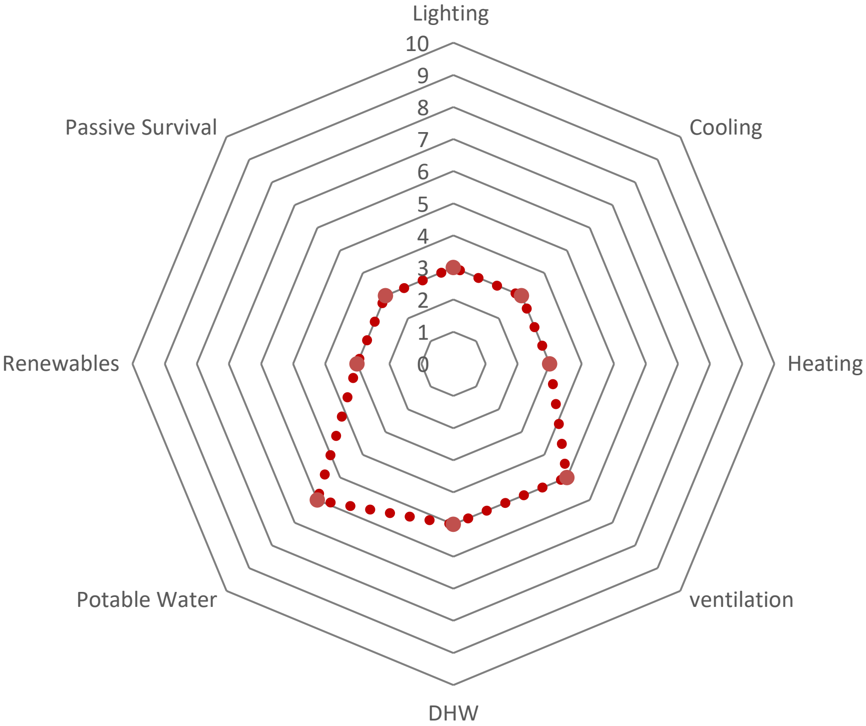
1.Passive Performance of the Stanford University Central Energy Facility, Stanford, California, Climate Zone 3C



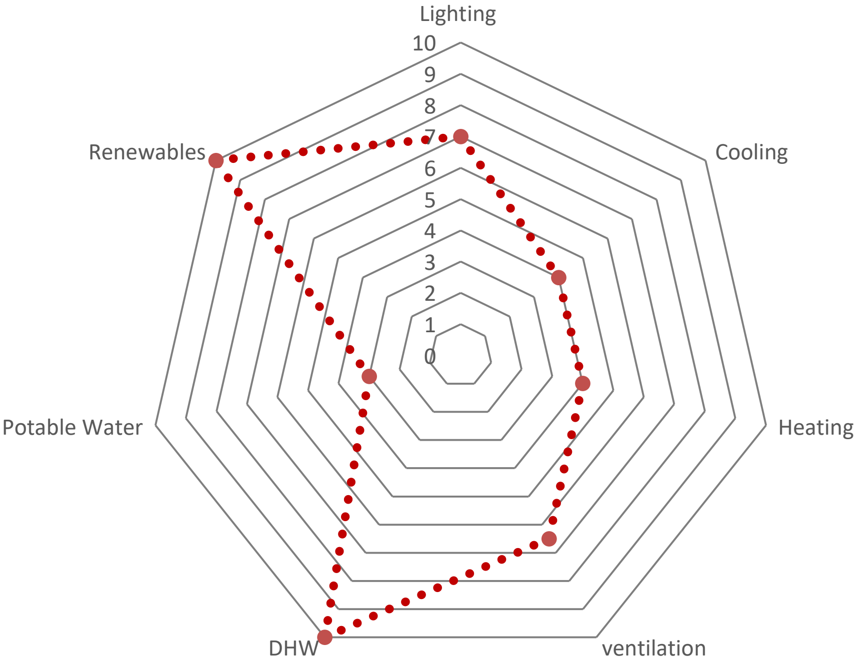
2. Passive Performance of the Bristol Community College John J. Sbrega Health and Science Building, Fall River, Massachusetts, Climate Zone 6A



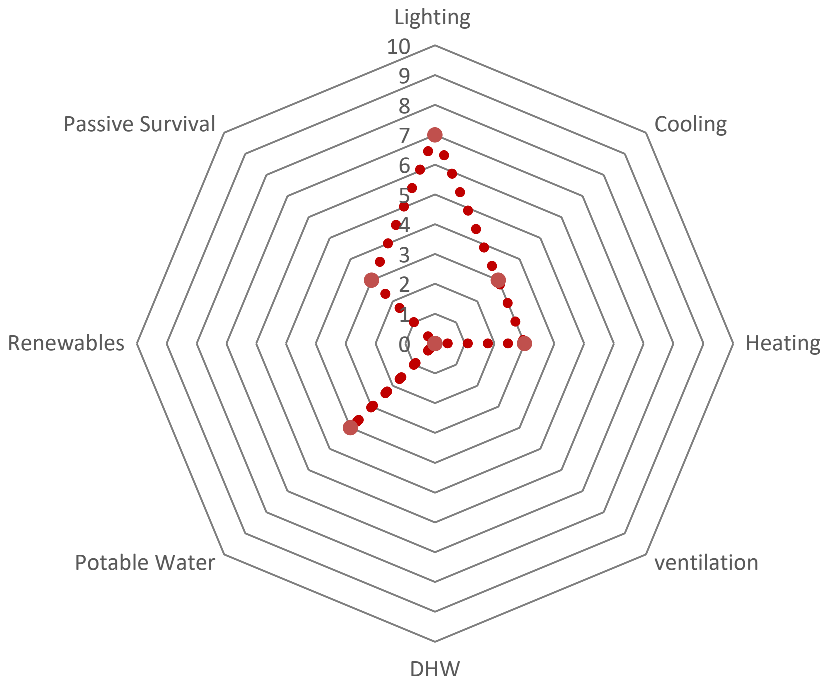
3. Passive Performance of the Brock Environmental Center Virginia Beach, Virginia, Climate Zone 3A



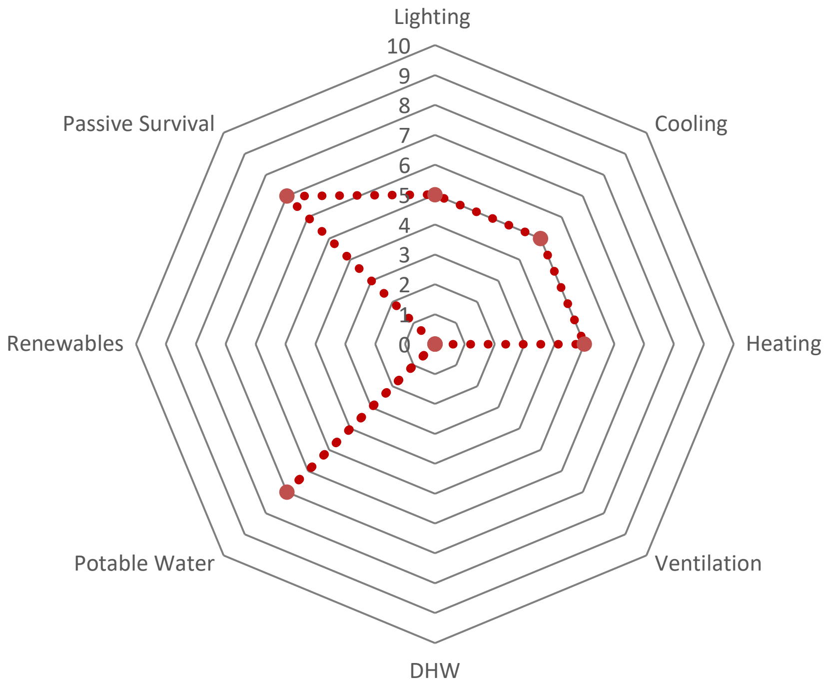
4. Passive Performance of Chatham University Eden Hall Campus, Richland Township, Pennsylvania, Climate Zone 5A



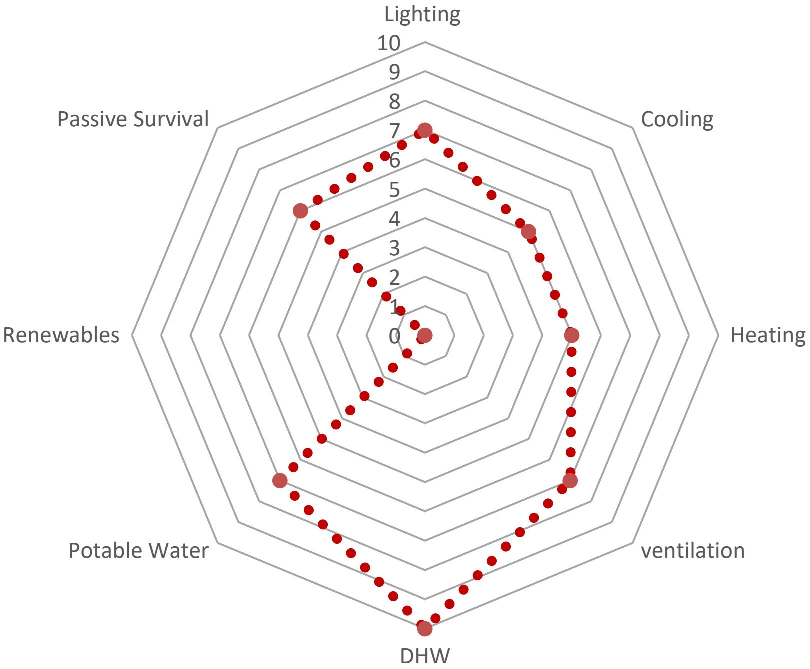
5. Passive Performance of the Discovery Elementary School (Passive Survival information was insufficient), Arlington, Virginia, Climate Zone 4A



