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ENERGY USE AND DESIGN OPTIONS FOR TEXAS STATE BUILDINGS

Final Report

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Prepared For
Energy Management Center
Office of the Governor
Austin, Texas

SUMMARY

In 1984, the Office of Governor in the State of Texas, working through the Energy Efficiency Division of the Public Utility Commission, instituted a program to reduce the energy costs in state owned buildings. One facet of this program was the reduction of energy use of all new buildings constructed for state agencies. The first phase of this program was to estimate the energy use of new buildings corresponding to current construction practices in state facilities and to make recommendations for improvements. This phase also included an evaluation of how building standards might impact the energy use of new construction. The second phase includes the development and implementation of energy standards for all new construction. It should be noted that the report does not investigate the economic impact of the proposed changes.

This report summarizes the first phase of the program to reduce energy use in proposed new construction in state-owned buildings. The Energy Systems Group of the Department of Mechanical Engineering at Texas A&M University worked jointly with the Energy Management Center (EMC) of the Governor's Office (formerly the Energy Efficiency Division of the Public Utility Commission) and the State Purchasing and General Services Commission (SPGSC). A total of six buildings were analyzed. One of the buildings had just been completed when this project was initiated in 1986. The other five buildings were in various design phases.

The annual energy use and conservation options were studied for one existing building (Travis) and five proposed buildings (Supreme Court Complex, Texas Department of Health, Texas Youth Commission/Texas Rehabilitation Commission, Warehouse Facility and Records and Storage). The studies were made using the DOE 2.1B computer program. The weather data used for the simulations was Typical Meterological Year (TMY) based on the period from 1953 to 1975 for Austin, Texas.

The annual energy use for all the buildings was first analyzed for the base, or "as proposed," case. Then the building designs were modified to comply with the proposed ASHRAE Standard 90.1P, 1986, and the existing California standard, 1984. Modified building energy use was estimated and compared to the original design for each building.

TRAVIS BUILDING

The Travis building is a twelve story office building located in Austin, Texas. The base case for the Travis building was a simulation of its annual energy use as it was actually built and operated. The simulations performed for the Travis building included: (i) base case, (ii) effect of weather, (iii) effect of the ASHRAE standards, (iv) effect of the California standards and (v) effect of improved glass type. The results are shown in Table 1. The EUI is defined as the Energy Utilization Index and is a measure of the annual energy consumption of the building in kBtu's per square foot per year.

Table 1 – Comparison of EUI For Travis Building with Various Options.

Option	EUI kBtu/sf/yr	% Reduction in EUI
BASE	101	–
ASHRAE	95	6
ASHRAE+GLASS-1	79	22
CALIFORNIA	65	36
CALIFORNIA+GLASS-1	59	41

To compare the variation in climate across the State of Texas, the base case and the ASHRAE standard for the Travis building were analyzed at various locations in Texas as shown in Table 2. There is a wide variation of EUI's. The cooling energy decreased and the heating energy increased as the building was moved from South to North. The EUI's ranged from 99 to 132 kBtu/sf/yr for the base case. The reduction with the ASHRAE standard ranged from 6 to 10 percent.

Table 2 – Comparison of EUI For Travis Building at Different Locations in Texas.

Location	Base EUI kBtu/hr/yr	ASHRAE EUI kBtu/hr/yr	% Reduction in EUI
BROWNSVILLE	99	92	7
HOUSTON	93	86	8
AUSTIN	101	97	4
LUBBOCK	117	105	10
EL PASO	134	126	6

SUPREME COURT COMPLEX

The Supreme Court and Attorney General's Complex located in Austin, Texas, consists of four buildings labeled A,B,C and D. First, the base energy use for these buildings was analyzed as proposed in the design plan. The base energy use was then compared to the energy use with various energy conservation options. The comparisons for EUI for the complex with the various options is shown in Table 3.

Table 3 – Comparison of EUI for Supreme Court and Attorney General Complex for Various Options.

Option	Building A&B EUI	Building A&B % Reduction	Building C EUI	Building C % Reduction	Building D EUI	Building D % Reduction
BASE	186	–	181	–	152	–
ASHRAE	89	52	109	40	91	40
CALIFORNIA	76	59	82	55	60	60
CALIFORNIA +SOLAR FILM	67	64	61	66	53	65

There was a substantial reduction in heating energy for all three buildings both with the ASHRAE and the California standards. The reduction in annual energy use also was quite substantial. A major factor for high annual energy use for the buildings as designed was the use of a Dual–Duct Variable Volume system (DDV) for heating and cooling. Neither of the standards recommend this system because of high energy use.

TEXAS DEPARTMENT OF HEALTH

The Texas Department of Health Building (Health Building) is a proposed seven story office building located in Austin, Texas. The annual energy use for the Health building was estimated for: (i) base case, (ii) California standards, (iii) and base case with a variable speed fan and an economizer cycle. The comparisons of the annual energy use for base case, the California standards and base case with ventilation rate of 10 cfm/person are shown in Table 4.

Table 4 – Comparison of EUI For Health Building with Various Options.

Option	EUI kBtu/sf/yr	% Reduction in EUI
BASE	142	–
CALIFORNIA	79	44
VENTILATION	136	3

Again, substantial amount of energy saving could be achieved if the Health Building would conform to the requirements of the California standards.

TYC/TRC

The Texas Youth Commission/Texas Rehabilitation Commission (TYC/TRC) building was a proposed seven story office building located in Austin, Texas. The annual energy use was estimated for: (i) base case, (ii) the ASHRAE standard, (iii) the California standard and (iv) base case with variable air volume (VAV). The building as proposed had a dual duct variable volume (DDV) system for heating and cooling. The reduction in annual energy use was 38 and 44 percent for the ASHRAE and the California standards, respectively. The comparisons for annual energy use for various options are shown in Table 5.

Table 5 – Comparison of EUI For TYC/TRC Building with Various Options.

Option	EUI kBtu/sf/yr	% Reduction in EUI
BASE	136	–
ASHRAE	84	38
CALIFORNIA	76	44
BASE+VAV	106	28

WAREHOUSE FACILITY

The Warehouse facility of the Human Services center complex is a proposed facility to be located in Austin, Texas. The annual energy use was estimated for the base case and the ASHRAE standard. The comparison for the annual energy use for the two options is shown in Table 6. Since a large part of the facility is not cooled, the potential for energy savings is small.

Table 6 – Comparison of EUI For Warehouse Facility and Facility with ASHRAE Standards.

Option	EUI kBtu/sf/yr	% Reduction in EUI
BASE	59	–
ASHRAE	55	7

RECORDS AND STORAGE

The Records and Storage Building is a proposed extension to an existing building located in Austin, Texas. The annual energy use was estimated for: (i) base case, (ii) the ASHRAE standard, (iii) base case with increased insulation in walls and roof and (iv) base case with reduced lighting level. The comparisons of the energy use for the above mentioned options are shown in Table 7. Lighting reductions and insulation have little impact compared to ASHRAE standards.

Table 7 – Comparison of EUI For Base Facility and Facility with Alternative Options.

Option	EUI kBtu/sf/yr	% Reduction in EUI
BASE	80	–
ASHRAE	57	29
Increased Insultion	77	4
Reduced Lighting	76	5

In general the proposed ASHRAE and the existing California standards provide significant reduction in energy use over the current parctices. The range of saving over a year for the buildings investigated with the ASHRAE standards was between 6 (warehouse) – 60 (office buildings) percent and with for the California standards it was between 36 – 60 percent.

The current construction practices of State buildings reflect improvements in energy use over buildings built several years ago. However, adopting new standards will reduce energy consumption even further. The California standards are more stringent and may be a better choice for State owned buildings which have a life of 30 or 40 years.

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CHAPTER 1

INTRODUCTION

In 1984, the office of Governor in the State of Texas, working through the Energy Efficiency Division of the Public Utility Commission of Texas, instituted a program to reduce the energy costs in state owned buildings. One facet of this program was the reduction of energy use of all new buildings constructed for state agencies. The first phase of this program was to estimate the energy use of new buildings corresponding to current construction practices in state facilities. This phase also included an evaluation of how building standards might impact the energy use of new construction. The second phase includes the development and implementation of energy standards for all new construction.

This report summarizes the first phase of the program to reduce energy use in new construction in state-owned buildings. The Energy Systems Group of the Department of Mechanical Engineering at Texas A&M University worked jointly with the Energy Management Center (EMC) of the Governor's Office (formerly the Energy Efficiency Division of the Public Utility Commission) and the State Purchasing and General Services Commission (SPGSC). A total of six buildings were analyzed. One of the buildings had just been completed when this project was initiated in 1986. The other five buildings were in various design phases.

Annual energy use for each building was first estimated for the buildings as they were proposed (or already built) to establish the base case performance. Design changes which could reduce their energy consumption were then made in each building. The specific design changes made depended on the building use and requests from the architects who had designed the building. In addition, building performance was also estimated if constructed under the existing California and proposed American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standards [1,2].

The energy use estimates for all the buildings in this study were made using the DOE 2.1B computer program. The program needs detailed inputs of the physical parameters of the building, operational schedules of the building, summer and winter set point temperatures, HVAC system specifications, etc. Most of these inputs were obtained from the building plans and specifications provided by the SPGSC staff. However, some of the inputs, such as operational schedules, were assumed because no information was available.

The weather data used for the simulation represents Typical Meteorological Year (TMY) based on the period from 1953 to 1975 for Austin, Texas. The ambient conditions include continuous hourly weather data (dry-bulb temperature, humidity ratio, wind speed, solar radiation, etc.).

This is a final report under the contract to the Energy Management Center. In Chapter 2 of this report the proposed ASHRAE and the existing California standards are discussed in detail. Summary and recommendations for each of the six buildings analyzed are presented in Chapter 3. Finally, the conclusions and recommendations are presented in Chapter 4.

As a followup to this study, a survey form was sent to SPGSC to evaluate what changes were made in the design of the buildings that were being built. The results of the survey are presented in Appendix A.

CHAPTER 2

ASHRAE AND CALIFORNIA STANDARDS

The proposed ASHRAE Standard 90.1P, 1986, and the existing California standard encourage innovative design of new buildings so that the buildings consume less energy without constraining the necessary building functions. Both standards provide for two alternative methods of compliance: prescriptive and system performance. Prescriptive standards typically specify the thermal, electrical or physical parameters of the building envelope which would lead to energy efficient operation of the design. System performance standards provide procedures for determining the upper limits of the energy use for the building. The ASHRAE standard also permits a building energy cost method. This method allows innovative designs but it requires more effort and calculations.

ASHRAE STANDARD

The ASHRAE standard provides criteria and minimum standards for energy conserving design of new buildings. It also provides methods for determining compliance with these criteria and standards. The ASHRAE standard, provides for three alternative methods of compliance: (i) prescriptive, (ii) system performance and (iii) building energy cost budget. The prescriptive criteria requires a minimum amount of calculations and effort to achieve the required compliance. The system performance criteria and the building energy cost criteria require more effort and calculations; however, these two alternative methods have more flexibility and encourage innovative designs.

The standard concentrates on the areas of largest opportunity for energy conservation, such as:

- electric power and distribution,
- lighting systems and equipment,
- building envelope,
- HVAC systems and equipment and
- service water heating.

Each of the above mentioned categories have minimum, or mandatory, requirements. The mandatory requirements, according to the standard, are either fundamental to good practice or represent the minimum acceptable state-of-the art in the efficient use of energy in the design of buildings. In addition to the mandatory requirements, the prescriptive or the system performance requirements must also be met. If the prescriptive and/or system performance criteria cannot be satisfied, then building energy cost method must be used.

All buildings which have an electric service connection in excess of 250 kVA are required to meter electrical energy consumption. The consumption has to be subdivided in accordance with the following categories:

(i) lighting and receptacle outlets,

(ii) HVAC and service water heating systems,

(iii) special occupant equipment or systems of more than 20 kW.

Also, the standard requires that all the buildings which have a gross area of more than 100,000 sf should have an energy management system.

Prescriptive Standard

The standard recommends the reduction of energy consumption by minimizing the installed power and optimizing the time of use. The recommended approach to minimize the installed power is by use of efficient lamp/ballasting systems and luminaries. To reduce the time of use, lighting devices are required to have manual and automatic controls using occupancy sensors, lighting level sensors, etc.. Lighting power densities for building exteriors are categorized in the standard; they range from 0.1 W/sf for a private driveway to 0.2 W/sf for storage and work areas. The interior power densities are classified by building type. For example, an office building can have lighting levels as shown in Table 2.1.

Table 2.1 - Allowable Lighting Load for an Office Space.

Floor Area Building (sf)	Allowable Lighting Load (W/sf)
0 - 1,000	2.0
1001 - 4,000	1.9
4,001 - 10,000	1.8
10,001 - 20,000	1.7
20,001 - 35,000	1.6

Source: ASHRAE Standard 90.1P, 1986

The criteria for selection of maximum light or heat transmittance values for wall assembly (opaque) and fenestration are given for 30 different cities. The cities in Texas for which data is available are: Abilene, Austin, El Paso, Fort Worth, San Antonio, Brownsville, Corpus Christi, Amarillo and Lubbock. If data is not available for a city, the nearest city should be chosen.

