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A SURVEY OF URBAN-SCALE BUILDING ENERGY MODELERS

A Report to the ASHRAE Technical Committee TC 4.7,
Subcommittee on Multi-Scale Building Energy Modeling (MBEM)

Submitted by:

Xi Zhao
Jeff Haberl, Ph.D., FASHRAE, FIBPSA

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ENERGY SYSTEMS LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

Foreword

At the request of ASHRAE Technical Committee TC 4.7, Subcommittee on Multi-Scale Building Energy Modeling (MBEM), Mr. Ron Judkoff (Chair), the Energy Systems Laboratory (ESL) at the Texas A&M Engineering Experiment Station of the Texas A&M University System conducted Zoom/phone surveys with urban-scale building energy modelers from several universities, research laboratories, and a building energy modeling consultant in the U.S.

This report “A Survey of Urban-Scale Building Energy Modelers”, presents the survey results, which are based on transcriptions of the Zoom/phone interviews with the modeling experts at Massachusetts Institute of Technology (MIT), Argonne National Laboratory (ANL), Oak Ridge National Laboratory (ORNL), Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL), University of Colorado Boulder (CU Boulder), and Big Ladder Software LLC, Denver Colorado.

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Executive Summary

The Energy Systems Laboratory (Laboratory), a division of the Texas A&M Engineering Experiment Station and a member of The Texas A&M University System, at the request of ASHRAE Technical Committee TC 4.7, Subcommittee on Multi-Scale Building Energy Modeling (MBEM), submits its survey report, "A Survey of Urban-Scale Building Energy Modelers" to the ASHRAE TC 4.7 Subcommittee on Multi-Scale Building Energy Modeling (MBEM).

The report is organized in two parts:

- Part I – Report, which provides summaries of surveys and results, including an executive summary. A tabular format is used for showing survey results.
- Part II – Appendix, which contains detailed survey activities and transcriptions/notes.

Based on the summary of all the surveys/interviews, a list of future research needs to ASHRAE TC 4.7 is recorded below:

- A need for better coordination of UBEM analysis efforts at different institutions/universities.
- A need to create the next generation climate models to link to future planning.
- A need to cultivate talented simulators who have expertise with both GIS and building energy modeling.
- Use of UBEM to reduce big gaps in connecting the analysis of critical infrastructure and climate.
- Although ResStock is available, ComStock is difficult to distribute because of NDA restrictions. Therefore, there is a need to find a solution for the public distribution of ComStock for use in UBEM.
- Establishment of best practices, guidelines or standards for UBEM.
- A need to develop standard methods for how to use standard TMY3 weather data and translate it to a building specific location.
- Building template formats need to be further developed to facilitate different applications.

- There's a need to create a MBEM community where everybody can contribute to grow a common set of data (i.e., UBEM data bank).
- Research on how to better characterize building stock for more accurate UBEM.
- Research on how to incorporate new building technologies and new materials in a MBEM model.
- A need to have good data on the shading of single-family residential.
- A need for better moisture transport models.
- Investigate quality and current condition of real building systems to improve modeling assumptions.
- A need to determine how to model smart thermostats and their impact on IEQ and building energy use.
- A need to determine how actual buildings are zoned vs how the models are zoned, and how it impacts the accuracy of the MBEM model.
- Develop a standard method to perform a modeling of a two-story house with a temperature-stratified atrium space (i.e., cooling mode). What are the implications on the building stock?
- Research on standard procedures for how to validate MBEM models. A need for better validation test data.
- A need to better streamline the validation and data-sharing of UBEM.
- A need to establish a standard platform for research computing and reporting.
- A need to develop a standard method to perform a sensitivity analysis for UBEM.
- A need to provide advice on how to connect inverse models with forward models for improved calibration.
- A standard guideline for UBEM programming languages for ASHRAE TC 4.7.
- Using UBEM to develop portfolio level of energy master planning.
- Public tools for using UBEM on cloud computing resources.
- Research support for quantitative approaches to resiliency modeling for UBEM.
- Development of methods and protocols for developing a fast-running, inverse model from a slow-running, whole-building energy model.

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1 Introduction

In recent years, ASHRAE Technical Committee TC 4.7 has become interested in Urban-Scale Building Energy Modeling (UBEM), due to the increasing research activities in this field. Currently, work is being performed on UBEM at different universities, laboratories, and other organizations in the U.S. However, no known document exists that summarizes the work that is being prepared at these different institutions. Therefore, at the request of ASHRAE TC 4.7, Subcommittee on Multi-Scale Building Energy Modeling (MBEM), Mr. Ron Judkoff (MBEM Chair), the Energy Systems Laboratory (ESL) at the Texas A&M Engineering Experiment Station of the Texas A&M University System conducted Zoom/phone surveys with urban-scale building energy modelers from universities and research laboratories in the U.S. This report "A Survey of Urban-Scale Building Energy Modelers", presents the survey results, which are based on transcriptions of Zoom/telephone interviews with Dr. Christoph Reinhart at Massachusetts Institute of Technology (MIT), Dr. Ralph Muehleisen at Argonne National Laboratory (ANL), Dr. Joshua New at Oak Ridge National Laboratory (ORNL), Dr. Tianzhen Hong at Lawrence Berkeley National Laboratory (LBNL), Dr. Anthony Fontanini at National Renewable Energy Laboratory (NREL), Dr. Wangda Zuo at University of Colorado Boulder (CU Boulder), and Mr. Peter Ellis and Dr. Neal Kruis at Big Ladder Software LLC.