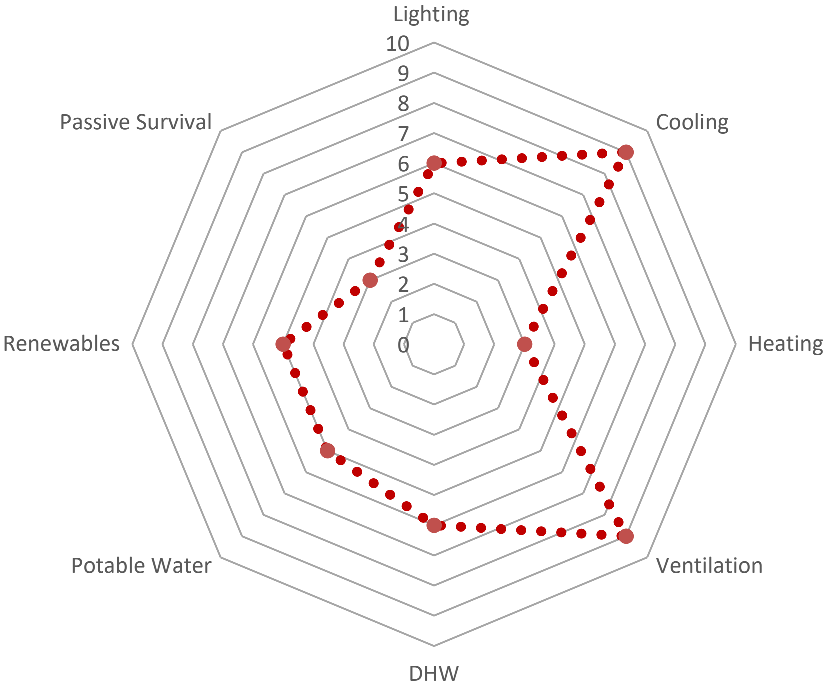
6. George Washington University, Milken Institute School of Public Health, Washington DC, Climate Zone 4A



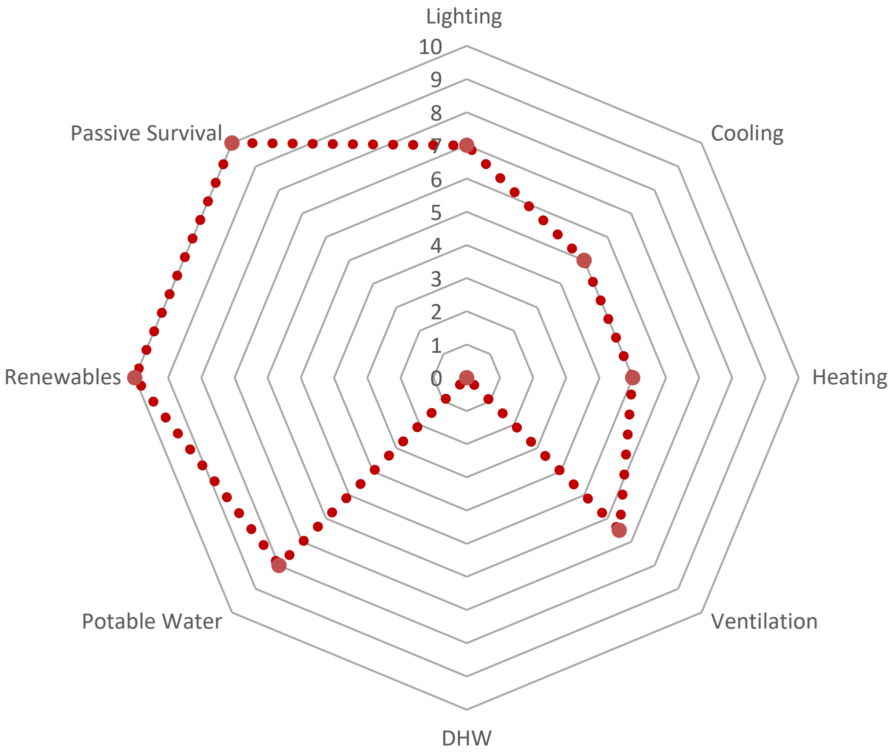
7. Manhattan Districts 1/2/5 Garage & Spring Street Salt Shed, New York, Climate Zone 4A



8. Green Mark Platinum-certified Ng Teng Fong General Hospital (NTFGH), Singapore, Climate Zone 1A



9. NOAA Daniel K. Inouye Regional Center, Honolulu, Hawaii, Climate Zone 1A



10. R.W. Kern Center for Hampshire College Campus, Amherst, Massachusetts, Climate Zone 5A

APPENDIX F

TABULAR ANALYSIS OF AIA COTE TOP TEN 2017 AND 2010 AWARDS

In the following pages each awarded project from the year 2017 (Table F.1) and the year 2010 (Table F.2) has been analyzed based on its passive and active performance achievements and design strategies. The tables related to the analysis of projects inside the US are shown in gray and the tables related to projects outside the US are shown in coral color. These projects were studied and analyzed mainly based on the data available on AIA website at https://www.aia.org/resources/73026-cote-top-ten-2017 and http://www.aiatopten.org/taxonomy/term/5.

Table F.1. 2017 AIA COTE Top Ten Award Case Studies

Project	Year of completion	Project team	Location /Climate	Envelope/Water	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
Stanford University Central Energy Facility	2015 Industrial/ Institutional -design completion in 2013 Gross conditioned: 9,530 SF Gross unconditioned: 116,084 SF Number of occupants/visitors: 42	**Architect:** ZGF **Prime contractor/lead mechanical/electrical/plumbing engineer**: Affiliated Engineers Inc. **Construction contractor:** The Whiting-Turner Contracting Company **Civil engineer:** BKF Engineers **Structural engineer:** Rutherford + Chekene **Landscape architect:** Tom Leader Studio https://www.zgf.com/contact/ **Function:** Office and Other (power plant and teaching facility)	Stanford, California/ 3C	- Will be connected to a future municipal system that will provide non-potable water for process cooling and irrigation of native landscaping. native plants and porous gravel to assist in recharging the ground water table - Bioswales will collect stormwater runoff. Drip irrigation, rather than spray, waters the plants. - Low-flow fixtures will minimize potable water use (lavatory faucets: 0.35 gpm; kitchen faucets: 1.5 gpm; toilets: 1.28 gpf; urinals: 0.125 gpf) - 67% reduction from the previous co-generation facility, which is equivalent to making 557 typical office buildings net-zero water.	-Use of BioPCM (a phase-change material) located in the ceiling provides additional thermal mass to mediate temperatures -Extensive shading roof which is integrated with 175 kW PV array provides four times the building's internal energy needs	-Maximizes daylighting with floor to ceiling glass panes -Narrow 27 ft. floor for office building, along with shading of the PV canopy, offers glare-free daylight and views -Industrial areas of the building, housing chiller and boilers, have translucent skylights and ground level curtain walls to provide ambient light during daytime hours PFVO[1]: 100% PFW/O[2]: 100%>300 lux at 3pm March 21 SDA: 100%	-The open-air plan with high ceilings, fans, and operable windows permits natural ventilations PFW30[3]: 100%	-68 MW solar farm (150000 PV panels) producing 65% of the energy for the plant - Extensive shading roof (which also has an integrated 175 kW PV array providing four times the building's internal energy needs -Converts heat supply of all buildings from steam to hot water -Heat recovery loop captures 2/3 of heat waste from campus cooling system for hot water -Radiant slab is used with exposed chilled beam for heating and cooling -LED lights with occupancy sensors and daylight dimming control	The switch from campus steam to hot water reduces losses throughout the system, uses the waste heat entrained in the chilled water return loop to meet 93 percent of the campus heating demands, and reduces the need for cooling towers. The project is designed to connect to a future municipal system that will provide non-potable water for process cooling and irrigation of native landscaping—the largest water demands. The landscaping utilizes native plants and porous gravel to assist in recharging the ground water table, as well as bioswales to collect stormwater runoff. Drip irrigation, rather than spray, waters the plants. The building features low-flow fixtures. -No blackwater or graywater reuse -Potable water for Irrigation	-Net positive energy -Greenhouse gas emissions reduced by 68%, fossil fuel use reduced by 65%, and water use reduced by 18% - Predicted consumed EUI: 25 kBtu/sq ft/yr - Predicted Net EUI: -75.2 kBtu/sq ft/yr - Predicted Net carbon emissions: -14.4 lb/sq ft/yr -Predicted percent reduction from national average EUI for building type: 230 percent -Predicted lighting power density: 0.44 W/sq ft - Anticipated number of days the project can maintain function without utility power: 3 days (the plant can provide 72 hours of thermal utilities, and has three fuels for hot water production for maximum resiliency) -Because of the mild climate, daylighting, and use of natural ventilation, the administrative office is claimed passively survivable year around

[1] Percentage of floor area or percentage of occupant work stations with direct views of the outdoors (PFVO)

[2] Percentage of floor area or percentage of occupant work stations achieving adequate light levels without the use of artificial lighting (PWF/O)

[3] Percentage of floor area or percentage of occupant work stations within 30 feet of operable windows (PFW30)