A sample prescriptive criteria from the ASHRAE standard is shown in Table 2.2. Maximum U_o (overall heat transfer coefficient) for all the opaque wall assembly is given in the top left corner of the table. The U for roof, unconditioned space, and wall below grade are given in the top right corner. According to the standard, U values should not exceed those shown in the table. The steps to determine maximum allowable percent fenestration are:

(i) Select one of the three options; 1) base case, 2) perimeter day–lighting, or 3) wall thermal mass.
(ii) Select the internal load range, including the lighting power limit, the equipment power limit and occupancy load.
(iii) Select the shading coefficient of the fenestration (SC_x).
(iv) Select appropriate fenestration type, i.e., determine the thermal transmittance value U_{of} of the fenestration assembly.
(v) Finally, select external shading projection factor according to the equation 8.5–1.

All HVAC systems are required to have an economizer cycle and the fan systems at design conditions should not exceed 0.8 W/cfm for constant volume systems and 1.25 W/cfm for variable volume systems. Also, HVAC systems are required to avoid reheat, recool or mixing of hot and cool air in one zone.

System Performance Standard

The lighting power limit for each portion of the building can be estimated for each task from the tables provided in the standard. Maximum thermal transmittance requirements for each component, such as roof, floor, walls below grade and external walls, are given in terms of heating and cooling degree days (Figure 2.1). The minimum efficiency requirements for the HVAC equipment are also given in tables (example Table 2.3). New construction must be designed to conform to the requirements shown on these tables.

Table 2.2 – A Sample Prescriptive Criteria for the ASHRAE Standard.

ALTERNATE COMPONENT PACKAGES FOR: Abilene TX, Austin TX; Bakersfield CA, Daytona FL; El Paso TX, Fort Worth TX; Jacksonville FL, San Antonio TX; Tallahassee FL, Tampa FL

TABLE NUMBER: 8.A - 9

MAXIMUM OPAQUE WALL Uo VALUE (For HC < 5)	FOR BASE CASE, PERIM DAYLIGHT, OR HIGH PERFORMANCE GLAZING 0.20 Uow	FOR WALL THERMAL MASS ACP (For HC >= 7) 0.20 Uow		Max Uo
		Only for Insulation Exterior to Mass	ROOF:	0.065
			WALL ADJACENT TO UNCOND SPACE:	0.37
			FLOOR OVER UNCOND SPACE:	0.15

THERMAL MASS ADJUSTMENT TO OPAQUE WALL (Uow)	Insul. Loc.--->	INTEGRAL Interior/	Exterior
	HC >= 5	0.22	0.35 Uow
	HC >= 10	0.32	0.44 Uow
	HC >= 15	0.43	0.47 Uow

TO DETERMINE MAXIMUM PERCENT FENESTRATION ALLOWED, CHOOSE ONE OF THREE ALTERNATE COMPONENT PACKAGES (ACP), THEN CHOOSE A FENESTRATION TYPE

CHOOSE AN INTERNAL LOAD RANGE (W/ft2)	CHOOSE A SHADING COEFFICIENT RANGE (SCx)	BASE CASE						PERIMETER DAYLIGHTING									WALL THERMAL MASS					
		Uof 1.15 - 0.82			Uof 0.81 - 0.00			Uof 1.15 - 0.82			Uof 0.81 - 0.00			Uof 0.81 - 0.00 VT >= SC			Uof 1.15 - 0.82			Uof 0.81 - 0.00		
		Proj. Factor .0	.25	.5	Proj. Factor .0	.25	.5	Proj. Factor .0	.25	.5	Proj. Factor .0	.25	.5	Proj. Factor .0	.25	.5	Proj. Factor .0	.25	.5	Proj. Factor .0	.25	.5
		PCT FENESTR			PCT FENESTR			PCT FENESTR			PCT FENESTR			PCT FENESTR			PCT FENESTR			PCT FENESTR		
0 - 1.0	1.000 - 0.71	18	24	31	19	25	32	19	26	33	20	26	34	20	26	34	21	27	35	21	28	36
	0.709 - 0.60	23	30	39	23	31	40	24	32	41	25	33	42	25	33	43	26	34	43	26	35	44
	0.599 - 0.50	27	36	46	28	37	48	28	37	48	29	39	50	30	39	51	30	40	50	31	41	52
	0.499 - 0.38	33	43	54	34	45	58	34	45	57	35	47	61	36	47	61	36	47	58	37	49	67
	0.379 - 0.25	43	56	70	45	60	77	45	58	83	47	62	80	48	63	81	47	60	73	49	63	
	0.249 - 0.00	64	82	100	69	92	100	66	84	100	72	95	100	73	96	100	68			73		
1.01 - 1.5	1.000 - 0.71	17	22	29	17	23	30	19	25	32	19	25	33	20	26	34	19	25	33	20	26	33
	0.709 - 0.60	21	28	36	21	29	37	23	31	40	24	32	41	24	33	42	24	31	40	24	32	41
	0.599 - 0.50	25	33	42	26	34	44	28	36	47	29	38	49	29	39	50	28	37	47	29	38	49
	0.499 - 0.38	30	39	50	31	41	54	33	44	55	35	46	60	35	47	61	34	44	55	35	46	58
	0.379 - 0.25	40	52	65	41	55	71	44	57	71	46	61	78	47	62	80	44	56	69	46	59	75
	0.249 - 0.00	60	76	95	64	85	100	65	82	100	71	92	100	72	94	100	64			68		
1.51 - 2.0	1.000 - 0.71	15	20	26	15	21	27	18	24	31	19	25	32	19	26	34	18	24	30	18	24	31
	0.709 - 0.60	19	25	33	20	26	34	23	30	39	23	31	41	24	32	42	22	29	37	22	30	38
	0.599 - 0.50	23	30	39	23	31	40	27	36	46	28	37	48	29	39	50	26	34	43	27	35	45
	0.499 - 0.38	28	36	46	28	38	49	33	43	55	34	45	58	35	47	61	31	41	51	32	42	54
	0.379 - 0.25	36	48	61	38	50	65	43	56	70	45	60	77	47	62	79	41	52	65	42	55	70
	0.249 - 0.00	55	71	89	59	78	100	64	81	98	70	90	100	77	93	100	60	75		63		
2.01 - 2.5	1.000 - 0.71	14	18	24	14	19	24	18	24	31	18	24	32	19	26	34	16	22	28	16	22	28
	0.709 - 0.60	17	23	30	18	23	31	22	30	38	23	31	40	24	32	42	20	27	34	21	27	35
	0.599 - 0.50	21	27	35	21	28	37	27	35	45	27	37	48	29	39	50	24	31	40	24	32	41
	0.499 - 0.38	25	33	42	26	34	44	32	42	54	33	44	58	35	47	61	29	38	47	29	39	49
	0.379 - 0.25	33	44	56	34	46	59	42	55	69	44	59	75	47	62	79	38	49	61	39	51	64
	0.249 - 0.00	51	66	83	54	72	93	64	79	97	69	88	100	72	93	100	56	70		59	76	
2.51 - 3.0	1.000 - 0.71	12	15	20	12	16	20	17	22	29	17	23	30	18	25	32	14	19	24	14	19	24
	0.709 - 0.60	15	19	28	15	20	26	21	28	36	21	28	37	23	31	40	18	23	29	18	23	30
	0.599 - 0.50	17	23	30	18	24	31	25	33	42	25	34	44	28	37	48	21	27	35	21	28	36
	0.499 - 0.38	21	28	36	22	29	37	30	39	50	31	41	54	34	45	58	25	32	41	25	33	43
	0.379 - 0.25	28	37	47	29	39	50	39	52	65	41	55	70	45	60	76	33	42	53	34	44	56
	0.249 - 0.00	43	56	71	45	60	79	59	74	89	65	82	100	69	88	100	49	62	76	51	66	
3.01 - 3.5	1.000 - 0.71	9	13	16	9	13	16	15	20	26	15	20	27	17	23	30	12	15	20	12	16	20
	0.709 - 0.60	12	16	20	12	16	21	19	25	32	19	26	34	22	29	38	15	19	25	15	20	25
	0.599 - 0.50	14	19	24	14	19	25	22	30	38	23	31	40	26	35	46	17	23	29	18	23	30
	0.499 - 0.38	17	23	29	17	23	30	27	36	46	28	37	49	32	42	55	71	27	35	21	28	36
	0.379 - 0.25	23	30	39	24	31	41	36	47	60	37	50	65	43	57	72	28	36	45	28	37	47
	0.249 - 0.00	35	46	59	37	47	64	64	69	82	59	75	97	66	83	100	41	53	65	43	56	70

Table 2.3 – Standard Rating Conditions & Minimum Performance for the ASHRAE Standard.

CENTRIFUGAL AND ROTARY (SCREW) TYPE WATER CHILLING PACKAGES

ELECTRICALLY OPERATED

CATEGORY/ REF. STANDARDS		EFFICIENCY TERM	MINIMUM PERFORMANCE BEGINNING JAN. 1, 1988	JAN. 1, 1992
CENTRIFUGAL		COP	2.4	2.45
ARI 550-83	AIR COOLED	IPLV	2.4	2.45
	-WATER COOLED			
	--<250 TONS	COP	4.8	5.0
		IPLV	4.9	5.1
	- ≥250 TONS	COP	5.0	5.2
		IPLV	5.1	5.3
ROTARY (SCREW)		COP	2.4	2.45
ARI 550-83	-AIR COOLED	IPLV	2.4	2.45
	-WATER COOLED	COP	4.1	4.25
		IPLV	42	4.5

RECIPROCATING WATER CHILLING PACKAGES

ELECTRICALLY OPERATED

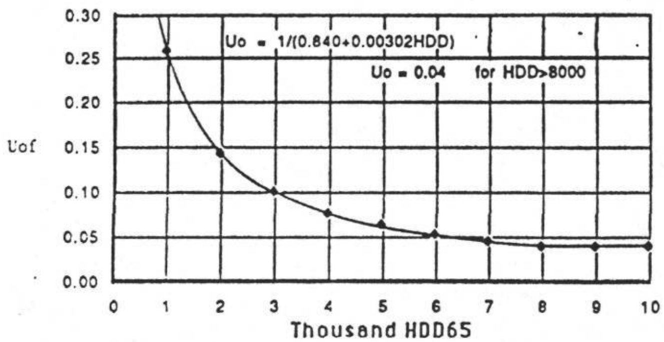
CATEGORY/ REF. STANDARDS		EFFICIENCY TERM	MINIMUM PERFORMANCE BEGINNING JAN. 1, 1988	JAN. 1, 1992
AIR COOLED				
ARI 590-81	WITH CONDENSER	COP	2.6	2.7
		IPLV	2.6	2.8
	WITHOUT CONDENSER	COP	3.0	3.1
		IPLV	3.0	3.2
WATER COOLED		COP	3.7	3.8
ARI 590-81		IPLV	3.8	3.9

HEAT OPERATED WATER CHILLING PACKAGES

WATER COOLED CONDENSING

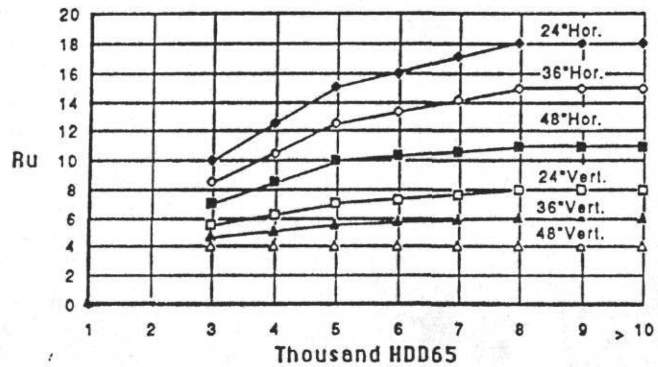
Category/ Ref. Standards	Efficiency Term	Minimum Performance Beginning Jan. 1, 1988	Jan. 1, 1992
Direct Fired ANSI Z21.40.1-1981 Z21.40.1a-1982	COP (1)	.48	.5
Indirect Fired ARI 560-82	COP (1)	.68	.7

(1) COP: Net Cooling Output/Total Heat Input Electrical Auxiliary Inputs Excluded



Thermal Transmittance for Floors of Conditioned Spaces Over Unconditioned Spaces

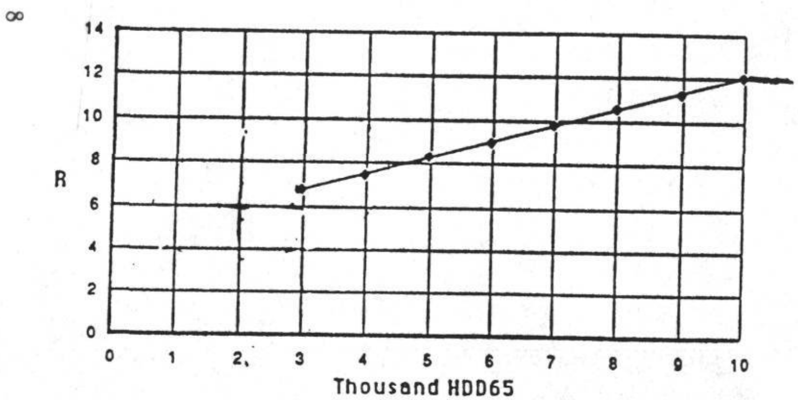
HDD65: Heating Degree Days Base 65 F



Note: R values for heated slab on grade = R for unheated slab + 2
Rh = Ru + 2

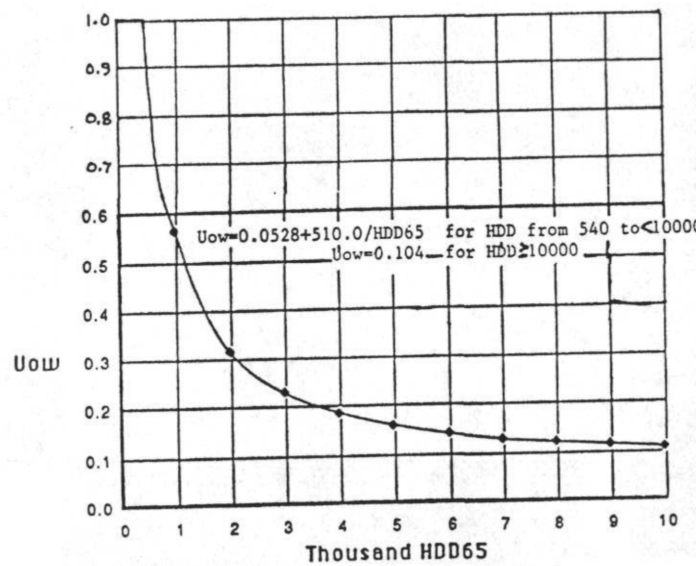
Thermal Resistance for Unheated Slab on Grade

For HDD65 < 3000: Ru = 0



For HDD65 < 3000; R = 0.
For HDD65 ≥ 10,000; R = 12.