For each of the experts who were interviewed, a phone conference was set up, the interview was conducted, and the content of the interview was transcribed. Transcriptions of the individual interviews are in the appendix to this report. After a review of the content of the interviews with the interviewees, a summary report was then developed that it summarizes activities at the individual institutions. In order to facilitate the summary, a tabular format was developed that lists the basic information about each entity, what was done, why it's important, etc.

The report is organized in two parts:

- Part I – Report, which provides summaries of surveys and results, including an executive summary. A tabular format is used.
- Part II – Appendix, which contains detailed survey activities and transcriptions/notes.

2 Summary

Based on transcriptions of Zoom/phone interviews with modeling experts, seven tables were created to illustrate the survey/interview results. Table 1 is a summary table, which lists the overall timeline, hosts, participants, universities/labs, tools, webpages for tools and documentation for all the surveys/interviews. Dr. Jeff Haberl and Mr. Ron Judkoff were the hosts to all the surveys/interviews. The first survey/interview meeting was hosted via Zoom on January 27, 2021, with Dr. Christoph Reinhart, Dr. Ralph Muehleisen, Dr. Joshua New, and Dr. Tianzhen Hong. The second survey/interview meeting was hosted via telephone on January 29, 2021, with Dr. Anthony Fontanini. The third survey/interview meeting was hosted via telephone on February 3, 2021, with Dr. Wangda Zuo. The fourth survey/interview meeting was hosted via Zoom on September 2, 2022, with Mr. Peter Ellis and Dr. Neal Kruis. A summary paragraph is provided for each participant.

Dr. Christoph Reinhart (2021) is a Professor and Director for the Building Technology Program at the Massachusetts Institute of Technology (MIT), Department of Architecture. Table 2 summarizes Dr. Reinhart's answers to the purpose of his work and future research needs for UBEM. Key references are also listed. Dr. Reinhart and his lab have been working with urban planning firms to model whole new developments for 8+ years. The Urban Modeling Interface (UMI) is a platform for UBEM developed by Dr. Reinhart's team over multiple years. The parametric modeling of new urban developments performed by Dr. Reinhart and his lab contributes to the simulation and optimization of energy planning of urban design. In addition, Dr. Reinhart and his lab conduct workshops on carbon reduction strategies for cities with different stakeholders. In this effort they use urban-scale modeling to find how much carbon reduction different cities can achieve based on different upgrade options. Dr. Reinhart envisions future urban-scale modeling with high fidelity models for each building to exactly predict energy savings, and the linking of building energy use to the electric grids. Dr. Reinhart uses various types of weather data, including TMY weather data, AMY weather data, and

morphed weather data (i.e., consider urban heat island effects) in his UBEM research projects (see Appendix F).

Dr. Ralph Muehleisen (2021) is the Chief Building Scientist, Building & Energy Section leader, and the Urban Science and Engineering Program lead at Argonne National Laboratory (ANL). Table 3 summarizes Dr. Muehleisen's answers to the purpose of his work and future research needs for UBEM with key references. Dr. Muehleisen and Argonne National Laboratory has developed LakeSim, a platform for urban design, to simulate and estimate energy use, transportation, wastewater, and more for the 600-acre Chicago Lakeside Development. At Argonne, different groups of scientists have interactions when working on building energy modeling, critical infrastructure, and climate modeling. In addition, Dr. Muehleisen works on acquiring funding for surrogate modeling to support the ComStock publicly share data. Dr. Muehleisen uses various types of weather data, including TMY weather data, AMY weather data, XMY (eXtreme Meteorological Year) weather data, and future versions of TMY, AMY, or XMY in his UBEM research projects (see Appendix F).

Dr. Joshua New (2021) is a senior R&D staff at Oak Ridge National Laboratory (ORNL). Table 4 summarizes Dr. New's answers to the purpose of his work and future research needs for UBEM with key references. Dr. New and his team developed an urban-scale building energy model for Chattanooga Tennessee with 178,333 individual building models and empirically validated the urban-scale model with 15-minute whole-building electricity use data. In addition, Dr. New and his team have developed the Automatic Building Energy Modeling (AutoBEM) software suite to model nearly all buildings in the United States, which is part of the "Model America" project funded by Office of Energy Efficiency and Renewable Energy (EERE), Building Technologies Office (EE-5B), National Nuclear Security Administration (NNSA), Office of Nonproliferation and Verification Research and Development (NA-22), Office of Electricity Delivery and Energy Reliability (OE), and Office of Science (SC). Dr. New also leads digital twin

seminars. Dr. New didn't provide specific information about what type of weather files he is using in his UBEM research.