Project	Year of completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
Bristol Community College John J. Sbrega Health and Science Building	July 2016 -design completion in 2011 Area: 50,600 SF Number of occupants/visitors: 11,111	**Landscape Architect and Architect:** Sasaki **MEP:** Bard Rao+ Athanas Consulting Engineers **Structural:** RSE Associates **Fire protection:** Fernandez Associates **Civil engineer:** Nitsch Engineering **Geothermal:** Haley and Aldrich **Specifications:** Steven McHugh, Architect **Code:** Jensen Hughes **Construction management:** Bond Brothers WWW.SASAKI.COM fcrowell@sasaki.com principal: Fiske Crowell, FAIA, LEED AP **Function:** Educational Replacement project for a science and health learning center	Fall River, Massachusetts, Zone 6A	–	- Six solar thermal roof-mounted hot water collectors (65 MMBtu/Yr. hot water) -Use of ground temperature in GSHP - Self-shading with deep roof overhangs; shading devices	-Daylight/occupancy sensors -Glazed atrium -Clerestory on the east side -curtain walls south and north -Glare is controlled with both fritted glass and window treatments PFVO: 92% PFW/O: 70%>300 lux at 3pm March 21	Natural ventilation with operable windows, automatic in the living room and manual in labs PFW30: 90%	-3.2 MW solar array over a parking lot in addition to the site array, but is not part of the project - Enthalpy wheel heat recovery -Decoupling cooling/heating from ventilation -Fan coil units are used for local control -Ductless/filtration fume hoods/air-quality monitoring is used in laboratories -Ground source/air source heat pump -DOAS for ventilation -LED	-A 10,000-gallon detention facility is located underneath the lawn to offset the limited storage capacity of the basins. See diagram illustrating the flow of storm water. -The landscape plantings are native species and do not rely on irrigation. -Low-flow fixtures reduce water usage by 40 percent. -Water is not re-used, but the bioswales and infiltration basins recharge the aquifer - Blackwater or graywater is not reused	-Reaching a NZE building without changing the budget -Predicted consumed EUI: 50 kBtu/sq ft/yr -Predicted Net EUI: 0 kBtu/sq ft/yr -Predicted Net carbon emissions: 3.45 lb/sq ft/yr - Predicted percent reduction from national average EUI for building type: 100 percent -Predicted lighting power density: 0.58 W/sq ft - 67% reduction in airflow -33%-67% ACH reduction -40 percent reduction in LPD - Awarded by Massachusetts DOER the highest commercial building Pathways to Zero grant -LEED Silver - The claimed passive survival is year around

Project	Year of completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Milestones
Brock Environmental Center	2015 -Design completion in 2013 Gross conditioned floor area: 10,518 SF Number of occupants or visitors: 25,000	**Architect:** SmithGroupJJR WWW.SMITHGROUPJJR.COM **Engineer (MEP):** SmithGroupJJR **Engineer (civil):** WPL Site Design **Engineer (structural)**: A+F Engineering **General contractor:** Hourigan Construction **Landscape architect:** WPL Site Design **Owner's representative:** Skanska USA **LBC/LEED management:** Janet Harrison Architect **MEP commissioning:** Brooks + Wright **Building enclosure commissioning:** The Facade Group **Function:** Education, General, Office, and Public Assembly. Chesapeake Bay Foundation's (CBF) Hampton Roads office, supporting their education, advocacy and restoration initiative	Virginia Beach, Virginia/ 3A	-Exterior envelope (R-31 walls, R-50 roof, R-7 windows) significantly reduces heating demand. -sized windows (25% WWR) to provide optimal daylight, views, and ventilation, without excessive heat gain - All materials used inside the center comply with the LBC Red List	-Direct gain: long bar curves slightly to the east, allowing morning sun to preheat the interior -Porch along south façade shading the interior from unwanted heat gain	-North-facing clerestory windows provide glare-free daylight - 97 percent reduction in lighting energy. A white, acoustical metal deck ceiling and high, north clerestory windows maximize daylighting effectiveness from direct daylight -Blinds PFVO: 100% PFW/O: 100%>300 lux at 3pm March 21	-Loft-like interiors to promote natural stack/cross ventilation -breaking floor plate with a dogtrot; a dogtrot is an open air pass-through that creates a comfortable micro-climate while promoting airflow to reduce horizontal stratification. -The primary circulation corridor along the south edge buffers workstations from cool breezes to extend the natural ventilation season - Operable windows PFW30: 100%	-VRF HVAC system coupled with DOAS ventilation, utilizes 18 ground-source wells, improving heating and cooling efficiency -45 KW roof mounted PV on the south-facing roof -Two 10 kW wind turbines -Occupancy sensors control lighting, ventilation, and plugs -Ceiling fans/task lights	Living Building Challenge LEED Platinum (2009) NPE (produce 80% more energy than consumed yearly) Zero Waste -first project in the stat e to gain approval for potable use of rainwater -Predicted consumed EUI: 15.5 kBtu/sq ft/yr -Predicted net EUI: -6.6 kBtu/sq ft/yr -Predicted net carbon emissions: -7.7 lb/sq ft/yr - Predicted percent reduction from national average EUI for building type: 100 percent -Predicted lighting power density: 0.69 W/sq ft POE results: -Actual consumed EUI: 14.12 kBtu/sq ft/yr -Actual net EUI: -11.69 kBtu/sq ft/yr -Actual net carbon emissions: -12.6 lb/sq ft/yr -Passive survivability claimed: 5 days

Project	Year of completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
Chatham University Eden Hall Campus	2015 -design completion in 2013 Gross conditioned floor area: 42,219 SF Gross unconditioned floor area: 3,050SF Number of occupants/visitors: 150	WWW.MITHUN.COM **MEP:** Interface Engineering **Constructed wetlands and water system design:** Biohabitats **Civil:** Civil and Environmental Consultants (CEC) **Structural:** KPFF Engineers **Onsite project management:** Rothschild Doyno Collaborative **General contractor:** Sota Construction **Commissioning agent:** CJL Engineering **Food service:** The Marshall Associates **Lighting designer:** WSP | Parsons Brinckerhoff **AV/Acoustics:** Shen Milson & Wilke **Accessibility:** Studio Pacifica **Envelope:** Simpson Gumpertz & Heger **Function:** Education, Restaurant, Dormitory, Public Assembly	Richland Township, Pennsylvania/ 5A	-Superinsulated envelope - PPG cost-effective double glazed products that out-perform triple glazed options - Innovative rainscreen cladding by TAKTL, a local business that developed a low embodied energy method	-Solar hot water -Earth loop -Shading with overhangs	PFVO: 94% PFW/O: 30%>300 lux at 3pm March 21	operable windows PFW30: 77%	- Photovoltaic (PV) rooftops (such as 58 KW Welcome Shelter and 38 KW for a lab) and canopies; geo-exchange -10 kW co-generation plant in the dining commons produces electricity and hot water using natural gas with bio-fuel equivalency -Energy loop links buildings, enhancing the efficiency as low temperature geo-exchange water acts as a thermal sink and distributes excess heat to other buildings. -Electric induction cooking, high-efficiency refrigeration and a root cellar (65% reduction in energy use) -Radiant heating and cooling system embedded in the gypsum board ceiling, quietly heating and cooling -DOAS	-Use of potable water is reduced through onsite water treatment and reuse of effluent from all buildings except the Orchard Dorms -The toilet flushing demand is provided by reclaimed water from the campus system -Percentage of water consumed onsite from rainwater capture: 39% -Percentage of water consumed onsite from greywater/blackwater capture and treatment: 16%	Targeting Living Building Challenge, and LEED Platinum; Grid connected, targeting net energy positive campus 20 EUI for building loads exclusive of food prep and aquaculture systems -Predicted consumed EUI: 105.9 kBtu/sq ft/yr -Predicted net EUI: 76.23 kBtu/sq ft/yr -Predicted net carbon emissions: 727,525 lb/sq ft/yr - Predicted percent reduction from national average EUI for building type: 70% -Predicted lighting power density: 0.72 W/sq ft POE results: -Actual consumed EUI: 91 kBtu/sq ft/yr -Actual net EUI: 62.23 kBtu/sq ft/yr -Actual net carbon emissions: 593,912 lb/sq ft/yr -Passive survivability claimed: 1 day

Project	Year of completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
Discovery Elementary School	2016 -design completion in 2014 Gross conditioned floor area: 97,588 SF Number of occupants/visitors: 715	**Architect:** VMDO Architects WWW.VMDO.COM **Engineer (mechanical, lighting, net-zero energy design)**: CMTA Consulting Engineers **Engineer (power, plumbing, fire protection):** 2rw Consultants Inc. **Engineer (structural):** Fox + Associates **Engineer (civil):** Bowman Consulting Group **Food service consultant:** EIS Inc. **Landscape architect:** Oculus **Traffic:** Toole Design Group **Cost estimating:** Downey & Scott **Construction manager:** Heery Philip Donavan (architect member) **Function:** Education–K-12 School	Arlington, Virginia/4A	Air tight envelope tested at 0.12 cfm/ft2 38% glazing Super insulated but over-conservative amounts of polystyrene roof insulation were reduced Interior CMU was replaced with high-impact, high recycled content gypsum wall board The exterior envelope was a load-bearing insulated concrete wall system (one of the first in the region)-allowing for a significant reduction in the high levels of embodied energy contained in structural steel	Ideal orientation for solar generation Solar hot water High thermal mass through ICF construction ((Insulated Concrete Forms) Thermal mass Roof shape	PFVO: 76.8% PFW/O: 75%>300 lux at 3pm March 21 62 Solatubes A terraced building section that brought light deep into the building while maximizing roof top	Operable windows PFW30: 72%	- Roof mounted photovoltaic (PV) panels maximum 500kW (due to local utility maximum permission) A lab-quality sensor constantly monitors CO₂ levels in every regularly occupied space and all break-out instructional spaces: a total of 61 monitoring points. When any space exceeds 700 ppm, an increased rate of fresh air is supplied. All electric kitchen Geothermal source energy	Rainwater captured for use by the project; 1% of water consumed onsite comes from rainwater captured Greywater or blackwater not captured for re-use; Percent of rainwater that can be managed on site from maximum anticipated 24-hour, 2-year storm event: 19.2%	First net zero energy school in the Mid-Atlantic, the largest in the US -Predicted consumed EUI: 21.2 kBtu/sq ft/yr -Predicted net EUI: -0.85 kBtu/sq ft/yr -Predicted net carbon emissions: -0.39 lb/sq ft/yr - Predicted percent reduction from national average EUI for building type: 69% -Predicted lighting power density: 0.55 W/sq ft POE results: -Actual consumed EUI: 16.21 kBtu/sq ft/yr -Actual net EUI: -0.65 kBtu/sq ft/yr -Actual net carbon emissions: -0.29 lb/sq ft/yr - Actual percent reduction from national average EUI for building type: 76% -Passive survivability claimed: unknown (several days)