Thermal Resistance of Walls Below Grade



For HDD 65 < 540; U_{ow} = 1.000

Thermal Transmittance of Opaque Wall Sections

Figure 2.1 – Maximum Overall Transmittance/Miminum Resistance for the ASHRAE Svstem Performance Standard.

CALIFORNIA STANDARD

The California standard also has specified mandatory requirements in addition to the prescriptive or system performance requirements. Mandatory requirements addressed in the standard include: maximum wall, roof and pipe insulation; appliance minimum efficiencies; design heating (70 F) and cooling (78 F); ventilation requirements (ASHRAE Standard 62–81); economizer cycle for the HVAC system; types of doors and windows; allowable infiltration rates; and lighting controls.

Prescriptive Standards

This approach determines prescriptive requirements that were specified to meet the energy budget. The parameters addressed in this section include: R-value of opaque building envelope; maximum amount of vertical and horizontal (skylighting) glazing; lighting power densities; and space conditioning systems. A sample prescriptive compliance table for the California standard is shown in Table 2.4. It has three different packages listed and any one of the three packages can be selected depending upon the building requirement. The R-value of the opaque building envelope should at least equal the value shown on top of the table. The minimum R-value of the wall can be selected based on the thermal capacity of the wall assembly. Maximum allowable vertical and horizontal fenestration are given for different shading coefficients. Maximum allowable lighting levels are also given in the table.

System Performance Standards

This approach specifies the maximum energy use per square foot year for each of the sixteen climate zones (Table 2.5). The energy calculation can be performed by any public domain program certified by the California Administrative Code. The total energy consumption includes: all energy used for comfort heating and cooling; ventilation for the health and comfort of occupants; service water heating; lighting; and equipment. Nondepletable (renewable) energy is excluded from the total calculated energy consumption regardless of the purpose of the energy consumed.

Table 2.4 – A Sample Prescriptive Criteria for the California Standard.

ALTERNATIVE COMPONENT PACKAGES FOR CLIMATE ZONE #01
FOR HIGH RISE OFFICE BUILDINGS

Component	A	PACKAGE B	C
OPAQUE ENVELOPE			
Minimum Roof Total R-Value (R_t)	14.9	14.9	22.9
Minimum Opaque Wall Total R-Value (R_t) *(one of the following)*:			
Heat Capacity [Btu/°F/ft^2]			
0.0-3.99	7.4	7.4	3.9
4.0-9.99	6.5	6.5	3.3
10.0-14.99	4.7	4.7	2.4
15.0-19.99	3.9	3.9	2.1
20.0 or more	3.5	3.5	2.0
Minimum Suspended Exterior Floor Total R-value (R_t)	9.5	9.5	9.5
GLAZING			
Maximum Allowed Total & West-Facing Vertical Glazing (one of the following):			
Shading Coefficient			
1.00-0.72	29%	37%	29%
0.71-0.61	35%	45%	35%
0.60-0.46	38%	50%	38%
0.45-0.01	43%	56%	43%
See Section 2-5342(b)5. for adjustment for overhangs.			
Maximum Allowed Horizontal Glazing (one of the following):			
Shading Coefficient			
1.00-0.51	Not Allowed	7%	Not Allowed
0.50-0.01	Not Allowed	11%	Not Allowed
LIGHTING (Either:)			
Maximum Adjusted Lighting Power Density, watts per square foot	1.50	1.50 Daylighting Controls Required	1.40
Maximum Adjusted Connected Lighting Load, watts	See Section 2-5342(d)2	See Section 2-5342(d)2	Not Allowed
SPACE CONDITIONING SYSTEM (Both:)			
General Requirements	See Section 2-5342(e)1	See Section 2-5342(e)1	See Section 2-5342(e)1
Performance Criteria (applicable to any Alternative Component Package)			

Fan Wattage Index	1.02
Source Heating Power Index	32.8
Source Cooling Power Index	19.5

Table 2.5 – Energy Budget for Offices of Four or More Habitable Stories.

	Conditioned Cross-Sectional Area of a Story in Square Feet		
Climate Zone	10,000 or less	10,001 to 22,500	greater than 22,500
1	111	107	99
2	130	124	113
3	107	103	96
4	112	108	100
5	113	109	101
6	129	124	114
7	106	103	97
8	113	109	101
9	117	113	104
10	127	122	112
11	147	141	126
12	145	139	131
13	141	135	122
14	152	144	128
15	159	151	135
16	139	133	118

CHAPTER 3

SUMMARY OF ENERGY USE AND CONSERVATION OPTIONS

The energy analyses of all the buildings in this study were performed using the DOE 2.1B computer program [3]. This program estimates annual energy consumption and peak usage by simulating hourly loads and system performance of the building. Various output data can be examined: peak load for each zone; peak load for the entire building; total energy use for each zone; total energy use for the entire building; etc. The energy use for all the buildings was first analyzed for the base, or "as proposed," case. Then the buildings were modified to comply with the ASHRAE and the California standards and their energy use estimated and compared to the base case.

TRAVIS BUILDING

The first building analyzed was the Travis building. It is a twelve story office building located in Austin, Texas [4]. This building was completed in 1986 and was the only building of the six analyzed that was already completed. The total conditioned floor area is 460,855 sf. Approximately 77 percent of the exterior walls are glass. The building has 30 inch offsets for the windows on all sides except on the North and Northeast. It is externally shaded by two adjacent high rise buildings (Johnson and Austin). The maximum occupancy of the building is 2100 people.

The "base case" for the Travis Building was a simulation of its energy use as it was actually built and operated. Data was collected on lighting levels, computer systems, office equipment, etc., and schedules to obtain as realistic a simulation as possible. The building was then moved to four other cities around Texas (Brownsville, El Paso, Houston and Lubbock) to study influence of weather on the energy use in the Travis building. Another set of simulations was performed to evaluate the energy use of the building if it had been built to conform to the proposed ASHRAE and the existing California standards. Finally, a glass with high reflectivity and low overall heat transfer coefficient was used to study the effects of a reduction in glass conduction and glass solar loads.

The peak cooling and heating loads for the base case are shown in Figure

All Units are in kBtu/h

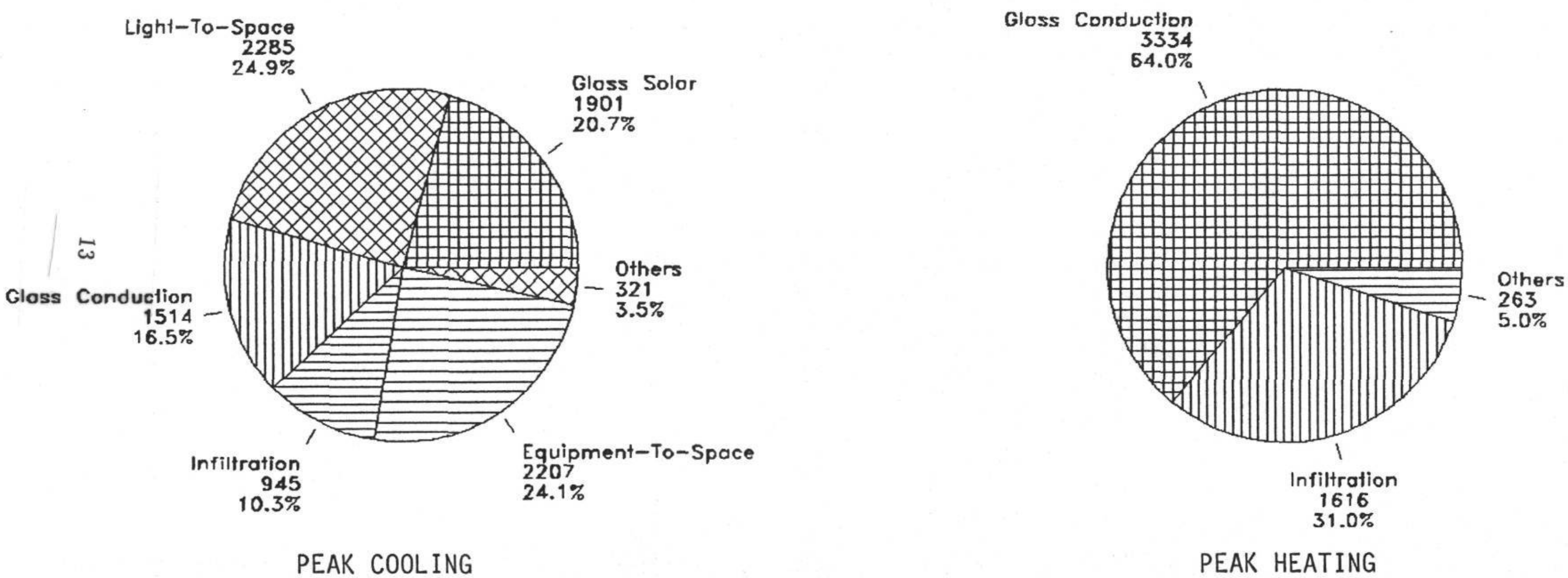


Figure 3.1 – Peak Cooling and Heating Base Travis Building.

3.1. The internal loads constitute about 50 percent of the peak cooling load. Since the Travis building is an office building, much of the internal loads are from lights and office equipment. Because 77 percent of the exterior walls are glass, the solar and conduction heat gains from glass are also quite significant (37%). The heat loss from infiltration and glass conduction make up almost the entire heating load. The heat loss from infiltration, in the case of heating, is much more significant than the heat gain for cooling, because the indoor-outdoor temperature difference is much greater in winter than in summer.

The breakdown of the annual cooling and heating loads for the base case is shown in Figure 3.2. The major portion of the annual cooling load is due to the internal loads (67%), followed by solar heat gain from glass which is about 27 percent. The conduction heat loss from glass constitutes about 73 percent of the annual heating load and the infiltration heat loss is about 19 percent.

The peak loads and annual energy use of the Travis building for different cities in Texas were estimated for the base case. The comparisons of various loads and the Energy Use Index (EUI), defined as the ratio of the annual energy use of the building to the conditioned floor area of the building, for each location are shown in Table 3.1. There is a wide variation of EUI's for the same building at different locations. It can be seen that the cooling load decreased and heating load increased as the building was moved from South to North. The EUI's ranged between 99 to 132 kBtu/sf/yr for the base case.

Table 3.1 - Comparison of Energy Use For Travis Building at Different Locations in Texas.