Dr. Tianzhen Hong (2021) is a senior scientist and Deputy Head of the Building Technologies Department at Lawrence Berkeley National Laboratory (LBNL). Table 5 summarizes Dr. Hong's answers concerning the purpose of his work and future research needs for UBEM with key references. Dr. Hong and his team has developed the UBEM tool CityBES (City Buildings, Energy, and Sustainability) to model and evaluate technologies and strategies to retrofit existing city building stocks for energy efficiency, energy resilience, electrification and decarbonization. CityBES also models district energy systems for multiple city blocks to test whether it is good to put in a district energy system and which type of district energy systems needs to be chosen. Dr. Hong and his team also work with cities and utilities to target potential customers for incentive and rebate programs. In addition, Dr. Hong and his team have been working with disadvantaged communities in Fresno, California to promote clean energy and energy equity for low-income communities, which may not have funding to deploy clean energy technologies community-wide (e.g., PV). Dr. Hong uses various types of weather data, including TMY weather data, AMY weather data, predicted future weather data, and multiple local weather station data, if available, in his UBEM research projects (see Appendix F).

Dr. Anthony Fontanini (2021) is a researcher at the National Renewable Energy Laboratory (NREL). Table 6 summarizes Dr. Fontanini's answers to the purpose of his work and future research needs for UBEM with key references. Dr. Fontanini and his team have recently published TMY3 files for 900 locations around the U.S. In addition, Dr. Fontanini and his team has published ResStock, which is now available online at NREL (2021). NREL also uses hourly ERCOT load research data for building stock model simulations and analysis in Texas. Dr. Fontanini didn't provide specific information about what type of weather files he is using in his UBEM research.

Dr. Wangda Zuo (2021) is an associate professor at the University of Colorado Boulder (CU Boulder). He also holds a joint appointment at the National Renewable Energy Laboratory (NREL). Table 7 summarizes Dr. Zuo's answers to the purpose of his work and future research needs for UBEM with key references. Dr. Zuo worked with LBNL to develop a Modelica Buildings Library, which models building energy system, as well as district heating and cooling systems at the community scale, integrates micro-grid with HVAC systems. In addition, Dr. Zuo works with NREL team to develop URBANopt, a platform for UBEM. As the Principal Investigator of ASHRAE RP-1771, Dr. Zuo and his team published energy models of typical commercial buildings to support large-scale building energy analysis. The current urban modeling project Dr. Zuo is working on includes net zero energy community, district heating and cooling systems at the CU Boulder campus, future smart and connected communities by coupling energy, transportation and communication systems. Another recently achievement for Dr. Zuo's team is the completion of coupling CFD and Modelica for a data center. Dr. Zuo uses various types of weather data, including TMY weather data and AMY weather data in his UBEM research projects (see Appendix F).

Mr. Peter Ellis and Dr. Neal Kruis are the President and Vice President of Big Ladder Software LLC (2022), which is a Denver-based firm providing services for the building energy modeling industry. As members of the EnergyPlus Development Team, Mr. Ellis and Dr. Kruis have expertise in programming EnergyPlus. Table 8 summarizes Mr. Ellis and Dr. Kruis's answers to the purpose of their work and future research needs for UBEM with key references. Working with US Army Corps of Engineers (USACE), Mr. Ellis and Dr. Kruis developed the System Master PLanner / Net Zero Planner (SMPL/NZP) tool. SMPL/NZP is a web-based platform for energy master planning currently being used by the US Army for their bases and installations. The tool uses detailed EnergyPlus models generated with Big Ladder's Modelkit framework to simulate large numbers of buildings, including commercial, residential, and Army-specific buildings. The commercial models are based on the U.S. DOE prototype building models from NREL and PNNL. The tool also integrates water, waste water, stormwater, district energy systems, and a resiliency analysis. The SMPL/NZP web application is in

the process of being adapted into a public, commercial product to model large portfolios of buildings such as university campuses, hospital campuses, national retail chains, and municipalities. Mr. Ellis and Dr. Kruis uses TMY weather data in their UBEM research projects (see Appendix F).

Table 1: Overview of the Survey/Interview

Date	Hosts	Participants	Universities/Labs	Tools	Webpages for Tools	Webpages for Documentation	Survey Content
1/27/21	Jeff Haberl, Ron Judkoff	Christoph Reinhart	Massachusetts Institute of Technology (MIT)	Urban Modeling Interface (UMI) & UBEM.IO	• http://web.mit.edu/sustainabledesignlab/projects/umi/index.html • http://www.ubem.io	• http://web.mit.edu/SustainableDesignLab/publications.html	See Table 2
1/27/21	Jeff Haberl, Ron Judkoff	Ralph Muehleisen	Argonne National Laboratory (ANL)	LakeSim, Argonne's ISOmodel, POLARIS	• https://www.anl.gov/es/lakeside-sustainable-infrastructure-model	• https://www.anl.gov/argonne-scientific-publications	See Table 3
1/27/21	Jeff Haberl, Ron Judkoff	Joshua New	Oak Ridge National Laboratory (ORNL), Department of Energy (DOE)	Automatic Building Energy Modeling (AutoBEM)	• https://www.ornl.gov/news/ornls-simulation-tool-creates-digital-twin-buildings-coast-coast	• https://doi.ccs.ornl.gov/ui/doi/339 • https://www.ornl.gov/btric/publications	See Table 4
1/27/21	Jeff Haberl, Ron Judkoff	Tianzhen Hong	Lawrence Berkeley National Laboratory (LBNL)	CityBES	• https://buildings.lbl.gov/urban-science/tools • https://citybes.lbl.gov/	• https://buildings.lbl.gov/urban-science/publications	See Table 5
1/29/21	Jeff Haberl, Ron Judkoff	Anthony Fontanini	National Renewable Energy Laboratory (NREL)	Urban Renewable Building and Neighborhood optimization (URBANopt), ResStock, ComStock	• https://www.nrel.gov/buildings/urbanopt.html • https://docs.urbanopt.net/ • https://resstock.nrel.gov/ • https://comstock.nrel.gov/	• https://resstock.nrel.gov/page/publications • https://www.nrel.gov/research/publications.html • https://www.nrel.gov/analysis/los-angeles-100-percent-renewable-study.html • https://www.nrel.gov/buildings/end-use-load-profiles.html	See Table 6