Project	Year of completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
George Washington University , Milken Institute School of Public Health	2014 -design completion in 2012 Gross conditioned floor area: 145,700 SF Gross unconditioned floor area: 15,400SF Number of occupants/visitors: 1477	**Architect:** Payette WWW.PAYETTE.COM **Civil engineer:** Wiles Mensch Corporation **MEP/FP engineer:** Affiliated Engineers, Inc. **Structural engineer:** Tadjer-Cohen-Edelson Associates **LEED consultant**: Paladino and Company **Lighting designer:** Atelier Ten **Elevator consultant:** Zipf Associates, Inc. **Acoustical/Audiovisual:** Shen Milsom Wilke **Code consultant:** Rolf Jensen Associates **Fire protection consultant:** R.W. Sullivan Engineering **Function:** Education—College/University campus level	Washington, DC /4A	Triple glazing to minimize heat gain/loss	An extensive green roof, with plantings adapted to the heat and harsh urban environment of DC White PVC roof to minimize heat island effect	PFVO: 84% PFW/O: 64%>300 lux at 3pm March 21 SDA=64% Skylit atrium design brings daylight into all floors of the building (20' wide maximum)	PFW30: 0%	- Heat recovery chiller and energy wheel -Meters were installed to permit energy measurement and verification -Active chilled beams which decouple cooling from ventilation (hydronic chilled beam requiring less space) -Occupancy sensors to control lighting and ventilations -Low velocity underfloor displacement air in seat pedestals -DOAS for ventilation with dual wheel exhaust air heat recovery -Occupant sensing LED	Low flow plumbing fixtures The rainwater harvest system contributes to a 41 percent reduction in building fixture water usage. The use of native and adaptive plants for landscaping Rainwater captured for use by the project; 15% of water consumed onsite comes from rainwater captured Greywater or blackwater is not captured for re-use	LEED Platinum (v2009) Predicted consumed EUI: 84 kBtu/sq ft/yr Predicted net EUI: 84.1 kBtu/sq ft/yr Predicted net carbon emissions: 28.2 lb/sq ft/yr Predicted percent reduction from national average EUI for building type: 64% -Predicted lighting power density: 0.84 W/sq ft - 30% reduction in lighting power density POE results: -Actual consumed EUI: 82.3 kBtu/sq ft/yr -Actual net EUI: 82.3 kBtu/sq ft/yr -Actual net carbon emissions: 30.3 lb/sq ft/yr - Actual percent reduction from national average EUI for building type: 65% Passive survivability claimed:1 day Payback period: PV—18 yrs; heat recovery chiller—16 years; triple glazing—30 years

Project	Year of completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water
Manhattan Districts 1/2/5 Garage & Spring Street Salt Shed	2015 Design completion in 2012 Gross conditioned floor area: 302,023SF Gross unconditioned floor area: 140,152 SF Number of occupants/visitors: 238 FTE staff	**Architect:** Dattner Architects WWW.DATTNER.COM **Manhattan Districts 1/2/5 Garage** **General contractor:** DeMatteis **Construction Company/Darcon Joint Venture** **Engineer (structural):** The Burns Group **Engineer (civil & MEP):** Greeley and Hansen **Commissioning:** Horizon Engineering Associates **Engineer (geotechnical):** Langan Engineering **Curtain wall consultant:** Front Inc. **Lighting designer:** Domingo Gonzalez Associates, Inc. **Landscape architect:** Abel Bainnson Butz, LLP **Vertical transportation:** Van Deusen & Associates (VDA) **Engineer (traffic):** Philip Habib & Associates Architectural specifications: Robert Schwartz Associates **Construction manager:** Turner Spring Street Salt Shed **General contractor:** Oliveira Contracting, Inc. **Engineer (structural):** The Burns Group **Engineer (civil & MEP):** Greeley and Hansen **Engineer (geotechnical):** Langan Engineering **Lighting designer:** Domingo Gonzalez ssociates, Inc. **Landscape architect:** Abel Bainnson Butz, LLP **Architectural concrete consultant:** Reginald Hough FAIA/Terra Tech Associates Inc. **Architectural specifications:** Robert Schwartz Associates **Construction manager:** Turner **Function:** Office and maintenance garage	New York, NY/4A	Double-skin facade that reduces solar gain while allowing daylight; comprised of glazed curtain wall and 2,600 custom perforated-aluminum solar shading devices (fins)	Ideal orientation for solar generation A 1.5-acre green roof protects the roof membrane, reduces heat-island effect, enhances storm water retention and thermal performance. The green roof is comprised of 13,250 pre-planted trays to allow for a quick installation and to bring already established plants to the site.	PFVO: 93.5% PFW/O: 0%>300 lux at 3pm March 21 The 2,600 perforated sunshades reduce direct sunlight on the glazing by 67 percent, limiting solar heat gain within the garage while still allowing in an abundance of natural light At the south-facing personnel areas, and at the repair bays on the west side, the fins are operable and track the sun's location throughout the day -Daylight harvesting	FW30: 0%	- 35.8% reduction calculated using the ASHRAE 90.1-2004 methodology. -Use of municipal steam for heating -and cooling - a condensate heat recovery system -Multi-level lighting fixtures -use of continuous air monitoring and BMS control of ventilation rates - Through the use of municipal steam, no fuels are burned in the building. The steam is used to generate hot water to temper the air in the Garage, heat the personnel spaces, and provide domestic hot water. Steam absorption chillers provide air-conditioning in the personnel offices and locker rooms. A 275 kW extracting turbine generator, powered through the step-down process from the high-pressure steam service to the working pressure steam used in the building, further reduces grid loads.	The green roof participates as a building system by providing a habitat and food for migratory birds, capturing 100 percent of rainwater and improving views for neighboring buildings. Greywater is used as a source for flushing restroom fixtures and truck washing. Planted with 25 distinct drought-resistant species, the roof requires no permanent irrigation. The plant variety includes a bio-diverse mix of sedum, sempervivum, and flowering perennials. Percentage of water consumed onsite from rainwater capture: 64.2% Greywater/blackwater captured for reuse 100% of rainwater can be managed on site

Project	Year of completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
Green Mark Platinum-certified Ng Teng Fong General Hospital (NTFGH)	2015 -design completion in 2011 Gross conditioned floor area: 1,962,853 SF Number of occupants/visitors: 1100	**Architect:** HOK WWW.HOK.COM **Architects/Structural/ Civil:** CPG Consultants Pte Ltd **Design Consultant and Medical Planning:** HOK **Design Consultant:** Studio 505 Melbourne **Green Mark Consultant:** ZEB Technology Pte Ltd Singapore **Mechanical and Electrical Engineer:** Parsons-Brinkerhoff **Landscape:** Peridian Asia Pte Ltd **Interior Design:** Bent Severin and Associates Pte Ltd **Function:** Health Care (Clinic, Hospital Inpatient, Medical Office; Outpatient) General	Singapore/1A	Pre-fabricating precast modules	70% of the facility is passively cooled with natural ventilation - 100% hot water demand met by solar thermal Thermal mass Cross ventilation Exterior shading Dense vegetation covering low roofs and much of the site which form healing gardens Vegetation also grows vertically up the building, both in planter boxes and along wires linking floors Projecting slabs and light shelves shade the high sun angles. Custom external shading devices include sliding sunscreens and light shelves. The shading design was optimized to provide at least 60 percent shading for critical facades and 40 percent for other facades.	PFVO: 70% PFW30: 70% PFW/O: 50%>300 lux at 3pm March 21 DF in all wards> 2% Illumination is 850 Lux near the windows to 100 lux in circulation spaces A saw-tooth design that provides every patient with a window.	70% of the facility is naturally ventilated, representing 82% of inpatient beds Every patient with an adjacent operable window NTFGH incorporates parks, green roofs and vertical plantings throughout the campus	-100kWp photovoltaic array -Demand-controlled ventilation -Ceiling fans -Fluorescent T5 and LED lighting with daylight and occupancy sensors -BMS incorporates monitoring, occupancy levels, and sleep modes -The mechanical system uses efficient plant-side and air-side equipment, with a target system efficiency of <0.625 kW/ton -Heat recovery in ORs: heat pumps and heat exchangers with runaround coils -Chiller plant measurement and verification system -For mechanically cooled spaces, dual mode switches automatically cut off air conditioning when windows are open -Escalators and elevators in standby mode when occupancy is low	-The use of natural ventilation and passive cooling for 70% of the building significantly reduces water use. For the remaining cooling needs, the HVAC system uses NEWater, a pillar of Singapore's water sustainability strategy. This municipally scaled wastewater treatment system treats reclaimed water to high-grade, potable standards. Because of its low mineral content, NEWater is more effective than standard tap water in the HVAC system and can be used for more cycles -Low flow fixture; future possibility for toilet flushing reusing the water -No potable water for irrigation	NTFGH was the first to use a cross ventilation scheme that allows for high ventilation rates at every patient bed without cross-contamination -Predicted consumed EUI: 70 kBtu/sq ft/yr -Predicted net EUI: 69.8 kBtu/sq ft/yr -Predicted net carbon emissions: 19.5 lb/sq ft/yr - Predicted percent reduction from national average EUI for building type: 38% (70% compared with US type hospitals) -Predicted lighting power density: 0.74 W/sq ft -Passive survivability claimed: 7 days