Location	Cooling [COP = 3] MBtu ++	Heating MBtu	Lighting & Equipment MBtu (MWh)	HVAC MBtu (MWh)	Annual MBtu	EUI + kBtu/sf/yr
BROWNSVILLE	10375	1084	18795(5507)	15219(4459)	45473	98.7
HOUSTON	6987	2762	18795(5507)	14494(4247)	43038	93.4
AUSTIN	6972	5873	18795(5507)	14968(4386)	46608	101.0
LUBBOCK	4779	14113	18795(5507)	16115(4723)	53802	116.7
EL PASO	5803	22367	18795(5507)	14638(4289)	61603	133.7

+ Area = 460,855 sf ++ 1 MBtu = 10^6 Btu

The major differences between the actual design of the Travis building and

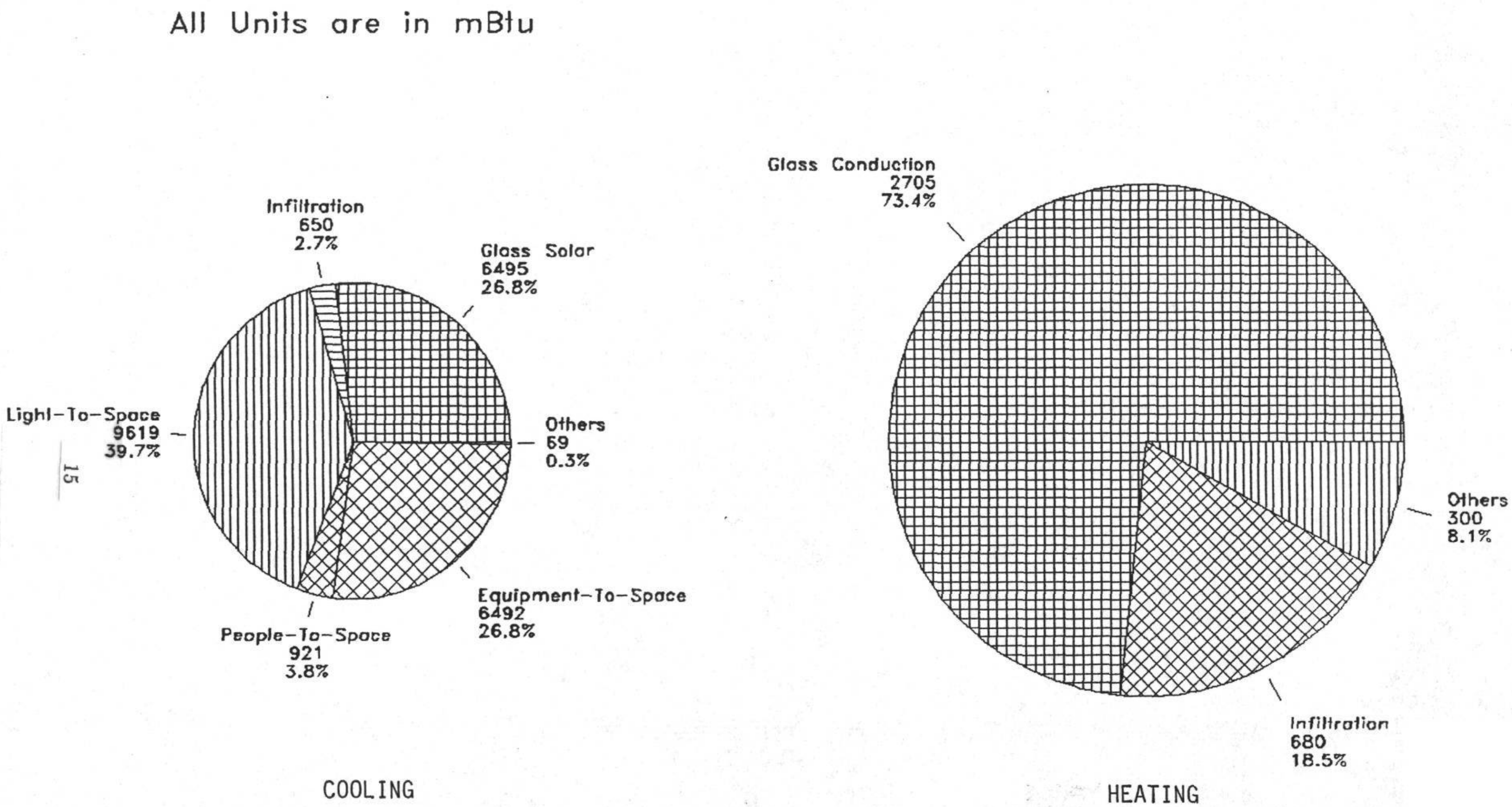


Figure 3.2 – Annual Cooling and Heating Base Travis Building.

the proposed design criteria in the ASHRAE standard are shown in Table 3.2. The Travis building has more lighting load (2.2 W/sf) than that specified by the ASHRAE standard. The higher design temperature (cooling) in the ASHRAE standard should allow for smaller capacity equipment than was actually used in the Travis building.

Table 3.2 – Comparison of Base Building and ASHRAE Standard Requirements.

Item	Base	ASHRAE Standards
Lighting	2.2 w/sf	1.8 W/sf
Design Heating	74°F	70°F
Design Cooling	75°F	78°F
Maximum Glazing	77%	–
Cooling	VAV	VAV
Heating	Electrical	–
Economizer Cycle	Yes	Required

The change in peak loads for the Travis building and the building modified to comply with ASHRAE standard are shown in Table 3.3. There was an average reduction of 4 percent in the peak cooling load. The major reduction was due to reduced heat gain from lights. The peak heating load increased for the building with ASHRAE standard also due to reduction in heat gains from lights.

Table 3.3 – Comparison of Peak Loads For Travis Building with the Proposed ASHRAE Standard at Different Locations in Texas. (MBtu/h)

Location	Base Cooling Load	ASHRAE Cooling Load	% Reduction	Base Heating Load	ASHRAE Heating Load	% Reduction
BROWNSVILLE	11.09	10.68	3.6	2.11	2.43	-1.5
HOUSTON	9.89	9.48	4.2	3.13	3.23	-3.0
AUSTIN	9.17	8.76	4.5	2.78	3.10	-1.0
LUBBOCK	9.24	8.84	4.4	5.26	5.61	-6.1
EL PASO	9.21	8.79	4.5	3.53	3.62	-2.7

The distribution of the loads and the EUI for the building with the ASHRAE standards are shown in Table 3.4. Both the heating and cooling energy use were reduced with the ASHRAE design. The reduction in cooling loads is from the reduced lighting levels and the increase in design cooling temperature. The reduction in heating energy is primarily from the decrease in the design heating temperature.

Table 3.4 - Comparison of Annual Energy Use For Travis Building with Proposed ASHRAE Standard at Different Locations in Texas.

Location	Cooling [COP = 3] MBtu	Heating MBtu	Lighting & Equipment MBtu (MWh)	HVAC MBtu (MWh)	Annual MBtu	EUI kBtu/sf/yr
BROWNSVILLE	9768	1062	16885(4947)	14593(4276)	42308	91.8
HOUSTON	6591	2489	16885(4947)	13845(4057)	39810	86.4
AUSTIN	6562	5745	16885(4947)	14452(4234)	43644	94.7
LUBBOCK	4430	12622	16885(4947)	14614(4282)	48551	105.3
EL PASO	5470	20499	16885(4947)	15047(4409)	57901	125.6

The major differences between the base building and the California standards are shown in Table 3.5. The California Standard requires lower connected lighting load and a smaller amount of window area.

Table 3.5 - Comparison of Base Building and California Standard Requirements

Item	Base	Califorina Standards
Lighting	2.2 w/sf	1.5 w/sf
Design Heating	74°F	70°F
Design Cooling	75°F	78°F
Maximum Glazing	77%	≤50%
Cooling	VAV	VAV
Heating	Electrical	Non-Electrical or Heat pump
Economizer Cycle	Yes	Required

The comparisons of peak heating and cooling loads for the base building and the modified building which conformed to the California standards are shown in Table 3.6. The reduction in peak cooling load was 19 percent, due to a reduction in the total glazed surface and due to reduced lighting levels. Although there was a reduction in heat gains from lights, the reduction in peak heating load was about 12 percent, due to reduced in glass conduction losses.

Table 3.6 - Comparison of Peak Loads For Base Travis Building and Building Modified for California Standard. (MBtu/h)

Option	Cooling Load	Heating Load
Base	9.17	2.78
California Standard	7.42	2.45
% Reduction	19	12

The comparisons of the annual heating, cooling, electric energy, HVAC, and the EUI for the base building and the building conformed to California standards are shown in Table 3.7. Because the California standard restricts the total glazing to 50% of the exterior wall area, lighting levels to 1.5 W/sf, has higher summer and lower winter set point temperatures and requires a heat pump for heating - there was a 36% reduction in annual energy consumption. The major change in cooling energy was due to the reduced of solar gain through the glass, reduced heat gain from lighting, and an increase in the design cooling temperature. The reduction in annual heating energy was primarily from lower glass conduction losses and a decrease in the set point temperature.

Table 3.7 - Comparison of Energy Use For Base Travis Building and Building Modified for California Standard.

Option	Cooling [COP = 3] MBtu	Heating MBtu	Lighting & Equipment MBtu (MWh)	HVAC MBtu (MWh)	Annual MBtu	EUI kBtu/sf/yr
BASE	6972	5873	18795(5507)	14968(4386)	46608	101.0
CALIFORNIA	4873	2083*	15454(4528)	7311(2142)	29722	64.5

* Heat pump COP = 2.0

Heat gains and heat loss through the glass are a major contributor to the annual energy use of the building. The glass in the Travis building was slightly tinted, other types of glass which reflect more of the direct solar radiation and have lower thermal conductivity are available. One such improved glass type which had 45% reflectivity, 19% transmissivity and a U-value of 0.27 Btu/h-sf-F was used in the simulation, and energy consumption of the building was analyzed. The comparison of the energy use for the base case, ASHRAE standard, ASHRAE standard with improved glass type, California standard and California standard with improved glass type are shown in Table 3.8. There would be substantial reduction in energy use if the Travis building were to conform to either the California or the ASHRAE standard.

Table 3.8 – Comparison of Annual Energy Use For Travis Building with Various Options.

Option	Cooling MBtu	Heating MBtu	Electricity MBtu (MWh)	Annual MBtu	EUI kBtu/sf/yr	% Reduction in EUI
BASE	6972	5873	33763(9893)	46608	101.0	–
ASHRAE	6562	5745	31337(9182)	43644	94.7	6.2
ASHRAE + GLASS-1	5143	5171	25996(7617)	36310	78.8	22.0
CALIFORNIA	4873	2083*	22765(6671)	29722	64.5	36.1
CALIFORNIA + GLASS-1	4099	2321*	20951(6139)	27371	59.4	41.1

* Heat pump COP = 2.0

SUPREME COURT & ATTORNEY GENERAL BUILDINGS

The Supreme Court and Attorney General Complex consists of four buildings (A,B,C and D as referred in the floor plans) [5]. The complex is located in Austin, Texas. Buildings A&B are existing Supreme court buildings. However, the floor area of building B was to be increased to extend its library. The total area of buildings A&B are 178,664 sf. Building C was a proposed eight-story office building at the Southeast corner of Lavaca and West 14^{th} street. It was connected to A&B by a new underground executive parking garage, and by a connecting link at the first floor. The total floor area of building C is 172,072 sf. Building D was a proposed twelve-story office building, at the Northeast corner of Lavaca and West 15^{th} street, immediately South of the new state parking garage. The total floor area of building D is 365,615 sf.

The occupancy density of all the three buildings was estimated at 250 sf/person which was consistent with guidelines in the proposed ASHRAE standard. The base case for these buildings included the following: (i) building A&B were analyzed with the library extension and (ii) building C, and D were analyzed as proposed in the design plans. Assumptions concerning the lighting levels, occupancy, and operation of equipment were developed after consultation with SPGSC and the building designers.

First, the energy use of all three buildings was analyzed for the base case; the buildings were modified to conform to the ASHRAE and the California standards and their energy use was estimated and compared to the base case. In addition, the effectiveness of a thin solar film to reduce the direct solar heat gains through the windows was studied.

The peak cooling loads for the buildings A&B, C, and D are shown in Figures 3.3 through 3.5. The direct solar heat gains and glass conduction constitutes an average of 29% of the peak cooling load for the three buildings. The internal loads (light, people, equipments) constitute about 37%, 34%, and 38% for buildings A&B, C, D, respectively.

The peak heating loads for the buildings A&B, C, and D are shown in Figures 3.6 through 3.8. The heat loss from infiltration, in case of heating, are much more significant than cooling. The glass conduction loss constitutes 20%, 38%, and 29% of the peak heating load for the buildings A&B, C, and D, respectively.

The annual cooling and heating, electric energy, annual energy use, and EUI for all three buildings are shown in Table 3.9. The EUI's of all the three buildings are quiet high as compared to the Travis building (see discussion on next page).

Table 3.9 – Annual Energy Use For the Supreme Court and Attorney General Complex.

Building	Cooling MBtu	Heating MBtu	Electricity MBtu(MWh)	Annual MBtu	EUI (kBtu/sf/yr)
A&B	7452	6460	13975(4095)	27885	185.9
C	2770	7281	15228(4462)	25274	181.5
D	5930	15809	33513(9820)	55245	152.0

The HVAC system for all the three buildings was a dual duct variable volume system (DDV). This system is not economical because it provides both hot and cold air, each at constant temperature. Each zone is served by two ducts, one carrying the hot air, the other carrying the cold air. The ducts feed into a mixing box in each zone which, by means of dampers, mixes the two air streams to achieve an air temperature required to meet load conditions in the zone. Since

All Units are in kBtu/h

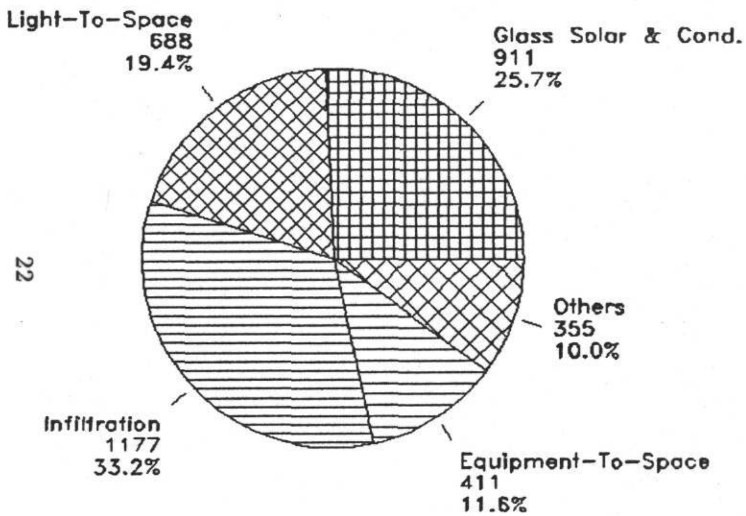


Figure 3.3 – Peak Cooling Base Building A&B.