Date	Hosts	Participants	Universities/Labs	Tools	Webpages for Tools	Webpages for Documentation	Survey Content
2/3/21	Jeff Haberl, Ron Judkoff	Wangda Zuo	University of Colorado Boulder (CU Boulder)	Modelica Buildings Library Smart and Connected Community (SCC) Library Net Zero Energy Community Library	• https://simulationresearch.lbl.gov/modelica/download.html • https://www.colorado.edu/lab/sbs/scc-library • https://www.colorado.edu/lab/sbs/nzec-library	• https://simulationresearch.lbl.gov/modelica/publications.html • https://www.colorado.edu/lab/sbs/publications	See Table 7
9/2/22	Jeff Haberl	Peter Ellis, Neal Kruis	Big Ladder Software LLC	Net Zero Planner (NZP) System Master PLanning Tool (SMPL) Modelkit	• SMPL/NZP Tool is used by the U.S. Army • Modelkit can be downloaded from https://download.bigladdersoftware.com/?ref=modelkit-catalyst-latest-win	• https://www.youtube.com/channel/UC2sdFPLVc5TENXyuRL4SzNw • https://bigladdersoftware.com/projects/modelkit/	See Table 8

Table 2: Survey/Interview Answers from Dr. Christoph Reinhart

Purpose of Work	Future Research Needs for UBEM	References
Four use applications of urban modeling: • (First use) use of UBEM by planning firms in developing new developments. • (Second use) developing carbon reduction strategies for cities. • (Third use) business-to-client interaction where each model has a high degree of fidelity to exactly predict energy savings. • (Fourth use) linking of buildings to the electric grids.	• A need for the coordination of UBEM analysis efforts at different institutions/universities. • An energy modeling computing environment that would bring past efforts in UBEM together. • Good initiatives creating next generation climate models to link to future planning. • More detailed urban microclimate data in cities or heat island effects. • Building templates, which NREL and PNNL created, can be converted for urban building energy modeling by having a good baseline. There is a need to inject additional funding to update/archive building templates. • In urban modeling, building templates contain non-geometric building information. There is a need to develop an export function to allow the desired template file format. • Need experts on GIS that are also good at building energy modeling. • UBEM.IO platform separates tasks for GIS managers from those for energy modelers reducing UBEM costs.	• Ang, et al. (2021) • Buckley, et al. (2021) • Ang, et al. (2020) • Nagpal, et al. (2019) • Cerezo, et al. (2017) • Dogan and Reinhart (2017) • Sokol, et al. (2017) • Davila, et al. (2016) • Reinhart and Davila (2016) • Monteiro, et al. (2016) • Reinhart, et al. (2013) • Street, et al. (2013)

Table 3: Survey/Interview Answers from Dr. Ralph Muehleisen

Purpose of Work	Future Research Needs for UBEM	References
• Building modeling. • Critical infrastructure modeling. • Climate modeling. • Trying to obtain funding for creating Machine Learning (ML) models or AI models that assist with modeling information that needs to be hidden. • Working with NREL and using ResStock and ComStock for the end-use load profile to calibrate to large hourly loads at the utility level.	• Not just for carbon reduction but for studying infrastructure. • Use of UBEM for climate change impact (i.e., flooding, big storms, electricity outages brownouts, etc.). • Use of UBEM to reduce big gaps in the connecting of critical infrastructure and climate modeling. • ResStock is available, ComStock is difficult to distribute because of NDA restrictions. There is a need to find a solution for the improved distribution of ComStock without oversharing data. • Create Machine Learning (ML) models or AI models that assist with modeling information that needs to be hidden for ComStock. • Develop standardized ways to generate weather files for microclimates in urban settings and recreate different climates for high-rise buildings (e.g., 40 stories up); connecting TC 4.2 and TC 4.7 together for this task. • Guideline of best practice of adjusting weather file to microclimates.	• Zhang, et al. (2021) • Muehleisen and Li (2019) • Muehleisen and Bergerson (2017) • Bergerson et al. (2015) • Guzowski, et al. (2014)