Project	Year of completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
R.W. Kern Center for Hampshire College campus	2016 -design completion in 2015 Gross conditioned floor area: 16,940 SF Gross unconditioned floor area: 870 SF Number of occupants/visitors: 36	**Architect:** Bruner/Cott & Associates WWW.BRUNERCOTT.COM **Advisor (Living Building Challenge):** Coldham & Hartman Architects **Construction manager:** Wright Builders **Consultant (code):** Cutler Consulting **Consultant (cost estimating):** A.M. Fogarty & Associates Inc. **Consultant (energy and systems):** South Mountain Company **Consultant (LBC material vetting):** Integrated Eco Strategy **Consultant (lighting design):** Lewis Lighting Design, LLC **Consultant (specifications):** Kalin Associates **Engineer (electrical):** R.W. Sullivan **Engineer (fire protection):** Rybak Engineering **Engineer (geotechnical):** O'Reilly, Talbot & Okun Associates **Engineer (mechanical, plumbing, and controls):** Kohler & Lewis Engineers **Engineer (site/civil and permitting):** Berkshire Design Group **Engineer (structural):** Foley Buhl Roberts & Associates **Landscape architect:** Richard Burke Associates	Amherst, Massachusetts/5A	WWR: 30% An air-tight envelope Simple, economical wood framing Double-stud cavity wall and roof are filled with cellulose to achieve assembly values of R-40 and R-60, respectively Cellulose insulation was selected for most parts as a low-carbon, high-performance, non-toxic, and recyclable material Carbon-sequestering wood as the major structural material	Thermal efficiency to help mitigate swings in temperature and humidity typical of New England Passive solar orientation Exterior shades; roof as a shading device Triple glazed windows	PFVO: 100% PFW/O: 100%>300 lux at 3pm March 21 -Tall operable windows help achieve a fully daylight building with a window to wall ratio of 30 percent -Light louvers for windows reflecting daylight and daylight harvesting control	-Operable windows -PFW30: 100%	- Grid tied PV system generates about 17% more energy than the building uses - Inverter-driven heat pump system provides heating and cooling to the spaces, separate from the heat recovery ventilation system. - Temperature-independent ventilation systems ensure adequate air circulation -LEDS	-Net-zero water - The building employs a net-positive water system, capturing, treating, and disposing of all its own water on site. Rainwater is collected from the roof and stored in two 5,000 gallon cisterns adjacent to the building. From these it passes through carbon and UV filters in the basement, and is ready to use as potable supply throughout the building; eliminates damaging stormwater runoff for a 10-year storm, capturing it in raingardens where it is re-absorbed on site and recharges the local watershed. - Composting toilets eliminated creation of blackwater and reduced overall water consumption to 100 gallons per day, about 10 percent of the standard usage for buildings of this type. -Greywater from sinks is filtered through indoor planters in the building's central common space, where it evapotranspires, and, if needed, to an on-site constructed wetland of native plantings.	Living Building Certified Achieved net zero energy and water and was built without red list products. Beyond these achievements, as a net-positive project, the Kern Center has no utility bills. -Predicted consumed EUI: 23 kBtu/sq ft/yr -Predicted net EUI: 0 kBtu/sq ft/yr -Predicted net carbon emissions: 0 -Predicted lighting power density: 0.52 W/sq ft -Passive survivability claimed: unknown

Project	Year of completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
NOAA Daniel K. Inouye Regional Center	2014 -design completion in 2010 Gross conditioned floor area: 350,000 SF Number of occupants/visitors: 800	**Architect:** HOK **Principal, project manager, project architect:** Ferraro Choi and Associates **Project engineer, general contractor:** Walsh Construction **Civil engineer:** Kennedy Jenks Consultants **Structural engineer:** SOHA Engineers **Mechanical engineer:** WSP Flack + Kurtz **Security, acoustics:** Shen Milsom Wilke **Fire protection:** S.S. Dannaway Associates, Inc. **Sustainability:** Built Ecology **Commissioning:** Glumac Engineers **Landscape architect:** Ki Concepts **Food service:** George Matsumoto Associates **Vertical transportation:** Syska Hennessy Group Inc. **Historic preservation:** Mason Architects **Exhibit space:** Downstream **Graphic design and copy writing:** Design Asylum Inc. Phase 3 **Cost estimating:** Davis Langdon **Code consulting:** Rolf Jensen & Associates **Environmental, geotechnical:** Kleinfelder **Geotechnical engineer:** Geolabs **Door hardware:** Door Hardware Consultants **Traffic consultant:** Wilbur Smith Associates **Air quality, wind:** Cermak Peterka Peterson Inc. **Seawater consultant:** Tom Nance Resource Engineering **Function:** Office—100,001 or greater, Public Assembly—General, Public Assembly—Library, Public Safety—General, Storage— general, other	Honolulu, Hawaii/1A	High performance envelope	Passive downdraft cooling Geo-exchange	PFVO: 4% PFW/O: 45%>300 lux at 3pm March 21 SDA: 57% Skylights and atriums Light wells Crafted light lanterns that capture and reflect sunlight down into the space without artificial lighting. Translucent reflectors below glow like light fixtures, distributing sunlight and reflecting it back up to the ceiling, which becomes a luminaire	Stack ventilation: Cool ventilation air through the passive downdraft system is supplied to occupied spaces via a raised access floor utilizing 'displacement' principles. After being supplied at low levels, the air draws heat from occupants, equipment, lights, solar and, as its temperature rises, it becomes less dense and more buoyant, rising up through the building via interconnected light wells and atria before being exhausted to atmosphere. The building ventilates its public and private/office spaces using no mechanical fans and 100 percent outside air. The exhaust ventilation system is also 100 percent passive. PFW30: 0%	PV system Solar thermal Geo-exchange Heat Recovery System Active Chilled Beams in labs Underfloor air distribution system Automated modulating dampers on the roof adjusting for the desired wind for the downdraft system	The harvested (non-potable) water supplies the toilet flushing requirements for plumbing systems. A second strategy relies on the capture and use of the greywater waste from electrical water coolers, condensate from the rooftop mechanical equipment, and the building lavatories and showers fitted with low-flow fixtures. The greywater supplies the site landscape irrigation systems and provides 100 percent of the irrigation demand, minimized by the use of native and adaptive landscaping.	LEED Gold The ecology of the Pacific Islands and the mission of NOAA inspired the biomimetic design of integrated systems for air flow, daylighting and water distribution. emulating the morphology of native Hawaiian trees for passive cooling, ventilation and lighting systems. Trees protect themselves from hot temperatures by pulling soil moisture through the vascular structure into the leaves. Moisture released as water vapor creates a cooling effect around the canopy. Similarly, a hydronic system pulls water from below the sea bed into roof cools. The prevailing sea breezes pass over these cool coils and enable natural ventilation that drops the cooled, fresh air supply into vertical "thermal chimneys" (passive downdraft) and through a displacement system of raised floors. -Predicted consumed EUI: 72 kBtu/sq ft/yr -Predicted net EUI: 72 kBtu/sq ft/yr -Predicted net carbon emissions: 6.28 lb/sq ft/ yr -Predicted percent reduction from national average EUI: 58% -Predicted lighting power density: 0.81 W/sq ft -Passive survivability claimed: 3 days

Table F.2. 2010 AIA COTE Top Ten Award Case Studies

Project	Year of Completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
355 11th Street	2008 14,000 SF	**Architect:** Aidlin Darling Design Joshua Aidlin Aidlin Darling Design http://www.aidlindarlingdesign.com/ **Contractor**: Daniel Pelsinger from Matarozzi/Pelsinger Builders **Environmental building consultant:** William Worthen from Simon and Associates, Green Building Consultants **Structural engineer**: Bill Lynch from Berkeley Structural Design **Mechanical and commissioning engineer**: Chikezie Nzewi, CB Engineers **Civil:** Bruce Davis from Sandis Engineers **Landscape architect:** Jeffrey Miller from Miller Company **Streetscape Designer:** Jane Martin from Shift Design Studio **Geotechnical Engineer**: Craig Herzog from Herzog Geotechnical Consulting Engineers **Lighting designer**: Leslie Siegel, LC from Associated Lighting Representatives, Inc. **Function:** Mixed – Use, Food Service Restaurant/Cafeteria Office	San Francisco, CA/ 3C	Customized CNC (computer numerical control) milling allowed the creation of a seamless, building-scale gradient—from opaque to over 50% open—across the entire façade	- A green roof with native plants which insulate the building, and decrease the urban heat-island effect - Natural ventilation - The perforated outer skin mitigates solar heat gain - Over 90% of all site surfaces (including building roof areas) are either planted or high-albedo, serving to lower surface temperatures and thus helping to mitigate the urban heat-island effect	PFVO: 100% Building's new metal skin perforated with fields of small holes that allow light to pass through new operable windows hidden beyond, to provide passive cooling and natural ventilation for warmer periods	-Breathable skin: a new metal skin is perforated with fields of small holes that allow air to pass through new operable windows hidden beyond for cross ventilation; perforated, operable east and west facades exploit these east-west breezes to provide passive cross-ventilation -Operable skylights	-30KW PV producing 38% of the building's annual electricity - In-floor radiant heating to maintain comfort on cooler days (for cooling the building in this mild climate is dependent on natural ventilation) - Daylight sensors automatically adjust the output of the main light fixtures to take full advantage of available sunlight. LED task lighting at each workstation ensures efficient personal control of individual lighting conditions.	Permeable surfaces on over 85% of the available non-building site area, allowing stormwater to drain directly to the water table. Naturally sandy soil in the immediate area absorbs water readily, discouraging saturation. Xeriscaping: Native/adapted plant species have been used throughout the site, resulting in a landscape that will not require supplemental irrigation after an initial one-year establishment period.	LEED-NC Gold (v2.2, 2009) adaptive reuse of a historic (and previously derelict) turn-of-the-century industrial building Predicted consumed EUI: 19 kBtu/sf/yr Predicted Net EUI: 12 kBtu/sq ft/yr Predicted lighting power density: 9.6-kW (6.5-kW)