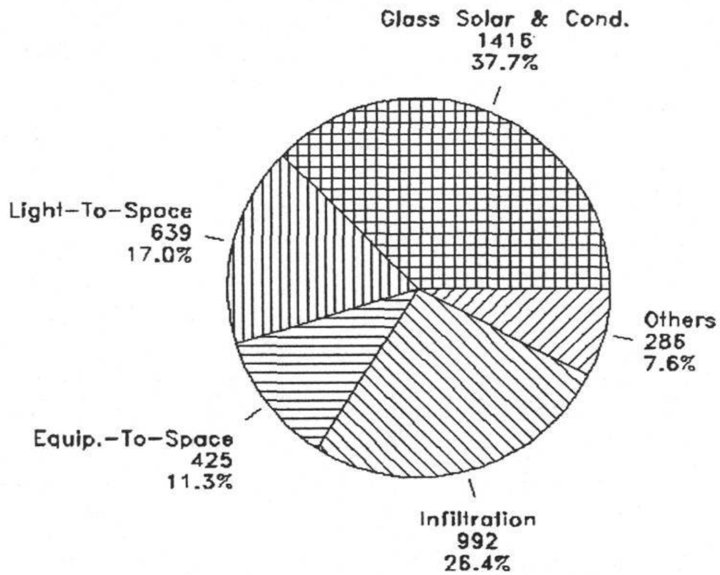


Figure 3.4 – Peak Cooling Base Building C.

All Units are in kBtu/h

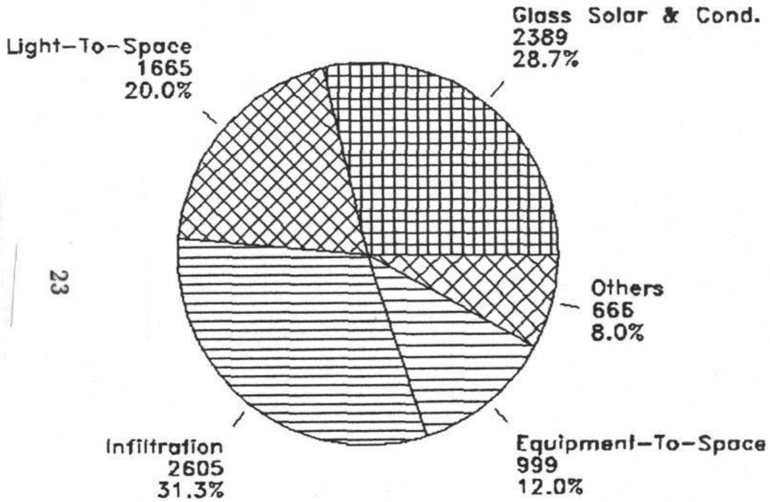


Figure 3.5 – Peak Cooling Base Building D.

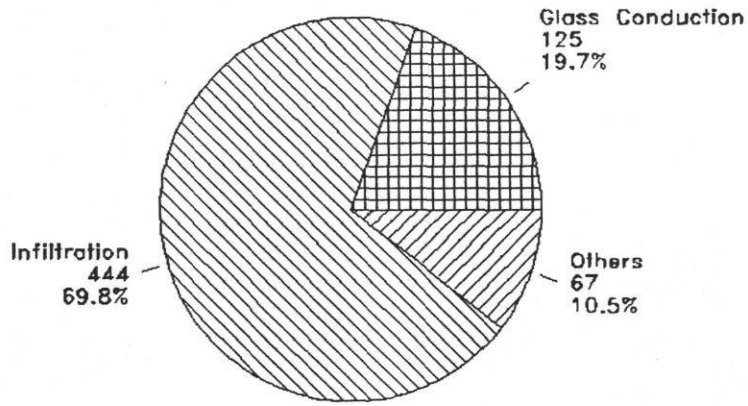


Figure 3.6 – Peak Heating Base Building A&B.

All Units are in kBtu/h

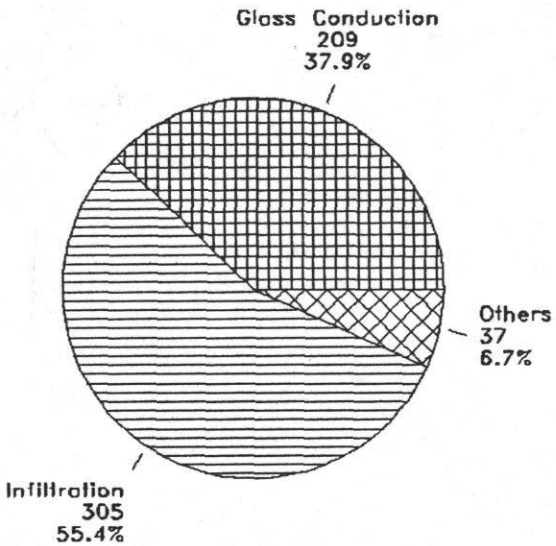


Figure 3.7 – Peak Heating Base Building C.

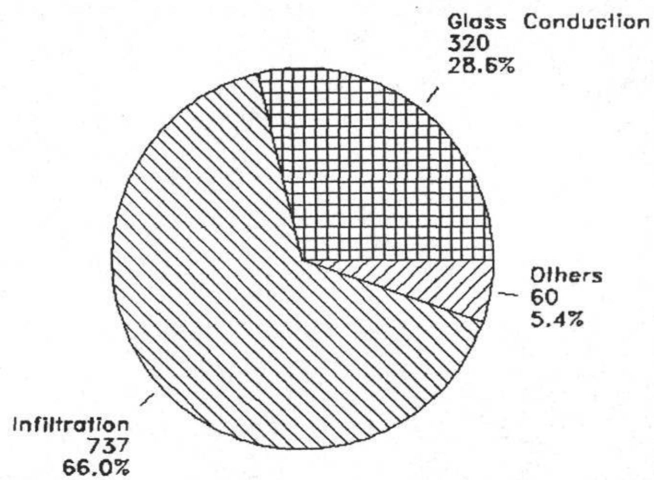


Figure 3.8 – Peak Heating Base Building D.

the air stream is simultaneously heated and cooled the system efficiency is quite low.

After analyzing the base case energy use for all the three buildings, they were modified to conform to the proposed ASHRAE standard. The major deviations of the base buildings with the standard are shown in Table 3.10.

Table 3.10 - Comparison of Base Complex and Standards Requirements.

Item	Base	ASHRAE	California
Lighting	2.0 w/sf	1.8 W/sf	1.5 W/sf
Design Heating	75°F	70°F	70°F
Design Cooling	75°F	78°F	78°F
Maximum Glazing	75%	-	$\leq$ 50%
Cooling System	DDV	VAV	VAV
Heating System	Electrical	-	Non-Electrical or
		-	Heat pump
Economizer Cycle	Yes	Required	Required

The comparisons of peak cooling and heating loads for the base buildings and the buildings conformed with the ASHRAE standard are shown in Table 3.11. There is an average reduction of 2% in peak cooling load for all the buildings; which is primarily a reduction of heat gains from lights. The peak heating load increased with the ASHRAE standard due to reduced heat gains from lights.

Table 3.11 - Comparisons of Peak Cooling and Heating Loads for the Base Buildings and Buildings with ASHRAE Standard. (MBtu/h)

Building	Cooling Base	Cooling ASHRAE	% Reduction	Heating Base	Heating ASHRAE	% Reduction
A&B	3.55	3.48	2	.64	.70	-9
C	3.76	3.69	2	.55	.60	-9
D	8.32	8.16	2	1.12	1.25	-12

The comparisons of the energy use for the base building and the buildings which conformed to the ASHRAE standard are shown in Tables 3.12 through 3.14.

Table 3.12 – Comparisons of Energy Use for the Base Building (A&B) and Building with ASHRAE Standard.

Option	Cooling MBtu	Heating MBtu	Electric Energy MBtu(MWh)	Annual MBtu
Base	7452	6460	13975(4095)	27885
ASHRAE	2352	1482	9515(2788)	13349
% Reduction	68	77	32	52

Table 3.13 – Comparisons of Energy Use for the Base Building (C) and Building with ASHRAE Standard.

Option	Cooling MBtu	Heating MBtu	Electric Energy MBtu(MWh)	Annual MBtu
Base	2770	7281	15223(4462)	25274
ASHRAE	2700	1876	10607(3108)	15179
% Reduction	2	74	30	40

Table 3.14 – Comparisons of Energy Use for the Base Building (D) and Building with ASHRAE Standard.

Option	Cooling MBtu	Heating MBtu	Electric Energy MBtu(MWh)	Annual MBtu
Base	5930	15809	33513(9820)	55245
ASHRAE	5655	4174	23313(6831)	33135
% Reduction	5	74	30	40

There is a substantial reduction in heating energy for all three buildings (75%). The reduction in cooling energy for buildings C and D are not significant, however, there was a 68% reduction in cooling energy for building A&B. The reduction in heating energy is due to the use of more efficient VAV system in place of DDV and a decrease in set point temperature. The reduction in annual energy use was 52%, 40%, and 40% for buildings A&B, C, and D, respectively.

The comparisons of peak cooling loads between the base buildings and the buildings conforming to the California standards are shown in Table 3.15. The average reduction in peak cooling load was 12% due to lower lighting levels and reduction in total glazed surface.

Table 3.15 – Comparisons of Peak Cooling Loads for the Base Buildings and Buildings Which Conform to the California Standard. (MBtu/h)

Building	Base	California Standards	% Reduction
A&B	3.55	3.08	13
C	3.76	3.34	11
D	8.32	7.21	13

The comparison of the energy use of the base buildings and the buildings modified to conform to the California standard are shown in Tables 3.16 through 3.18. Because the standards restrict the total glazing to 50% of the exterior wall area, lighting levels to 1.5 W/sf, require a heat pump for heating, and have higher summer and lower winter set point temperatures than the base buildings, there were savings of 60% in the annual energy use.

Table 3.16 – Comparisons of Energy Use for the Base Building (A&B) and Building with California Standard.

Option	Cooling MBtu	Heating MBtu	Electric Energy MBtu(MWh)	Annual MBtu
Base	7452	6460	13975(4095)	27885
ASHRAE	1453	1089	8863(2597)	11403
% Reduction	81	83	37	59

Table 3.17 – Comparisons of Energy Use for the Base Building (C) and Building with California Standard.

Option	Cooling MBtu	Heating MBtu	Electric Energy MBtu(MWh)	Annual MBtu
Base	2770	7281	15228(4462)	25274
ASHRAE	1678	814	7791(2283)	10283
% Reduction	37	82	35	49

Table 3.18 – Comparisons of Energy Use for the Base Building (D) and Building with California Standard.

Option	Cooling MBtu	Heating MBtu	Electric Energy MBtu(MWh)	Annual MBtu
Base	5930	15809	33513(9820)	55245
ASHRAE	3417	1771	17006(4983)	22039
% Reduction	42	89	50	60

There is a substantial reduction in both cooling and heating energy for all three buildings. The change in annual cooling energy is due to: use of a VAV system in place of the DDV system, lower lighting levels, higher set point temperature and reduction in amount of glazed surface area. The change in heating energy is due to: use of a heat pump, reduced set point temperature and reduction in glazed surface area.

Finally, the effectiveness of a thin window film in reducing solar and conduction heat gain through window in summer and conduction heat loss in winter were analyzed. The proposed glass of the buildings was a double pane with slight tint. Thin solar film having a 10% transmissivity and 51% reflectivity was used in the study.

The average reduction in direct solar and glass conduction heat gains for the three buildings was 85% and 40%, respectively. The average reduction in glass conduction heat loss for the three buildings was about 50%.

The comparisons of the energy use for all the options are shown in Tables 3.19 through 3.21 for the three buildings.

Table 3.19 – Comparison of Energy Use For Building A&B for Various Options.

Option	Cooling MBtu	Heating MBtu	Electricity MBtu (MWh)	Annual MBtu	EUI kBtu/sf/yr	% Reduction in EUI
BASE	7452	6460	13975(4095)	27885	186	–
ASHRAE	2352	1482	9515(2788)	13349	89	52
CALIFORNIA	1453	1089*	8863(2597)	11403	76	59
CALIFORNIA +SOLAR FILM	1230	868*	7890(2312)	9986	67	64

Table 3.20 – Comparison of Energy Use For Building C for Various Options.

Option	Cooling MBtu	Heating MBtu	Electricity MBtu (MWh)	Annual MBtu	EUI kBtu/sf/yr	% Reduction in EUI
BASE	2770	7281	15223(4462)	25274	181	–
ASHRAE	2770	1876	10607(3108)	15179	109	40
CALIFORNIA	1678	814*	7791(2283)	11403	82	55
CALIFORNIA +SOLAR FLIM	1146	604*	4539(1330)	8558	61	66

Table 3.21 – Comparison of Energy Use For Building D for Various Options.