Table 4: Survey/Interview Answers from Dr. Joshua New

Purpose of Work	Future Research Needs for UBEM	References
• Working primarily in Chattanooga Tennessee where a model of 178,333 buildings was created. • Empirically validating models with 15-minute whole-building electricity use data. • Quantify what the best data sources and algorithms are and to share that with the MBEM community. • Release a method for comparing different data sources when the needed data is classified. • Lead digital twin seminars.	• Establishment of best practices, guidelines, or standards for urban-scale building energy modeling. • Research on what instructions ASHRAE Guideline 14 can provide for Urban-scale Building Energy Modeling. • Set up a Standard Method Of Tests (SMOT) for the evaluation of urban scale building energy modeling practices. Establish public canonical data sets. • Research on what are the right metrics for urban-scale building energy modeling. What constitutes a good CV (RMSE) and NMBE? Are those even the right metrics? • Need a standard that tests the needed inputs for different buildings. • There needs to be a standard for how to take TMY3 weather data and translate it to a building-specific location.	• Bass, et al. (2021) • New, et al. (2021) • Wang, et al. (2021) • Allen-Dumas, et al. (2020) • New, et al. (2020) • Bass, et al. (2020) • Allen, et al. (2019) • Garrison, et al. (2019) • New, et al. (2018)

Table 5: Survey/Interview Answers from Dr. Tianzhen Hong

Purpose of Work	Future Research Needs for UBEM	References
• Inform city building energy efficiency, energy flexibility and energy resilience. • Evaluate district energy systems. • Working with city and utilities to help with incentive rebate programs. Helping to target potential customers. • Heat resilience modeling and recommendations for improvement. • Clean energy. Working with disadvantaged community in Fresno, California to promote energy equity and clean energy.	• Building template formats need more development to facilitate different apps and different applications. • There's a need to create a modeling community where everybody can contribute to grow a common set of data (i.e., public data bank). • GIS integrated 3D city data models and standards. • Calibration methods of urban-scale building energy models. • How to use available data to calibrate urban-scale building energy models. • Need to determine who are the stakeholders.	• Carnieletto, et al. (2021) • Chen, et al. (2020) • Ferrando, et al. (2020) • Hong, et al. (2020 a) • Hong, et al. (2020 b) • Jain, et al. (2020) • Luo, et al. (2020) • Chen, et al. (2019) • Chen and Hong (2018) • Hong and Luo (2018) • Chen, et al. (2017)

Table 6: Survey/Interview Answers from Dr. Anthony Fontanini

Purpose of Work	Future research needs for UBEM	References
• Recently published TMY3 files for 900 stations around the U.S. (one for every county). Does not cover urban heat island, nor coastal locations (i.e., sea breeze). • Recently published 900,000 statistically representative building energy models and sub-hourly end-use load profiles for the U.S. national building stock • BuildStock-Batch is available for public use. A simulation tool to run ResStock and ComStock on Amazon Web Services and High-Performance Computing resources. • Calibrated and validated ResStock and ComStock to 2.3 million AMI meter data from 11 utilities, load research data from 16 utilities, 15 submetering datasets, and electricity and natural gas data from EIA	• Develop weather files for areas with large temperature gradients. • Adjust EPW weather files which do not cover large changes in elevation. • Research on how to characterize the building stock. • ASHRAE could perform research to survey characteristics about the national building stock. Example: actual wall insulation values by climate zone, building type, and vintage to help establish better base characteristics. • Research on the degradation of insulation in attics, walls, etc. • Research on how aging of windows impacts performance and how new windows that have argon that leaks impact performance. • Research on new types of dynamic materials and how to incorporate in the MBEM models to investigate impact of energy savings, grid interactivity, and decarbonization. • Need to have better data on shading of single-family residential: impact of how much shading from trees, shading schedules for elms vs live oaks, etc. • Need better moisture transport models to perform national scale durability and resilience analyses. • Investigate the installed quality/performance of HVAC system and ductwork. • Survey the refrigerant charge in A/Cs and the condition of the evaporator and condenser coils. • How could smart thermostats better inform the UBEM models? How are actual buildings zoned vs how the model is zoned? How does that impact the accuracy of the MBEM model? What about two-story houses with an open space – stratification? Implications on the building stock? • Research on how to validate models. Need better validation data. Load data has been difficult to obtain. • Need way to better streamline validation data for building stock analysis. For example, ANN synthetic data that comes from an ANN that trains network to produce time series data that are identical to the real data but has been de-identified. • Simple problems still exist in many datasets, for example, daylight savings cause problems. Need to have standard data protocols. • Research on how to deal with bias in small AMI sets for validation. • Research on projections of the building stock and different scenarios how the national building stock will change in the future.	• Charan, et al. (2021) • Cochran, et al. (2021) • Zhang, et al. (2021) • Langevin, et al. (2020) • Frick, et al. (2019) • Sharma, et al. (2019) • Rakha and El Kontar (2019) • Fontanini and Abreu (2018) • Heidarinejad, et al. (2017)