Project	Year of Completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
Michael J. Homer Science and Student Life Center	2009 Gross Floor Area: 44,109 SF	**Architect:** Leddy Maytum Stacy Architects http://www.lmsarch.com William Leddy (main contact) **Contractor**: Eric Lamb from DPR Construction **Structural engineer**: David Mar from Tipping Mar **Landscape architect**: Marco Esposito SWA Group **MEP:** John Andary from Stantec **Civil engineer:** George Luk from LUK Associates **Theater / AV Consultant**: Adam Shalleck Theater / AV Consultant **Lighting designer**: David Malman from Architectural Lighting Design **Acoustical:** Charles Salter from Charles M. Salter Associates, Inc. **Commissioning agent**: Maia Speer Guttmann & Blaevoet **Food Service Consultant**: Patrick Stein from Patrick Stein and Associates **Laboratory Consultant**: Glen Berry from Design for Science **Function:** Education-K12	Atherton California/3C	High-performance glazing	-Building mass - a green roof/ living roof -Energy Star-rated cool roofing - high-albedo pavement -natural ventilation for cooling for the 100% areas of the building - Fixed sunshades on the south, east and west facades -Operable external sunshades are provided on the west-facing - The building is organized on an east-west axis, with the two-story classroom mass to the south and the auditorium, Oak Court and offices organized against it to the north; continuum of indoor/outdoor gathering spaces on the first floor, from the sunny southern dining patio to the shady northern Oak Court. Very compact form configuration to minimize conditioned area, maximize plan, structure and skin efficiencies The net-to-gross floor area ratio is 82%	PFVO: 98% Integrating proper orientation, light shelves and tubular skylights, 100% of classrooms, offices and corridors on the second floor employ daylighting. Overall, 55% of all buildings spaces use daylight as the primary light source High-efficiency lighting is controlled by timers, occupancy sensors, and daylight dimming systems	The building orients to the prevailing winds, allowing 100% of classrooms, offices, and the dining hall—and 50% of all combined interior spaces—to be naturally ventilated. Night-time flushing	40-kW PV on the auditorium roof provides 24% of the site energy High-efficiency gas-fired boilers serving in-floor hydronic heating and kitchen waste heat being recovered for water and space heating Energy-efficient lighting is operated by occupancy sensors, timers, and daylight dimming systems Ceiling fans (except in kitchen and auditorium) Energy-efficient evaporative cooling units for additional cooling in classrooms and offices in extreme conditions -Auditorium is conditioned by a hybrid natural ventilation/ underfloor displacement ventilation HVAC system -Energy and water use monitoring system	Potable water use is reduced by over 50% Non-native, water-intensive grass lawns were significantly reduced, while an area equivalent to 182% of the building footprint has been restored using native, drought-tolerant plantings Waterless urinals, super-low flow dual-flush toilets and other water-saving fixtures reduce water consumption by 51% from baseline for non-kitchen uses. The commercial kitchen utilizes water-saving commercial dishwashers and faucets Reduced lawn areas, drought-tolerant native landscaping and drip irrigation systems reduce landscape water use by 52.5% from baseline Irrigation system accommodating hydrozones and climate exposure, and by utilizing advanced, weather-based irrigation controllers living roof, pervious paving and a 8,500 cu. ft. storm drainage retention basin combine to reduce the project's stormwater flow rate by 91%. Stormwater collected in the basin is reduced and treated through infiltration into the soil, surface evaporation, and evapotranspiration from basin plantings	LEED Platinum (LEED 2007 for Schools v 2.0) -Reducing site energy use by 69% from the national average for schools (CBECS 2003) and exceeding the goal set for the 2030 Challenge. -49% less energy per ASHRAE 90.1 - Predicted consumed EUI: 34 kBtu/sf/yr - Predicted Net EUI: 30 kBtu/sq ft/yr Predicted lighting power density: 0.8 w/sq ft

Project	Year of Completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
KAUST	2009 Gross Floor Area: 5,340,000 SF	**Architect:** HOK **Contractor**: Eric Lamb from DPR Construction **Structural engineer**: David Mar from Tipping Mar **Landscape architect**: Marco Esposito SWA Group **MEP:** John Andary from Stantec **Civil engineer:** George Luk from LUK Associates **Theater / AV Consultant**: Adam Shalleck Theater / AV Consultant **Lighting designer**: David Malman from Architectural Lighting Design **Acoustical:** Charles Salter from Charles M. Salter Associates, Inc. **Commissioning agent**: Maia Speer Guttmann & Blaevoet **Food Service Consultant**: Patrick Stein from Patrick Stein and Associates **Laboratory Consultant**: Glen Berry from Design for Science **Function:** Education – College/University (campus-level)	Thuwal, KSA/1A	Terra-cotta, stone, glass and stainless steel were developed in a shared set of building enclosure strategies applied to most spaces Highly insulated metal roof	-Using compact forms, integrated sun shading screens, the passive cooling with natural ventilation and using daylighting applied learning from local traditional passive methods such as Souk, Mashrabiya, Bedouin tent's basic efficiency in sheltering from the sun -Solar thermal for the labs hot water -courtyard with possibility to be covered - Light-colored paving materials - Shading and orientation design: The compact, finger-shaped building floor plates allow for natural daylighting for all perimeter spaces and selected interior spaces. Building orientations limit harsh eastern and western sun exposure while taking advantage of prevailing Red Sea winds (N-NE) to act as a cooling mechanism -Two large solar towers (chimneys) -One million SF of the pedestrian spine is conditioned through passive means	Overall, 60% of all spaces use daylight as the primary light source	Two large solar towers (chimneys) Combined with the prevailing wind direction from the REDSEA	-Air delivery monitoring to remove harmful pollutants and carbon dioxide. - under-floor air distribution system - Dimming ballasts, occupancy sensors and time clocks - Chilled beams -heat recovery wheels - Displacement ventilation - Smart lighting controls - Variable frequency drives -Low-flow duct design The design employs large solar PV arrays, which with solar thermal, provides 7.8% of on-site energy - A comprehensive building automation system will collect energy flows for POE later	-Reducing the demand for the campus buildings by 40% • Low-flow lavatory faucets with electronic operators powered from room lighting; • Low-flow showerheads; • Low-flow sink faucets with electronic sensors powered from room lighting; • Laminar flow faucet outlets (that minimize water consumption); • Waterless urinals -Irrigation plan allocates water reclamation loads from condensate, storm, gray, and black water to satisfy a majority of the irrigation requirements. -Native vegetation and adaptive planting	LEED Platinum (LEED-NC, v.2.2, 2009) KAUST's overall energy savings is 27.1% better than ASHRAE 90.1-2004 standards - Predicted consumed EUI: 80 kBtu/sf/yr - Predicted Net EUI: 74 kBtu/sq ft/yr

Project	Year of Completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
Kroon Hall for the Yale School of Forestry and Environmental Studies	2009 Gross Floor Area: 68,800 SF	**Architect:** Nathaniel Moore and Michael Taylor from Hopkins Architects (UK, London) **MEP**: Craig Winter from Arup **Environmental building consultant** Shanta Tucker from Atelier Ten **Civil engineer:** Nicole Holmes from Nitsch Engineering **Landscape architect:** Cricket Brien from Olin Studio **Contractor**: Lynn Temple from Turner Construction Company **Function:** Education – College/University (campus-level) Public Assembly – Library	New Haven, Connecticut/5A extreme variation of local climate conditions	Building's outer shell becomes a sensitive skin that reacts seasonally to changing atmospheric conditions. North and south façades feature deeply recessed windows and highly insulated stone veneer walls	-Direct solar gain: building is oriented along an east-west axis, allowing the southern facade to act as a large solar collector -embedding most of the ground Floor in the hillside, aiding in thermal management -solar hot water heaters - significant thermal mass (visible in exposed concrete soffits and stair cores)	The building's narrow floorplate provides natural light to a large percentage of spaces and allows effective cross-ventilation via operable windows and Silenceair boxes above doors -frequently occupied areas have the most access to daylight while auxiliary spaces are located centrally. Indicators tell occupants appropriate times to open windows and when necessary -A central open stair with skylights above -top ceiling helps with daylight penetration -The east and west façades have timber louvers and large overhangs that shade curtain walls -Overall, 77% of all buildings spaces use daylight as the primary light source	The building's narrow floorplate provides effective cross-ventilation via operable windows and Silence air boxes above doors Top floor's high ceiling aids with air circulation The open central stair allows for stack-effect ventilation between levels	- 105kW PV panels are incorporated into the design and not simply fixed onto the facades informing for example the pitch of the large, arching roof and its optimized angle. Integrated solar array on the roof provides 25% of the building's energy. - Interior climate is maintained via displacement ventilation and indirect evaporative cooling, Indirect adiabatic cooling and heat exchangers recover 75% of energy from exhaust air and four ground source heat pumps to help regulate interior conditions Lighting occupancy sensors, and most fixtures are fluorescent or LED -Building energy use can be monitored by occupants at all times via two touch-screen monitors in the lobby	-Potable water use is reduced by over 75% -Courtyard's focal point also serves as a stormwater treatment basin -With a depth of only 2-3 ft available on top of the underground structure, a soil-based stormwater treatment solution was not practical; so an innovative water-based system was used comprised of floating rafts with native aquatic plants specially selected to remove pollutants carried by the stormwater that recycles through it -The green roof (courtyard) uses only harvested rainwater for landscape irrigation -Landscape clean stormwater through phytoremediation. The first inch of stormwater runoff collected from Kroon Hall's rooftop and site is diverted to this water basin. Treated overflow is directed to a subsurface 20,000-gallon cistern, from which it is continually recycled through the water feature by a small pump. Water harvested in the cistern is available for reuse in the building for toilet flushing and to irrigate portions of the landscape. -Waterless urinals, dual-flush toilets	LEED Platinum LEED-NC, v.2.2, 2010 A 100-year design lifespan building can run on nearly 60% fewer resources than its conventional peers - Predicted consumed EUI: 27 kBtu/sf/yr - Predicted Net EUI: 21 kBtu/sq ft/yr Predicted lighting power density: 0.7 w/sq ft