Option	Cooling MBtu	Heating MBtu	Electricity MBtu (MWh)	Annual MBtu	EUI kBtu/sf/yr	% Reduction in EUI
BASE	5930	15809	33513(9820)	55245	152	–
ASHRAE	5655	4174	23313(6831)	33135	91	40
CALIFORNIA	3417	1771*	16852(4938)	22039	60	60
CALIFORNIA +SOLAR FLIM	2584	1401*	15231(4463)	19215	53	65

* COP = 2.0

All four buildings in the Supreme Court and Attorney General Complex have much higher EUI's than the Travis building. If these buildings are build according to the requirements of either the ASHRAE or California standards, substantial energy would be saved. One of the major factors for the high energy use in this complex is the use of a DDV system for heating and cooling which is not as efficient as the VAV system. Both the proposed ASHRAE and the existing California standards do not recommend the DDV system.

TEXAS DEPARTMENT OF HEALTH BUILDING

The Texas Department of Health building (Health Building) was a proposed seven story office building to be located in Austin, Texas [6]. The exterior surface area of the building is 7,532 sf/floor, of which 2,233 sf is glazed. The total exterior surface area is 52,725 and the total floor area is 128,198 sf. The maximum number of occupants per floor are 175.

After discussion with SPGSC and the building designers a base case was established for operation and occupancy for the building. The energy use of the base building was then analyzed. As with the other buildings, energy use was estimated after implementing the California standard. The base building had a VAV system with a two speed fan but no an economizer cycle. An alternative to this system is one with an economizer cycle a variable speed fan. Also, the Health building has a high ventilation rate (20 cfm/person). The ventilation rate recommended by the ASHRAE standard is 10 cfm/person. The additional energy required to maintain the ventilation rate above the recommended level was also studied.

The peak cooling and heating loads are shown in Figure 3.9. The heat gains from lights and equipment constitute 42% of the peak cooling load. The heat gains from infiltration constitutes about 33% of the peak cooling load. The total contribution from the internal loads is 53%. The heat loss from the walls and glass make up about 77% of the peak heating load. The heat loss from infiltration load in the case of heating was 12% of the peak. Although the building has more wall area than the glass area, the glass conduction loss constitutes 58% of the peak as compared to 19% from wall conduction.

The annual cooling and heating energy consumption are shown in Figure 3.10. The heat gains from lights and equipment constitute a major portion of the annual cooling use (69%). The heat gains from the glass solar and people are each 13% of the annual cooling load. Over 80% of the cooling load is from internal heat gains. The annual heating use is entirely made up of heat loss from

All Units are in kBtu/h

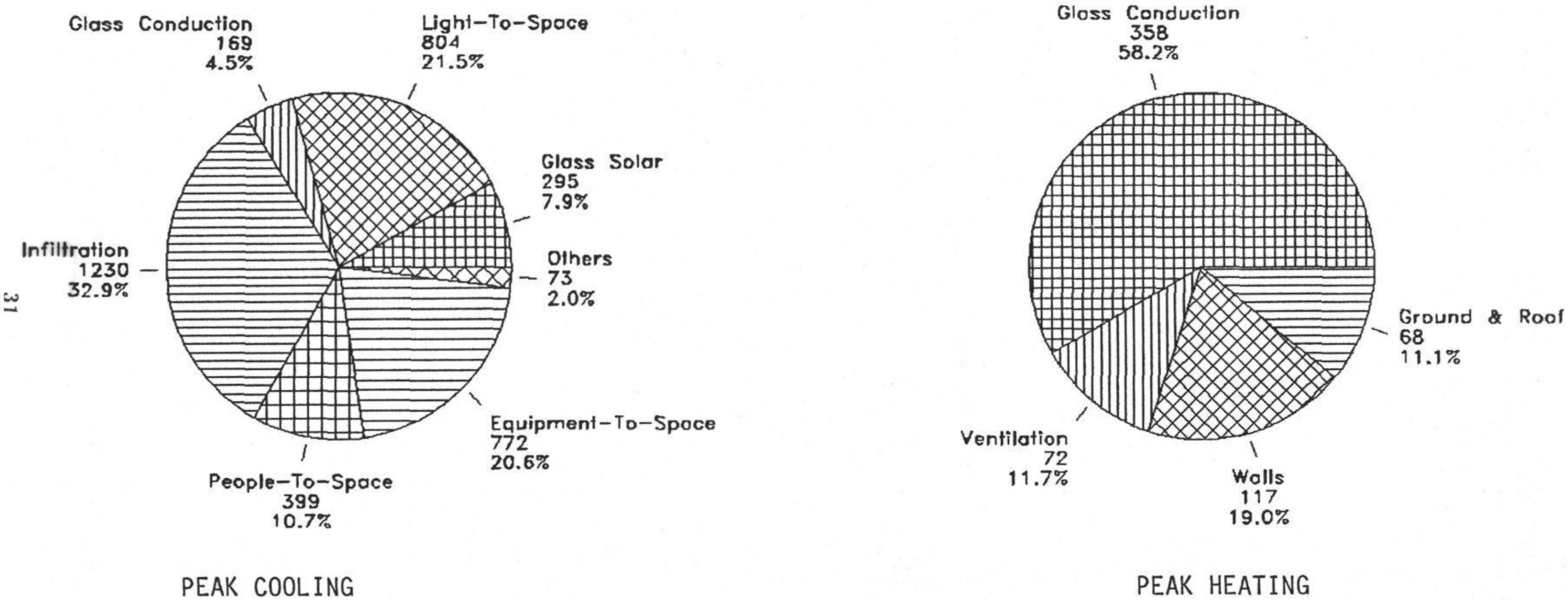


Figure 3.9 – Peak Cooling and Heating Base Health Building.

infiltration and ventilation. The glass conduction loss constitute less than 1% of the annual heating load. The heat loss from roof, walls and underground surface constitute about 3% of the annual heating load.

The major differences between the base building and the California standard requirements are shown in Table 3.22.

Table 3.22 - Comparison of Base Health Building and California Standard Requirements.

Item	Base	Standards
Lighting	2.2 w/sf	1.5 W/sf
Design Heating	75°F	70°F
Design Cooling	75°F	78°F
Maximum Glazing	33%	$\leq$ 50%
Ventilation	20 cfm/person	10 cfm/person
Cooling	VAV: Two speed Fan	VAV : Variable speed Fan
Heating	Electrical	Non-Electrical or Heat pump
Economizer Cycle	No	Required

The comparisons of peak cooling and heating loads for the base Health building and the building modified for the California standard are shown in Table 3.23. The reduction in peak cooling was 35% due to: reduction in fresh air requirement from 20 to 10 cfm/person, and reduction in lighting levels by 0.7 W/sf. However, there was an increase of 22% in peak heating load with the California standard. It was due to lower internal heat gains from lights.

Table 3.23 - Comparison of Peak Loads For Base Health Building and Building Modified for California Standard. (MBtu/h)

Option	Cooling Load	Heating Load
Base	3.74	0.18
California Standard	2.42	0.22
% Change	35	-22

The comparisons of annual energy use of the base Health building and the

All Units are in mBtu

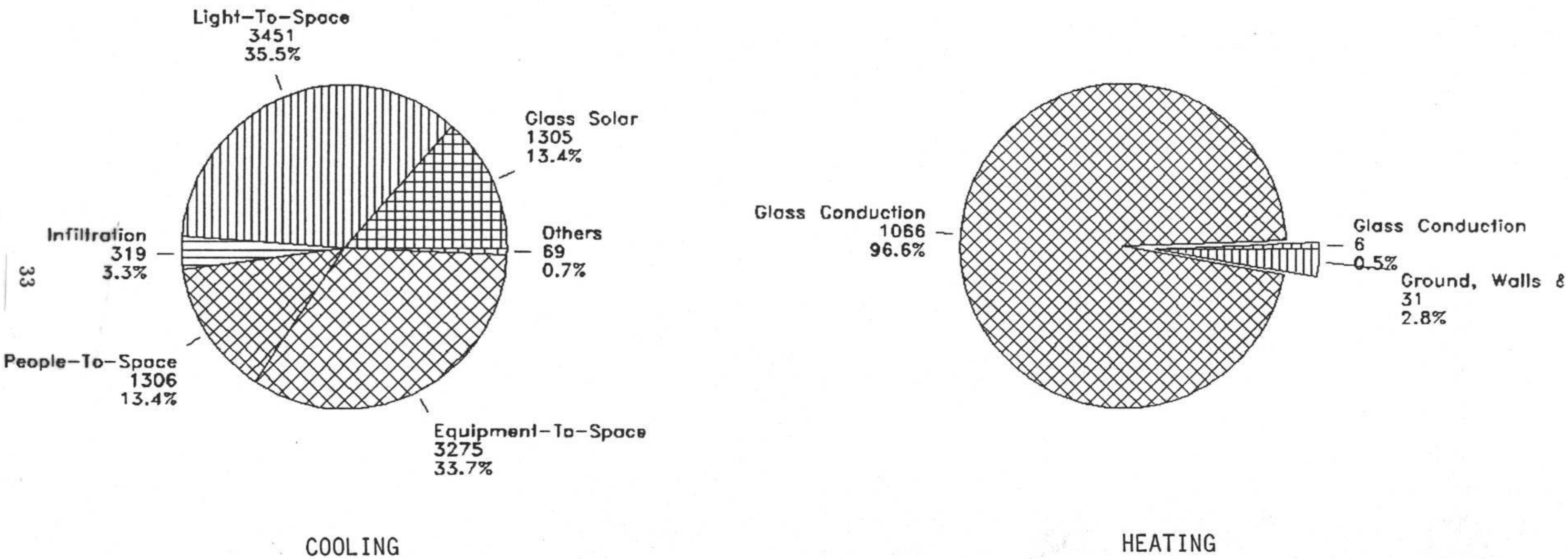


Figure 3.10 – Annual Cooling and Heating Base Health Building.

building modified for the California standard are shown in Table 3.24. Because the California standard restricts the zone set point temperature, lighting level, and require a heat pump for heating, the annual energy use was reduced by 44%. The major reduction in cooling energy use was due to reduced heat gains from lights and increase in set point temperature. The reduction in heating energy use was due to use of heat pump and decrease in set point temperature.

Table 3.24 – Comparison of Annual Energy Use For Health Building and Building Modified for the California Standard.

Option	Cooling MBtu	Heating MBtu	Electricity MBtu (MWh)	Annual MBtu	EUI kBtu/sf/yr	% Reduction in EUI
BASE	2489	1103	14639(4289)	18231	142.0	–
CALIFORNIA	1498	641*	8038(2355)	10177	79.4	44

* Heat pump COP = 2

The comparisons of energy use for the various options for the Health building are shown in Table 3.25. The reduction of annual energy use for the building with reduced ventilation (20 to 10 cfm/person) was 3.4%. The reduction of annual energy use for the building with a variable speed fan and economizer cycle was 12%. The reduction in cooling energy for the economizer option was 7%; however, there was a slight increase in heating energy.

Table 3.25 – Comparison of Annual Energy Use For Health Building with Various Options.

Option	Cooling MBtu	Heating MBtu	Electricity MBtu (MWh)	Annual MBtu	EUI kBtu/sf/yr	% Reduction in EUI
BASE	2489	1103	14639(4289)	18231	142.0	–
CALIFORNIA	1498	641	8038(2355)	10177	79.4	44.0
VENTILATION	2440	571	14620(4284)	17631	137.5	3.4

There would be a substantial amount of energy savings if the Health building would conform to the requirements of the California standard. The options for reducing the energy use in the Health building include: (i) reducing the lighting levels, (ii) reducing the ventilation rate from 20 to 10 cfm/person, (iii) employing a variable speed fan for the VAV system with an economizer cycle, and (iv) employing the California standard with all the previous options.

TYC/TRC BUILDING

The Texas Youth Commission/Texas Rehabilitation Commission (TYC/TRC) building was a proposed seven story office building located in Austin, Texas [7]. The total exterior surface area is 104,360 sf, of which 25,662 sf is glazed. The gross floor area of the building is 259,272 sf. The maximum occupancy is 1100.

The TYC/TRC building as initially proposed was assumed to be a base case. Its energy use was estimated and compared to the energy use of the building modified to comply to the ASHRAE and the California standards.

The peak cooling and heating loads of the TYC/TRC buildings are shown in Figure 3.11. The heat gains from lights and equipment constitute about 51% of the peak cooling load. The solar and conduction heat gains through the glass represent 8% of the peak cooling load. The internal loads constitute 55% of the peak cooling load as compared to 45% from the external loads. The heat losses from the walls and glass conduction make up about 72% of the peak heating load. The heat losses from infiltration and ventilation are about 14% of the peak heating load. The heat losses from the underground surfaces and roof constitute 14% of the peak.

The annual cooling and heating loads are shown in Figure 3.12. The heat gains from lights and equipment constitute the major portion of the annual cooling load (82%). The solar heat gains through the glass and people heat gains each contribute 7% to the annual cooling load. The heat losses from the roof and walls was 45% of the annual heating load. The loss from ventilation and underground surfaces are 8% and 13%, respectively, of the annual heating load.

The differences between the base building and the requirements of the ASHRAE and the California standards are shown in Table 3.26.