Table 7: Survey/Interview Answers from Dr. Wangda Zuo

Purpose of Work	Future Research Needs for UBEM	References
• Modelica modeling of community scale, district heating, cooling and integration of micro-grid into systems. • OpenStudio for city-scale energy predictions. • Working with NREL to develop URBANopt. • Use RP-1771 ASHRAE project to support open studio large-scale analysis for BEQ standards. Allows for the University of Colorado (CU) to apply new technology to analyze the impact of dynamic electricity pricing, etc. • Modelica work also includes model predictive control. Use physical-based models for controls design and evaluation and reduced-order models for MPC. • Using Modelica requires 1 year to train students. • Have project in Indonesia, had problems getting weather data. • Current urban project is trying to model district heating/cooling at CU Boulder campus. Using measured data to build regression models. Then focus on district heating systems. Use this to calculate heating/cooling loads for the campus plant. • Currently trying to generate EP+ models for each building. Trying to find balance for amount of information vs. project timeline. • Another team is testing open studio models, testing inputs for large complex buildings, takes a few months. • Current district model is a loop. Model ChW loop and have detailed model of plant. Heating side models use steam. Modeling steam pressure balance over the heating network and phase change from steam to water is challenging. Using Modelica models in plant and the loops. • Still working to create load models. Working towards coupled models. Started with R/C models and data from measured loads. • Have used Modelica dynamic model for inverse model. • Still working with CFD. Recently completed coupled CFD and Modelica for data center.	• Majority of students want to work on real buildings, not developing simulation tools, which makes recruiting difficult. • TC 4.7 could help attract more ASHRAE YEA members to modeling. • UBEM uses supercomputers. It would be good if NREL has platform for research computing using supercomputers. • Need to do sensitivity analysis on UBEM as well. • Weather data in use is from airport, not always useful. Would like to have weather data from the local city. • In US weather data is available but may not be outside U.S. • TC 4.7 needs to try to connect inverse models better with forward models. Very important for urban-scale models. • Heat Island is important in large cities. TC 4.7 need to reach out to work on this. Maybe TC 4.2 and TC 4.10 CFD modeling for air flow modeling outside the building might approach some of these issues. • Need extensive pressure coefficient models around the outside of buildings, might drive infiltration models better inside buildings. • Use CFD for COVID analysis. Would like to see more coupled models using CFD with building energy simulation. • Programming languages for TC 4.7? What to use? Modelica? C++? Python? Spreadsheets? Maybe TC 4.7 could create one model in FORTRAN, Modelica, C++, Python to be used as an example, regarding how to translate.	• Wang, et al. (2021) • Fan, et al. (2021) • Huang, et al. (2021) • Hinkelman, et al. (2021) • Fu, et al. (2019) • Fu, et al. (2018) • Tian, et al. (2018) • Zuo, et al. (2016) • Wetter, et al. (2014)

Table 8: Survey/Interview Answers from Mr. Peter Ellis and Dr. Neal Kruis

Purpose of Work	Future Research Needs for UBEM	References
• Developing System Master PLanner /Net Zero Planner (SMPL/NZP) Tool with the U.S. Army Construction Engineering Research Laboratory. • Energy master planning for US Army bases and installations. • Modeling large portfolios of buildings such as university campuses, hospital campuses, national retail chains, and municipalities. • Integrated analysis of energy, water, waste water, stormwater, district energy systems, and resiliency analysis. • Prototype modeling of commercial, residential, and military buildings using EnergyPlus. • Resiliency modeling of district energy networks using probabilistic analysis of discrete-event simulations.	• Research support for quantitative approaches to resiliency modeling for UBEM. • Methods and protocols for developing a fast-running, simplified inverse model, or surrogate model, from a slow-running, detailed, whole-building energy model. Running extremely large numbers of detailed models for UBEM analysis will become a bottleneck for practical use, even when deploying across cloud-compute resources.	• Zhivov (2022) • O'Keefe et al. (2021) • Liesen, Johnson, Swanson, Stinson, and Case (2018) • Ellis (2016) • Case et al. (2014) • Ellis, Liesen, Zhivov, and Herron (2012) • https://www.youtube.com/channel/UC2sdFPLVc5TENXyuRL4SzNw

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Appendix A: Cover Page for Notes of the Conference Calls

Appendix A is the cover page for Multi-Scale Building Energy Modeling (MBEM) Subcommittee of TC 4.7 notes of the conference calls. Table A-1 shows the information of dates, time, hosts, participants, and corresponding appendices for four conference calls.

Table A-1: Information for Four Conference Calls

Dates	Time	Hosts	Participants	Corresponding Appendices
Wednesday 1/27/21	4:30-5:30pm CST	Jeff Haberl, Ron Judkoff	• Christoph Reinhart • Ralph Muehleisen • Joshua New • Tianzhen Hong	Appendix B: First Call Notes
Friday 1/29/21	1:00-2:00pm CST	Jeff Haberl, Ron Judkoff	• Anthony Fontanini	Appendix C: Second Call Notes
Wednesday 2/3/21	4:00-5:00pm CST	Jeff Haberl, Ron Judkoff	• Wangda Zuo	Appendix D: Third Call Notes
Friday 9/2/22	2:00-3:00pm CST	Jeff Haberl	• Peter Ellis • Neal Kruis	Appendix E: Fourth Call Notes

Appendix B: First Call Notes

This appendix presents the detailed content of the first conference call. Table B-1 shows the conference call agenda sent to all participants before the call. Table B-2 shows the roles, names, and affiliations of hosts and participants.

B.1 Transcriptions/Notes of the First Conference Call

B.2 Sources and Papers Mentioned in the ZOOM Meeting Chat Box During the First Conference Call

Table B-1: Conference Call Agenda Sent to Participants Before the Call

Multi-Scale Building Energy Modeling (MBEM) Subcommittee of TC4.7
Notes of the Conference Call
Wednesday 1/27, 2021
4:30-5:30pm CST

Purpose of the Call

- To survey work being performed by TC 4.7 MBEM Subcommittee members to determine research needs.