Project	Completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
Manassas Park Elementary School + Pre-K	2009 Gross Floor Area: 140,000 SF	**Architect:** Robert Moje VMDO Architects http://www.vmdo.com/ Charlottesville Virginia United States **From VMDO Architects** **Architect** (Project Architect) Wyck Knox **Architect** (Design Architect) Robert Winsted **Architect** (Director of Sustainable Design) Stephen Davis **Intern Architect:** Dan Morgan, Kate Mora **Contractor (Project Manager)**: Greg Ramirez from Hess Construction + Engineering Services Jon-Michael from Lemon **Bowman Consulting Group, Ltd** **Landscape architect** (Principal) Pete O'Shea from Siteworks Studio, also John Meaney **Structure**: Fox & Associates **MEP**: from 2rw Consultants, Bob Crowell (Plumbing and Electrical), and Peter Mackey Mechanical **Commissioning agent**: Paul McNally from Sebesta Blomberg **Food Service Consultant** Lloyd Harrison EIS, Inc **Function:** Education – K-12 School	Manassas Park Virginia / 4A	Solar-selective glazing, Spray polyurethane foam insulation	-Fixed solar shading - Three-story educational houses (nearly cubic in volume) minimize building envelope exposure to the climate -Mature deciduous trees, on rising ground to the west, shade the buildings from the setting sun -The relatively exposed east side of the building is programmed with "closed" spaces (gym, loading dock, mechanical rooms) to minimize unwanted solar heat gain - A high-albedo white roof	-Daylighting at levels that allow lights to be off during daylight hours: 43% -Parabolic light louvers and light shelves -Glare free teaching wall -To optimize daylighting in the principal learning spaces, classrooms are organized into three houses with each classroom facing approximately north or south -Sloped classroom ceilings to optimize penetration of natural light entering through the light louvers -North–facing roof monitors and 100 tubular skylights for glare-free daylighting with reduced heat gains -Lights in all rooms with exterior windows are automatically dimmed using daylighting sensors	-Natural ventilation through operable windows and stack effect Although the temperate seasonal climate is humid with light and variable winds, natural ventilation is used for cooling when conditions are favorable. An induced stack effect, established by vertical ventilation ducts, draws fresh air in through manually operable windows and exhausts air through the penthouses. Favorable conditions are signaled by "green lights" which are tied to a weather-predictive mode in the building automation system.	-Three lighting zones with auto dimming sensors -Efficient mechanical systems include ground-source heat pumps, variable-speed pumping, pre-treatment and total energy recovery for ventilation air, BAS-optimized system operation (building automation system), natural ventilation mode, and high-volume low-speed fans in double-height spaces -DOAS Domestic water heating energy is minimized by the use of low-consumption fixtures and kitchen equipment. The kitchen utilizes a gas water heater with 98% combustion efficiency. Energy Star appliances are used throughout Interior and exterior installed lighting power falls below ASHRAE 90.1 energy standard requirements (38% and 54% less, respectively) Occupancy- and BAS-controlled light switching, and continuously dimmable daylighting controls for 41% of the connected interior lighting power 31% improvement over the ASHRAE baseline (major loads are cooling, ventilation, lighting)	All rainwater falling on building roofs is filtered and collected in a 79,000-gallon concrete cistern, yielding an estimated 1.3 million gallons per year. A portion of the harvested rainwater is further filtered and treated for delivery to the building flushing fixtures The remainder is used for irrigating small portions of the landscape. The top of the cistern, and associated controls house, functions as an outdoor classroom, featuring a 22-foot tank gage. Mounted on the outside of the cistern pump house, a 96-square-foot mural illustrates the system layout and the natural water cycle Low-flow and automatic faucets minimize municipal potable water use for flow fixtures – a 62% reduction from EPACT 2005 quantities.	- Predicted consumed EUI: 38 kBtu/sf/yr - Predicted Net EUI: 38 kBtu/sq ft/yr

Project	Completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
Manitoba Hydro Place	2009 Gross Floor Area: 697,609 SF	**Bruce Kuwabara** Kuwabara Payne Mckenna Blumberg Architects http://kpmbarchitects.com/ **Architect:** Kuwabara Payne McKenna Blumberg Architects; Smith Carter Architects and Engineers; Prairie Architects **Energy Consultant:** Thomas Auer from Transsolar Energietechnik **Contractor (Project Manager)**: Greg Ramirez from Hess Construction + Engineering Services **Structural engineer:** Crosier Kilgour & Partners Ltd.; Halcrow Yolles **Mechanical and electrical engineer**: Earth Tech Canada **Lighting designer**: Pivotal Lighting Design **Landscape architect**: Hilderman Thomas Frank Cram; Phillips Farevaag Smallenberg **Fire Protection and Building Code Engineering:** Leber Rubes **Building Envelope consultant:** Brook Van Dalen & Associates **Vertical Transportation consultant**: Soberman Engineering **Acoustic consultant**: Aercoustics Engineering, Ltd. **Energy consultant**: RWDI **Quantity surveyor:** Hanscomb Limited Water architecture: Dan Euser Water Architecture, Inc **Function:** mixed use, office, general public assembly; the primary energy utility in the province of Manitoba	Winnipeg, Manitoba/ 7A	Double- and triple-glazed curtain wall panels	-Geothermal -Massing and orientation - The concrete structure creates thermal mass to moderate extreme temperature swings. Large portions of the structure left exposed to increase the conductivity of the radiant concrete mass -Towers converge at the building's north end to minimize north-facing surface area. To maximize solar and wind exposure, the towers splay open to the south, where they are clad in low-iron glazing -South-facing, six-story "winter gardens" act as lungs, with 24-meter waterfalls that humidify/dehumidify air entering the building. -green roof on the podium roof: extra thermal insulation - Sunshine and dominant gusting south winds as free energies -A radiant slab between the double facades maintains minimum temperatures in winter and heat exchange with the geothermal field in summer. In the winter, the solar chimney draws exhaust air down to heat the parkade and preheat incoming cold air via the south atria. During warmer seasons, the solar chimney exhausts stale air from the building -Capital A option of the 15 tested thermal mass provided maximum passive solar gains in winter and natural ventilation in the shoulder and summer seasons	Daylighting at levels that allow lights to be off during daylight hours: 85% -Narrow, 11-meter-wide floorplates ensure access to views and natural light. East and west tower facades are double-glazed with motorized windows on the exterior and single-glazed with manually operable, hopper-style windows on the interior. Large-format automated louvers within the double façade open and close throughout the day to minimize solar gain and glare. Louver blades at the top act as a light shelf, bouncing additional light onto the white ceiling. -South atrium with ribbon water feature -Interior gallery space with west clerestory glazing	115 m tall solar chimney Large-scale entrance canopies protect against prevailing winds and provide shelter for pedestrians 100% fresh air and maximum daylight: automated louvers and windows open and close in reaction to light and temperature changes During shoulder seasons, windows open and supply air is drawn in passively by the solar chimney. Low-pressure, under-floor displacement air delivery allows for individual environmental control Manually operable windows punctuate the exterior façade at 10 feet on center	A massive geothermal system with 280 boreholes, each 125 m deep 31% improvement over the ASHRAE baseline (major loads are cooling, ventilation, lighting) Direct/indirect T5 HO fixtures are dimmable, equipped with daylighting and occupancy sensors, and are individually adjustable from the central building management system Slightly lower overhead lighting levels reduce potential glare, and individual LED task lights The large geothermal field, high-efficiency condensing boilers, and efficient heating and cooling systems ensure that supply and exchange is utilized. A sophisticated building management system monitors internal and external environments to optimize lighting, solar shading, and heating and cooling loads. The metering list includes main utility meters and a variety of sub-meters for lighting, plug loads, water heating, HVAC energy, and tenant spaces	Green roofs cover the podium roof with native plant species, irrigated by rainfall or, during drought conditions, by condensate collected from the building's mechanical equipment. Excess condensate generated by the building's fan coil units during the hot summer months is directed to large cisterns located in the building's parking garage. When conditions warrant, this reclaimed water is pumped back up to the green roof and redistributed via an efficient drip irrigation system Waterless urinals and low-flow toilets and sinks	-LEED Gold -64.9% energy savings by harnessing maximum passive solar, wind, and geothermal energy compared with Canada's Model National Energy Code for Buildings (MNECB) -Total EUI: 28 kBtu/sf/yr -Net predicted EUI: 28 kBtu/sf/yr -Lighting Power Density: -0.90 watts/sf -Integrated design process -To reflect the building's minimal active mechanical systems and optimized passive systems, the operations team includes an energy management engineer and a building controls specialist. With over 20,000 control points interacting with a weather station located on the roof

Project	Completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
The Omega Center for Sustainable Living (OCSL)	2009 Gross Floor Area: 6200 SF	**Primary contact:** Laura Lesniewski BNIM Architects http://www.bnim.com/ **Architect:** Steve McDowell, FAIAfrom Berkebile Nelson Immenschuh McDowell Architects; Brad Clark form BNIM Architects **MEP (Lighting)**: BGR Consulting Engineers **Energy Consultant (Lighting):** BNIM Architects **Civil:** Pierre Brissette from Chazen Companies **Landscape architect:** from Gerould Wilhelm Conservation Design Forum **Contractor**: David Sember from David Sember Construction **Commissioning agent:** EME Group; John Todd Ecological Design, Inc.; Natural Systems International **Structure**: Tipping Mar **Function**: Education and water filtration	Rhinebeck, New York/ 4A	The insulated thermal mass of the building and the thermal mass of the water (55°F) passing through the treatment cycle are instrumental in reducing demands upon mechanical systems.	-Harvest solar energy for passive heating and lighting, using the entire mass for thermal comfort -compact form -with an east-west axis, the building is oriented for optimal control of daylighting and solar heat gain - The building form and section serve the plants for wastewater treatment in the Eco Machine. Recognizing that the plants would reach a light saturation point at around 30,000 lux, the team flatten the amount of light falling on the plants surfaces during the summer months to this level in order to minimize the heat taken on by the space. Conversely, during colder months, the amount of light will be maximized and warm the space. Solar tracking skylights would do this. -Roof materials include a combination of vegetation and recycled metal, which help to cool interior spaces, mitigating the "heat island" effect -geothermal -shading devices	Daylighting at levels that allow lights to be off during daylight hours: 98% -Daylighting, natural ventilation, and views are achieved through a system of operable, fixed, and solar-tracking fenestration -Clerestory windows	-Natural ventilation through operable windows and stack effect - Clerestory windows ventilate the lobby, mechanical room, and restrooms. Solar radiation heats the upper volume of air, and then natural buoyancy induces stack ventilation, which causes the air to push its way out of the open windows and pull in fresh, cooler air from lower windows in these spaces. Operable windows integrated into the south façade also allow for natural ventilation to assist in pushing hot air out of the building by channeling prevailing breezes that have been cooled while moving over the wetlands	PV system producing more than needed energy (surplus electricity is sold to the local utility. The excess energy is sold to the local utility.) During evenings and certain winter periods energy is provided by the electric utility. (NP EUI: -8 kBtu/sq ft/yr) -The entire building and water process use site-harvested renewable energy achieving a net-zero energy system Fans: cooling only for classes Geothermal wells and heat pumps 78% of Building is Naturally	-Percent reduction of regulated potable water: 100% -he Eco Machine, based on the same natural science as estuaries, nature's own water filtration system. It is comprised of a series of holding tanks, each containing a slightly different ecosystem. Plants and natural bacteria break down waste by-products over a 1 to 3-day travel through the tanks, progressively purifying the water. -The system uses earth, plants and sunlight. -The new engineered biological wastewater treatment system now returns a higher quality of water back to the earth. Aerated lagoons carry graywater through the reclamation process. At the end, the water may be used to support the needs of the building. -For potable water uses, well water is still drawn from the earth. For toilet flushing, rainwater is collected from the building's roof. -Low-flow plumbing fixtures including waterless urinals -Blackwater and graywater are sent to the wastewater treatment lagoons and constructed wetlands for purification. By the end of this cycle that uses natural systems, cleaner water is reintroduced to the groundwater and lake	LEED Platinum certification, and the Living Building Challenge Certification Net-zero energy - Predicted consumed EUI: 13 kBtu/sf/yr - Predicted Net EUI: -8 kBtu/sq ft/yr -Highly sustainable wastewater filtration facility for their 195-acre campus -100% of Energy Supplied by On-Site Renewable Sources 100% of Precipitation Managed On Site 98% of Building is Daylit 78% of Building is Naturally Ventilated Net Zero Energy Net Zero Water Net Zero Waste