All Units are in kBtu/h

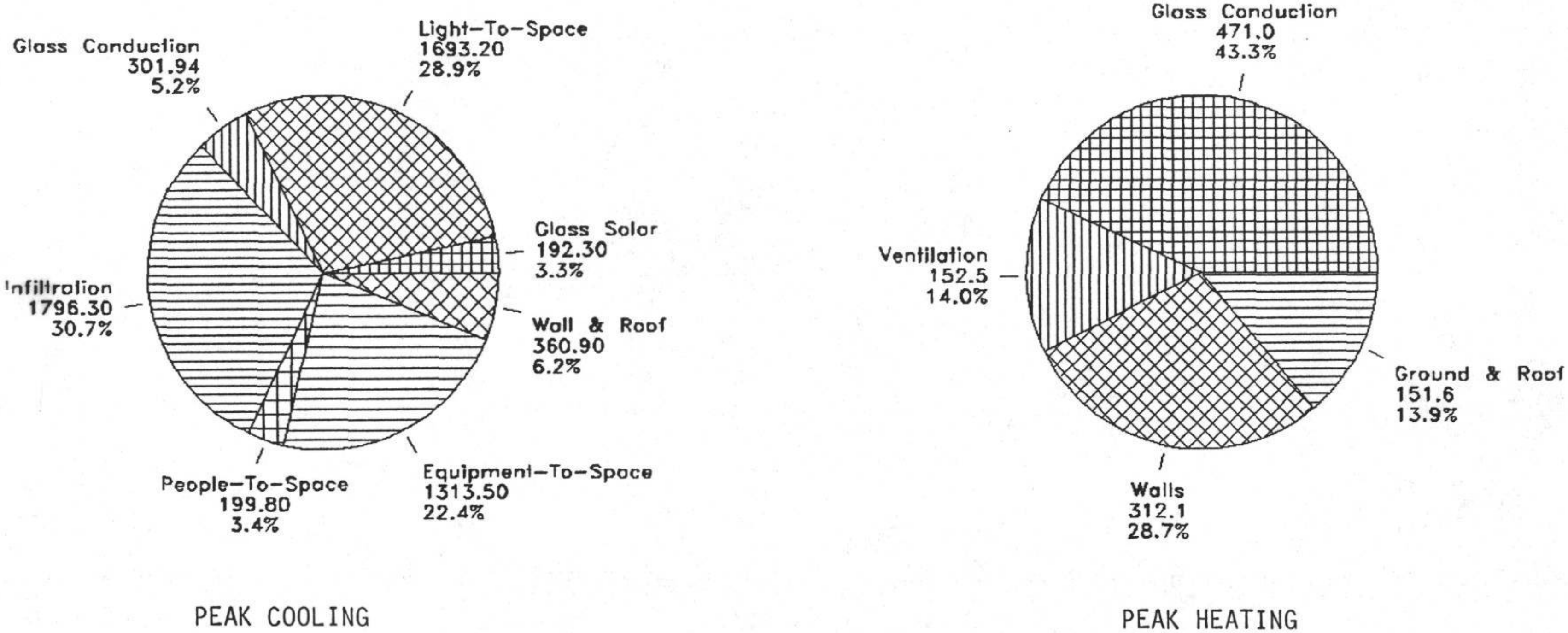
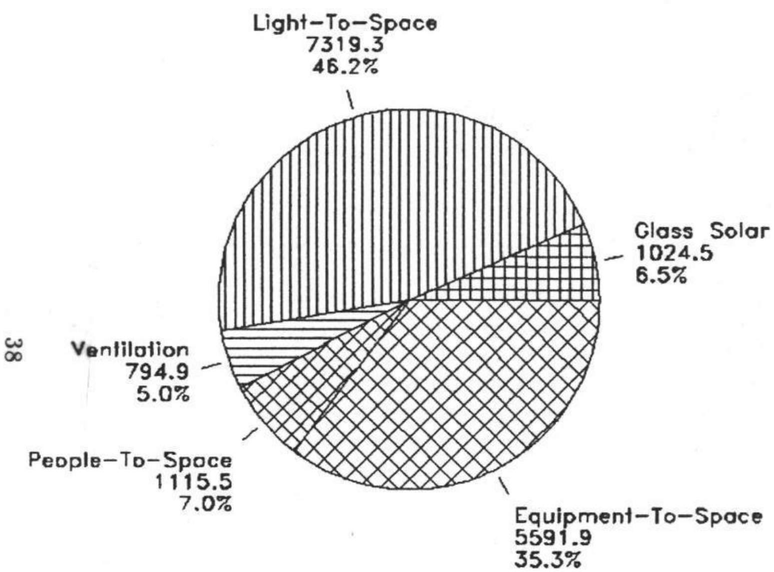
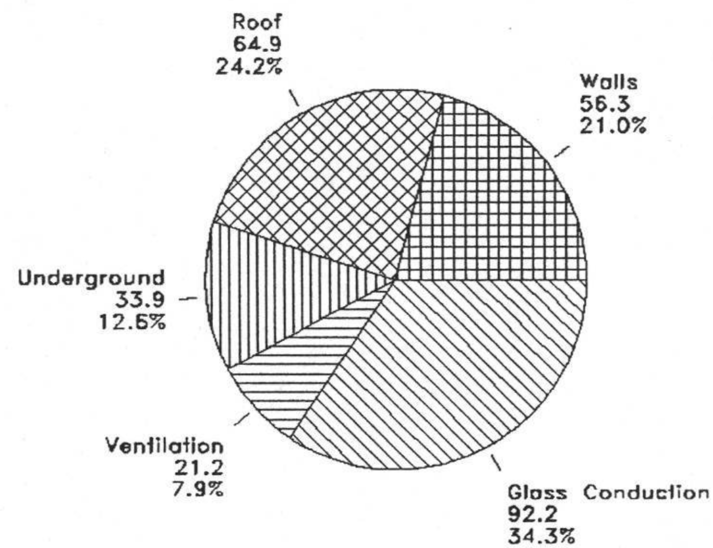


Figure 3.11 – Peak Cooling and Heating Base TYC/TRC Building.

All Units are in mBtu



Cooling



Heating

Figure 3.12 – Annual Cooling and Heating TYC/TRC Building.

Table 3.26 – Comparison of Base TYC/TRC Building and ASHRAE Standard Requirements.

Item	Base	ASHRAE	California
Lighting	2.5 w/sf	1.8 W/sf	1.5 W/sf
Design Heating	75°F	70°F	70°F
Design Cooling	75°F	78°F	78°F
Maximum Glazing	33%	–	$\leq$ 50%
Ventilation	20 cfm	10 cfm	10 cfm
Cooling	DDV	VAV Variable Speed Fan	VAV Variable Speed Fan
Heating	Electrical	–	Non-Electrical or Heat pump
Economizer Cycle	No	Required	Required

The comparisons of peak heating and cooling loads of the base building and the modified building which conformed to the ASHRAE and the California Standards are shown in Table 3.27. The reduction in the peak cooling load for both the ASHRAE and California standards is about 18%. The principal reasons for the reduction of the peak cooling load are due to reduction in lighting level and ventilation rate. There was no change in peak heating load for both the standards when compared to the base building.

Table 3.27 – Comparison of Peak Loads For Base TYC/TRC Building and Building Modified for the ASHRAE and the California Standards. (MBtu/h)

Option	Cooling Load	Heating Load
Base	5.6	1.1
ASHRAE Standard	4.6	1.1
California Standard	4.4	1.1

The comparisons of energy use of the base building and the building conformed to the ASHRAE and the California standards are shown in Table 3.28.

Table 3.28 – Comparison of Annual Energy Use For TYC/TRC Building with Various Options.

Option	Cooling MBtu	Heating MBtu	Electricity MBtu (MWh)	Annual MBtu	EUI kBtu/sf/yr	% Reduction in EUI
BASE	3593	8748	22828(6686)	35169	136	-
ASHRAE	3126	1740	16777(4916)	21643	84	38
CALIFORNIA	2961	1506	15172(4066)	19639	76	44
BASE WITH VAV	3575	4179	19700(5772)	27454	106	28

The reduction in the annual energy use with the ASHRAE standard was 38%. The reduction in cooling and heating energy was 13% and 80%, respectively, for the building conforming to the ASHRAE standard. The reduction in the cooling energy was due to increase in set point temperature, use of a VAV system with economizer cycle, reduction in ventilation rate and reduction in lighting levels. The reduction in heating energy was due to use of a VAV system, decrease in set point temperature and decrease in ventilation rate.

The reduction in annual energy use with the California standard was higher than the ASHRAE standard (44%). The reasons for the differences are because the California standard has lower lighting requirement and recommends a heat pump for heating.

As mentioned earlier, the VAV system is more efficient than the DDV system which was the proposed system for the TYC/TRC building. Therefore, the energy saving with the VAV system as compared to the DDV system were studied (rest of the parameters were the same as the base case). The comparisons of the energy use are shown in Table 3.28. The change in cooling and heating energy was 0.5% and 52%, respectively, when compared to the base. Although the reduction in annual cooling energy was not significant, there was a net reduction of 28% in the annual energy use.

There could be substantial savings in energy use if the TYC/TRC buildings were to comply with either of the two standards. The major savings can be achieved if the proposed DDV system is replaced with the VAV system. In addition, reducing the lighting levels, increasing the set point temperature in summer, and reducing it in winter to the recommended values would also provide savings in energy use.

WAREHOUSE FACILITY

The Warehouse facility of the Human services center complex was a proposed facility to be located in Austin, Texas [8]. The gross floor area of the facility is 105,368 sf, of which 26,465 sf is office area. The occupancy of the facility is 400.

The energy use of the base facility was analyzed and then compared to the facility that conformed to the ASHRAE standard. The peak cooling and heating loads for the base case are shown in Figure 3.13. The heat gain from infiltration, walls and roof, and lights constitutes 35%, 21% and 20% of the peak cooling load, respectively. The heat loss from the infiltration and walls constitute 75% and 22% of the peak heating load, respectively.

The HVAC system for the warehouse area of this facility consists of a constant volume system without cooling capability or humidity control. In its basic configuration, the system provides forced air heating from an air handling unit that contains a heating coil provided by gas fired radiant panels and a supply fan. The office areas will be heated by indirect gas fired and cooled with roof mounted packaged HVAC equipment utilizing Direct Expansion (DX) cooling and indirect gas fired heating. The Packaged Single Zone (PSZ) air conditioner with heating was used for the office areas. In its most basic configuration, the PSZ system consists of a compressor, an air-cooled condenser, an evaporator with a fan supplying cooled air to the indoors and a thermostat.

The comparison of peak loads of the Warehouse facility for the base case and with the ASHRAE standard is shown in Table 3.29. There was no change in peak cooling load for the facility. The lighting level was reduced by 0.2 W/sf in the office area. Therefore, the peak heating load increased by 1.1% with the ASHRAE standard, because of reduced heat gains from lights.

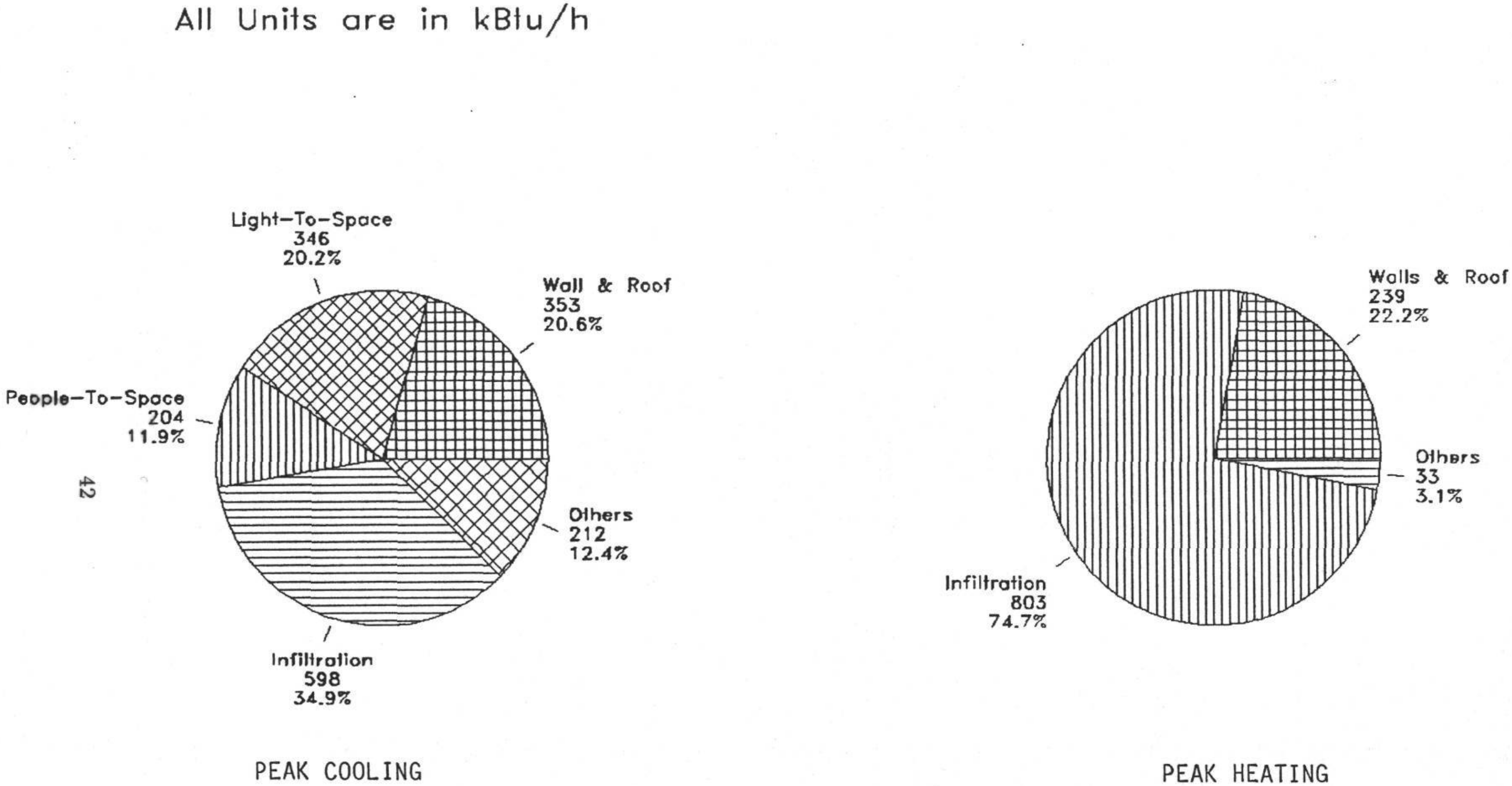


Figure 3.13 – Peak Cooling and Heating Base Warehouse Facility.