Possible Questions

- What work are you doing using BEM for Urban-scale Building Energy Modeling (UBEM)?
- What simulation programs are you using?
- What documentation is available regarding the work?
- What potential research do you see that needs to be done to improve the BEM for UBEM?

Table B-2: Roles, Names, and Affiliations of Hosts and Participants

Roles	Names	Affiliations
Host	Jeff Haberl	Texas A&M University (TAMU)
Host	Ron Judkoff	US National Renewable Energy Laboratory (NREL)
Participant	Christoph Reinhart	Massachusetts Institute of Technology (MIT)
Participant	Ralph Muehleisen	Argonne National Laboratory (ANL)
Participant	Joshua New	Oak Ridge National Laboratory (ORNL), Department of Energy (DOE)
Participant	Tianzhen Hong	Lawrence Berkeley National Laboratory (LBNL)

B.1 Transcriptions/Notes of the First Conference Call

Jeff (intro):

At the last ASHRAE virtual meeting that the following topic came up: what are the research topics from the people doing work in this field?
Do you have a wish list of research topics so that TC 4.7 might request a proposal to go in for ASHRAE funding?
The purpose of this call is to query folks doing work in MBEM.

Participants to the conference call:

Ralph (Argonne National Lab) Jeannie (Argonne)
Ron (NREL)
Joshua New (ORNL, and DOE)
Tianzhen (LBNL)
Christoph (MIT)

Ralph: a wish list of what you want DOE to hear. Joshua is eyes and ears for DOE.

Jeff (purpose of the call):

The purpose of this call really is to try to reach out to those of you who are known urban-scale building energy modelers and ask you what are some of the issues that TC 4.7 could help you with to build improved ability models, that could support some of your work.

Xi Zhao is a PhD student at Texas A&M, who's agreed to take some notes and write something up so we can get it into the paperwork for the TC 4.7 minutes.

Jeff (question):

So, Christoph if you've got a short fuse, we'll start with you.
If you had a wish list for things that TC 4.7 from ASHRAE can help you with?
What are the ideas that you've thought about that you just can't get to right now because you don't have the time or the bandwidth to create some of these things?

Christoph (answer):

Thank you all for involving me in this. We have done a lot of urban modeling...
...So, the U.S. has all these parallel efforts. Is there any coordination ever going on?...
(suggestion) (need)...an energy modeling environment that would bring our past efforts (in urban modeling) all together...
...I would say a couple of years ago we were still in this more nascent field (urban modeling) where we were trying to figure out if this works at all or not...
...I feel we have a pretty good understanding right now what are the different use cases...
...our lab just wrote a paper in Applied Energy that I can share which I think maps out pretty well how we are thinking about urban modeling and we have four use applications...

(First use case) The first one is working with planning firms who are developing new developments. So, in a new case study, you need to be able to quickly do parametric modeling and be able to do multi-dimensional optimization and simulation of a whole new development. We have been working on the first use case for 8 years.

(Second use case) The next use case is carbon reduction strategies at a high level for cities. This is something that we are entering right now. As an activity we did a workshop last week with eight cities: Singapore, Cairo, Dublin, Kiel, Braga, Middlebury Vermont, and Montreal. We had all these different stakeholders coming together and we spent three days modeling parts of their city to show on a high level how much carbon reduction they could implement based on a set of different upgrade options. And from a building technology standpoint these models all don't really need a fully calibrated model.

(Third use case) We are entering really into what we call business-to-client interaction where we want to have models where each model has a high degree of fidelity and that probably mimics most of what you guys (i.e., Jeff, etc.) have done for many years: modeling buildings on campus or otherwise and saying this is the way we do a model, this is the actual upgrade and energy saving potential. And of course, Tianzhen and Joshua have done a lot of work auto-calibrating building models. So, this is the first time where we really need a model that is able to exactly predict energy savings.

(Fourth use case) And then finally the linking of buildings to electric grids.

Ralph (question to Christoph):

What about looking direct not just the carbon reduction but infrastructure.
...global warming climate change impact...

We're going to have more flooding, big storms…
...not only hot days, but cold days with electricity outages, brownouts and that sort of a thing... (Climate Change) is the next level.

At Argonne we have different groups that do the building modeling and the ones who worry about the critical infrastructure, and we try to interact with those groups and the people doing climate modeling.

I see big gaps in the connecting of those two especially as we now talk to cities and policy makers.

...We can help you do carbon reduction plans but don’t forget we also have disadvantaged people on the south side, when the banks of the Charles River start flooding because of global warming...

Christoph (answer):

I think this is definitely interesting if you go back maybe 10 to 12 years there was the urban weather generator tool (can't be used anymore). That just shows how a little effort there has been going on in that field.

I think there are some good initiatives creating the next generation climate models, so we are hoping to be able to link that to future planning...

...More detailed urban microclimate in cities or island effects...

Christoph (question):

This ASHRAE task force or committee: what's your larger goal and how long is this going on?

Jeff (answer and gave an introduction of TC 4.7 to Christoph):

TC 4.7 roots of that go back to... before 1970. The purpose of TC 4.7 research is to figure out something for TC 4.7 to do. It's a great opportunity to bring together people, every six months, that are working in this area, people in the labs, academic, as well as new faces, and get better talent when it comes to computers and building energy modeling.