Project	Completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
Twelve West	2009 Gross Floor Area: 552000 SF	**Primary Contact:** Primary Submission Contact: ZGF Architects LLP http://www.zgf.com **Developer:** Developer Downtown Development Inc **Civil**: David Evans and Associates **Mechanical engineer**: Glumac **Contractor:** Hoffman Construction **Structure**: KPFF Consulting Engineers **Function**: mixed use: Food Service Restaurant/Cafeteria Office-Residential Multi-Family-Retail Store	Portland Oregon/4C	Low-E glass with 35% VT (visible light transmission) and SR 74% (of associated heat reflected)	Night-purge (fan assisted): exposed concrete becomes cool during night time and will make the indoor space cool during day time Roof garden Solar thermal panels heat 24% of hot water used in the building (payback of less than four years) -Roof terraces, high-albedo roofing, and 6,000 square feet of roof gardens with diverse native plantings. These intensive roofs reduce the urban heat island effect	Daylighting at levels that allow lights to be off during daylight hours: 55% Views to the Outdoors: 90% Daylighting sensors reduce lighting energy by 60% Metallic-coated roller shades allow occupants solar control in their work and living areas. Exposed concrete ceilings in the office spaces were painted white to improve daylight penetration but maintain mass effects The orientation of living and bedroom spaces along the floor-to-ceiling, glass curtain wall maximizes natural lighting.	Operable windows as well as many outdoor balconies and terraces, accessible throughout the building High floor-to-floor heights further facilitate daylighting and increase thermal comfort by allowing for stratification of warmer air	Passive chilled beams Four wind turbines on the top producing 10-12000 KW electricity/yr to run elevators (located through extensive wind tunnel simulations) Co2 monitoring Radiant heating and cooling Office area includes an underfloor air distribution (UFAD) system that delivers air directly to the occupied zone near the floor with individual controls for each work station. This system, combined with the operable windows allows for individual control of temperature and airflow High-efficiency mechanical equipment, heat recovery, fan-assisted night flush of thermal mass for the office floors, chilled beams and hydronic baseboard heat in the office floors	About 40% reduction in potable water use - Low-water roof plantings Rain water reuse for office toilet flushing (90%) and to irrigate the green roof (286000 gallons/yr reduction of city water) Exterior plantings were chosen from native species to use minimal irrigation, which results in an 84% irrigation water-use reduction relative to equivalent landscaping needs. 44% water use reduction through efficient plumbing fixtures Collecting condensation of 13000 gallons of water in summer from AHUs Water storage tank 23000 gallons from rainwater reuse and condensation water	Double LEED Platinum-certified (both LEED for New Construction and LEED for Commercial Interiors rating systems, LEED-NC, v.2.2, rated 2010) Energy savings of 45% over a baseline code building Total predicted EUI: 27 kBtu/sf/yr Net predicted EUI: 26 kBtu/sf/yr Lighting Power Density: 0.50 watts/sf

Project	Completion	Project team	Location /Climate	Envelope	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
Special No. 9 House	2009 Gross Floor Area: 1520 SF	**Primary Contact:** KieranTimberlake http://kierantimberlake.com **Project Architect:** John Williams John C. Williams Architects http://www.williamsarchitects.com/ **Mechanical engineer**: Mechanical engineer Bruce E. Brooks & Associates; Moses Engineers, Inc **Contractor:** C&G Construction **Structure**: Cali & LaPlace Engineers, LLC; CVM Structural Engineers **Function**: Residential	New Orleans Louisiana/2A	Min R30 ceiling insulation Pipes insulations Polypropylene mesh vine trellis	-Linear east-west axis, limiting most solar exposure during the summer and shoulder seasons to the long south facade. The solar heat gains that would normally result from such a design are moderated by an extensive trellis system along the entirety of the south façade with future vegetation -In the winter the trellis will allow solar access to the building envelope, providing a heating benefit.	Excessive glare from low western sun is moderated through occupant-controlled external shading devices that are fully compliant with the hurricane rated windows	-To facilitate natural ventilation, the house includes operable transoms above the windows and large operable windows integrated into the south, east, and west envelopes. These operable envelope components, coupled with ceiling-mounted fans and 10-foot ceilings, allow for significant passive climatic adaptation -Operable double hung windows; operable awning window; operable vent above interior door	Roof-mounted photovoltaic array at a 30-degree angle Ceiling fans High-efficiency HVAC system	100% of site-generated runoff to be infiltrated onsite through permeable surfacing. The parking and driveway areas, constituting 17% of the site surface, were constructed of permeable paving. All vegetated areas, accounting for 80% of the site, are permeable as well. The remaining 3% of the site consisting of impermeable surfaces is directed toward other permeable surfaces for infiltration. In the event of excessive precipitation, the runoff is directed towards a small modular wetland for bio-filtration prior to entering the storm sewer system - Cisterns located under the house are capable of retaining 62% of the precipitation realized from a normal rain event, or 600 gallons. -Toilet flushing: Although the regional code does not yet allow for the indoor use of rainwater, the house is pre-plumbed for cistern water reuse for toilet flushing in anticipation of future code revisions - Low-flow fixtures for all lavatory sinks, showers, and toilets.	LEED Platinum (LEED for Homes v.1, 2009) Total predicted EUI: 27 kBtu/sf/yr Net predicted EUI: 19 kBtu/sf/yr Mass production example of storm-resistant, affordable, and sustainable housing options for the residents of New Orleans' Lower Ninth Ward displaced by Hurricane Katrina. Two housing types: a Garden prototype that includes a roof deck, sunscreens, and mesh trellis; and a Gable prototype that includes sunscreens, slatted trellis, and an area of refuge. HERS (Home Energy Rating) index rating of 35, meaning the house consumes 65% less energy relative to a comparable baseline home in the same climate carbon neutrality (a HERS score of 0) by surpassing the 2030 Challenge energy target for 2010—a 60% reduction in energy consumption -Prefabrication

Project	completion	Project team	Location /Climate	Natural Heating Natural Cooling	Daylighting	Natural Ventilation	Active systems	Water	Milestones
Watsonville Water Resource Center	2009 Gross Floor Area: 16000 SF	**Primary contact:** Sam Nunes WRNS Studio http://www.wrnsstudio.com **Project Architect:** Lihsing Kuo from WRNS Studio **Civil:** Richard Irish Engineering, Inc. **Landscape architect:** Michael Bellinger from Bellinger Foster Steinmetz **Contractor**: Garret Tomforde from Devcon Construction **Lighting Designer:** David Maino from Integrated Design Associates **Electrical engineer** (Lighting designer) David Kaneda from Integrated Design Associates **Structure**: Jason Campbell from JEC Structural Consulting **Commissioning agent**: Rick Unvarsky Consulting Services, Inc. **Mechanical & plumbing**: Rumsey Engineers, Inc. **Function**: Laboratory; water recycle plant; office; education space.	Watsonville California/3C	- 290 feet in length, building is oriented on an east-west axis, allowing for the majority of the building's program to be placed along the north and south facades. - Solar heat gain is controlled through the building's eaves and trees placed along the southern edge, and thermal mass is provided by a polished concrete radiant floor. - The site prevailing coastal Pacific winds maximize comfort in the outdoor public spaces. Rooftop vent stakes along the building's ridgeline allow these breezes to draw warm out of the interior naturally	Daylighting at levels that allow lights to be off during daylight hours: 60% - Skylights along the central corridor wash the white walls with sunlight - Private offices are equipped with glass sidelights and operable clerestory windows to allow natural light to get through the building's private and public spaces -Automatic daylight controls augment controls in individual offices, allowing users to manage their own ambient light levels and task lighting	- The thinness of the buildings (just 43 feet in width on the operations side) and the number of strategically placed operable windows allow natural breezes to filter throughout all of the spaces. -Cross and stack natural ventilation - Glass sidelights and operable clerestory windows to allow the air move naturally through the building's private and public spaces -building chimneys	-Roof-mounted solar panels -For daylight harvesting occupancy sensors are included throughout the facility to minimize energy use. - In occupied spaces, water flows through radiant tubes underneath the floors to provide heating and cooling. - The ventilation and heating /cooling systems were decoupled, resulting in a system that is much less energy intensive than a standard forced-air system. - CO2 sensors in open areas	Percent reduction of regulated potable water: 50% To display water as a seasonal resource connected to the local agricultural growing season, water is supplied to a tiled water feature only when recycled water is available to the site. In addition, rainwater flows from eaves and rain chains into swales, then is carried to retention basins to be treated prior to infiltrating the groundwater system. Native and drought-tolerant plantings, requiring less than 70% of typical water usage, are watered only when recycled water is available. The irrigation system is predominantly an efficient, automatically controlled drip system utilizing recycled non-potable water	LEED Platinum 2009, Net Zero Energy Energy-efficiency targets exceed ASHRAE 90.1 by 76% - Predicted consumed EUI: 45 kBtu/sf/yr - Predicted Net EUI: 45 kBtu/sq ft/yr