Table 3.29 - Comparison of Peak Loads For Base Warehouse Facility and Facility Modified for the ASHRAE Standard. (MBtu/h)

Option	Cooling Load	Heating Load
Base	1.7	1.07
ASHRAE Standard	1.7	1.08
% Change	0	-1.1

The comparisons of annual energy use for the base case and the ASHRAE standard is shown in Table 3.30. The annual energy use was reduced by 7% with the ASHRAE standard. The reduction in cooling energy was use 4% due to reduced lighting levels and increase in set point temperature. The reduction of heating energy was 38% due to decrease in set point temperature alone. Since, most of the facility was heated and only the office portion of the facility was cooled the saving in heating was greater.

Table 3.30 - Comparison of Annual Energy Use For Warehouse Facility and Facility with the ASHRAE Standard.

Option	Cooling MBtu	Heating MBtu	Electricity MBtu (MWh)	Annual MBtu	EUI kBtu/sf/yr
BASE	452	171	5640(1653)	6263	59.4
ASHRAE	432	105	5299(1553)	5837	55.4
% Reduction	4.3%	38.4%	6%	6.7	6.7

Since, a large part of the facility is not cooled, the potential for energy savings is not attractive. However, some reduction in energy use could be achieved by changing the set point temperatures to that suggested by the standard.

ADDITION TO RECORDS AND STORAGE BUILDING

This building was a proposed extension to Records and Storage building located in Austin, Texas [9]. It consists of administrative and storage areas. The total floor area of this extension is 84,836 sf and it has an occupancy of 250 people.

The peak cooling and heating loads for the building are shown in Figure 3.14.

The heat gains from infiltration constitute a major portion of the peak cooling load (35%). The heat gains from lights account for 31% of the peak cooling load and the rest of it is made up of solar and conduction heat gains through glass. The heat loss from infiltration is a major contributor to the peak heating load (81%). The heat loss from the walls and roof are 16% of the peak heating load.

The differences between the base building and ASHRAE standard requirements are shown in Table 3.31.

Table 3.31 - Comparison of Base Building and ASHRAE Standard Requirements.

Item	Base	Standards
Lighting	1.94 w/sf	1.8 W/sf
Design Heating	75°F	70°F
Design Cooling	75°F	78°F
Maximum Glazing	2%	-
Cooling	VAV	VAV
Heating	Electrical	-
Economizer Cycle	No	Required

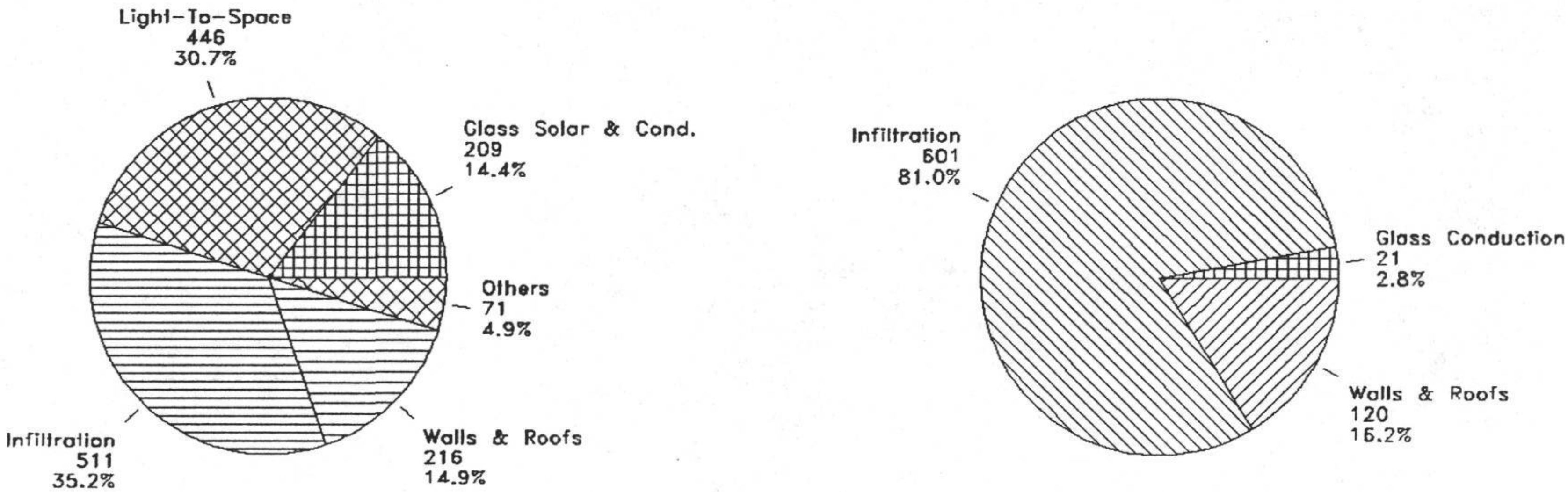
The comparisons of the peak loads of the base building and the building conformed to the ASHRAE standard is shown in Table 3.32. There is a reduction of 6% in peak cooling load for the building with the ASHRAE standard. The reduction was due to reduced heat gains from lights. The lighting level was reduced by 0.14 W/sf. The peak heating load increased for the building which compared to the ASHRAE standard. This increase was again due to reduced heat gains from lights.

Table 3.32 - Comparison of Peak Loads For Base Facility and Facility Modified for the ASHRAE Standard. (MBtu/h)

Option	Cooling Load	Heating Load
Base	1.46	.76
ASHRAE Standard	1.37	.87
% Change	6	-15

The comparisons of annual energy use of the base building and the building

All Units are in kBtu/h



PEAK COOLING

PEAK HEATING

Figure 3.14 – Peak Cooling and Heating Base Records and Storage Building.

which conformed to the ASHRAE standard are shown in Table 3.33. There is a reduction of 21% in cooling energy, due principally to the increase in set point temperature and reduced heat gains from lights. The reduction in heating energy was 50%, this is due to decreased set point temperature. The reason for a large reduction in heating energy is because the infiltration loads are the major contributor to the heating energy and any reduction in set point temperature will provide large saving in energy use. In winter the indoor-outdoor temperature difference is more than that in summer; therefore, the heat losses from infiltration are more severe in winter than in summer. The reduction in the annual energy use for the building with the ASHRAE standard as compared to the base building was 28%.

Table 3.33 – Comparison of Annual Energy Use For Base Facility and Facility with the ASHRAE Standard.

Option	Cooling MBtu	Heating MBtu	Electricity MBtu (MWh)	Annual MBtu	EUI kBtu/sf/yr
BASE	894	1276	4344(1274)	6514	80
ASHRAE	704	642	3321(974)	4669	57
% Reduction	21.2	49.7	6	28.3	29

Various other options were studied to estimate the energy saving potential. The options included: increase in R-value (from R–30 to R–44) of the insulation in the walls and roof, reducing the lighting levels (from 1.94 W/sf to 1.8 W/sf), and changing the indoor set point temperature (from 75 F to 78 F). The reduction in peak cooling and heating load with the increased R-value was 7% and 10%, respectively. The reduction in peak cooling with reduced lighting levels was 7%. The reduction of peak cooling load with an increase in summer set point temperature was 4%.

The comparisons of energy use for the various options are shown in Table 3.34. The reduction in cooling energy with an increase in R-value was approximately 4% and the reduction in heating energy was almost negligible. The annual energy use also reduced by 3% with this option. The reduction in cooling and heating energy with reduced lighting levels was 3.4% and 3.6%, respectively. The reduction in annual energy use was 4% compared to the base case.

Table 3.34 – Comparison of Annual Energy Use For Base Facility and Facility with Alternative Options.

Option	Cooling MBtu	Heating MBtu	Electricity MBtu (MWh)	Annual MBtu	EUI kBtu/sf/yr
BASE	894	1276	5640(1274)	6514	80
ASHRAE	704	642	5299(974)	4669	57
R-Value	861	1276	4177(1225)	6301	77
Lighting	863	1231	4153(1218)	6249	76

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

The Energy Systems Group of the Department of Mechanical Engineering at Texas A & M University worked jointly with the Energy Management Center (EMC) of the Governor's Office (formerly the Energy Efficiency Division of the Public Utility Commission) and the State Purchasing and General Services Commission (SPGSC). A total of six buildings were analyzed. One of the buildings had just been completed when this project was initiated in 1986. The other five buildings were in various design phases. This report summarized the first phase of the program to reduce the energy use in new construction in state–owned buildings.

It appears that there would be substantial reduction in energy use if the new state buildings were designed to satisfy the proposed ASHRAE or the existing California standard. The cost of installing the proposed ASHRAE standards was not compared to the energy cost saving, in other words, no economic analysis has been made. The California standard, having more restrictions, yield higher energy savings.

Weather plays a significant role in the energy use of the building. Although the Travis building was an office building with substantial internal loads, the energy use increased when the building was subjected to Brownsville weather as compared to El Paso weather. About 77 percent of the external walls in the Travis building were glass. Therefore, a large fraction of the energy use was from the heat loss through the envelope.

The new Supreme Court complex, which has three buildings, has a very high energy use index (170 kBtu/sf/h). The proposed HVAC system for this complex is a dual duct variable volume system. This system is not economical because it mixes both hot and cold air, each at constant temperature, to maintain comfort conditions in the building. Each zone is served by two ducts, one carrying hot air, the other carrying cold air. The ducts feed into a mixing box in each zone where the two air streams are mixed to achieve an air temperature required to meet load conditions in the zone. Since the air stream is simultaneously heated and cooled the system efficiency is quiet low.

Neither the proposed ASHRAE nor the existing California standard recommend a dual duct variable volume this system because of high energy use. They recommended the variable air volume system, which is more efficient than the other systems. Variable air volume systems vary the quantity of air to match the system load requirements. Thus, the energy consumption closely parallels the load on the air conditioning system.

The Texas Department of Health Building has a ventilation rate of 20 cfm/person, which is higher than the standard requirement (10 cfm/person). Approximately 4 percent of annual energy consumption can be saved by reduction of the ventilation rate. Also, the standards recommend an economizer cycle with the HVAC system. During the spring and fall of each year there are about 40 or more days in Texas when outside air conditions are suitable for an economizer [10].

The internal loads constitute a major portion of the cooling energy use for Austin weather, because most of the buildings studied were office buildings. Even when the outside temperature is in the range of 50 to 65 F, these buildings will need cooling [10]. Thus, the use of the economizer cycle will result in a substantial energy savings.

The solar and conduction heat gains through glass in summer and glass conduction in winter also contribute substantially to the annual energy use. The California standard restrict the amount of glass to 50% of the total exterior area and also restrict glass on the East and West facing walls. A glass with high reflectivity and low overall heat transfer coefficient will reduce energy use. Also, the use of external shading devices, such as overhangs, will reduce the amount of direct solar heat gains.

The current construction of state buildings reflect improvements in energy use over buildings built several years ago [11]. However, adopting the standards will reduce energy consumption further. The California standard is more stringent and may be a better choice for state owned buildings which have an expected life of 30 or 40 years.

APPENDIX A

The State Purchasing and General Services Commission has made some changes in the buildings described in the report based on our recommendations.

Building: Texas Youth Commission/Texas Rehabilitation Commission Building

1. No changes in lighting levels
2. Agreed to reduce heating set point and increase cooling set point to recommended values
3. Ventilation rate was not reduced
4. Expected completion date April '89

Building: Warehouse Facility

1. No change in lighting levels
2. Agreed to reduce heating set point and increase cooling set point to recommended values
3. Expected completion date April '88

Building: Records and Storage Facility

1. No change in lighting levels
2. Agreed to reduce heating set point and increase cooling set point to recommended values
3. Installed tinted glass in office area
4. Expected date of completion Aug. '88

Building: Supreme Court & Attorney Generals' Complex

1. No change in lighting levels
2. Agreed to reduce heating set point and increase cooling set point to recommended values
3. No change in glass area
4. Agreed to replace dual duct HVAC system with a VAV system
5. Expected date of completion not known

Building: Texas Department of Health Building

1. No change in lighting levels

2. Agreed to reduce heating set point and increase cooling set point to recommended values
3. No change in ventilation levels
4. Expected date of completion Nov. '88.

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