...In a friendly environment so we can get the ideas down and then write these up for proposals and get some seed money, maybe have matching money...
...and to have a little bit of an influence on the direction of the future research...

That's really the purpose of these subcommittees within ASHRAE TC 4.7.

Christoph (suggestion):

...The templates, the building templates that NREL did originally were building benchmark templates and then PNNL did this follow-up and so forth...

...I think these are really great initiatives...

...this is something that we can convert for Urban Building Energy Modeling (UBEM) by having a good baseline...

...I think it would be great to inject a little bit of money there and get them updated...

Ralph (answer):

...both the ResStock and ComStock projects that NREL is doing...
...this started out with reference buildings and is now generating a hundred thousand of each one...

...ResStock and ComStock are really meant to give you every flavor you can think of and be able to really match up a particular building much closer to exactly what your building would be like...

...the ResStock (models) is already out in some form, it's always a little bit dated but it's out available...

...ComStock is a little bit more difficult because of NDA restrictions...

Christoph (question):
What format are we talking about?

Ralph (answer):
These are open studio models.

Christoph (suggestion):
...in urban modeling...the templates where we get all the non-geometric building information...
...it's just always a bit of a pain to get it in the right format...
(suggestion)...it should be as simple as writing just an export function in any file format that you like, others can then grab into an API...

Tianzhen (confirmed Christoph):
Yeah, Christoph. I think that's an area that needs more development to facilitate different apps and different applications.

Christoph (suggestion):
I think labs would be perfect for that development.
...I can mostly query simulated results and not the base assumption energy model...

Ralph (answer):
...it's the whole thing that right now they're really trying not just to get you the results but the actual input files...

...ResStock, everything or almost everything has been publicly available...

...ComStock, troubles in publicly sharing data...

...I'm hoping that the probability distributions for the building type, sizes, equipment, and that sort of stuff, can be pulled out if they don't have to have direct reference to the co-star data...

Ralph (suggestion):
...We can have NREL create Machine Learning (ML) models or AI models that at least will mimic the response that comes out so even if we can't share some of the data, we can regenerate basically some of the features...

...surrogate modeling of some of the stuff that needs to be hidden and I’m working trying to get some funding for that...

Christoph (question):
...I don't see a way of getting the .idf files out of here (ResStock)...

Ralph (answer and confirmed Christoph):
...I think that it was missing would be an API...
that's a good question.

Ralph (suggestion):
...I'm working with NREL and using ResStock and ComStock for the end use load profile where we're actually calibrating those sets of data to large hourly loads at the utility level...

(suggestion) There may be a role within ASHRAE to do some work (i.e., making an API to generate desired formats)...

Christoph (suggestion):
...If you want to connect urban modeling to practice, it's very hard to find experts on GIS that are also good at energy modeling. So, if some of this part is taken on by us, it will be valuable...

Tianzhen (summary of LBNL work on urban modeling):
We are doing...district scale... district energy systems...
...for a few city blocks, is it good to put in a district system? What type of district system? Obviously the NREL tools can also answer those kind of questions...

We also working with city and utilities trying to help them with incentive rebate programs... They don't have an easy way to reach out to who are the potential customers, with our help, they can easily target those potential customers...

We're also doing some heat resilience modeling...
...heat waves now getting much more often...
...the work assumes there's a power outage and how bad the indoor temperature may be...

...clean energy... environmental perspective...
...working with disadvantaged community in France now...
...energy equity...
...low-income community may not have that the capital to deploy those kind of technologies (e.g., PV).

Tianzhen (suggestion):
One of the key challenges of all this urban scale modeling is about data.
...building stock data, electricity data, the prototype model, the standards and codes data, weather data and individual project data...

(suggestion) There's a need to create a community where everybody can contribute to grow a common a set of data (data bank).

Joshua (summary of ORNL work on urban modeling):

We've been working primarily in Chattanooga Tennessee where we created a model of 178,356 buildings...We had to throw away some data, so we got down to 178,333...
The work that Oak Ridge National Labs has been doing is with the electric power board in Chattanooga Tennessee where we created a model of their buildings. They've given us 15-minute whole-building electricity use from every single building.
So, we're not just creating models… we're also empirically validating them.

...what we've tried to do is swap out different data layers...
...going through different sources of data and swapping them out regenerating the models and then seeing what the CV (RMSE) and NMBE differences are to the 15-minute whole-building electricity use...

The idea was to really quantify what the best data sources and algorithms are and share that with the community.

Some data is classified and so…the best we've done is basically to release a method for comparing different data sources...

Joshua (suggestion):

My interest is in the maturation of the Urban-Scale Building Energy Modeling field and that means establishment of best practices and in ASHRAE Guidelines and Standards.

Joshua (suggestion to Jeff):

So, speaking of your background GPC 14, what guidelines can we provide for urban scale energy modeling?

Joshua (suggestion to Ron Judkoff):

What about a Standard 140 style Standard Method Of Test for the evaluation of urban scale modeling practices?
...set up a standard method of tests, some canonical data sets...

Ron (answer to Joshua):

On individual buildings it was always about the physics, so it was testing physics.

When we go to urban scale and the ComStock and ResStock, to me it's all about calibration, and so what needs to be tested is the calibration.

We've come up with amazing applications for simulation because of cloud computing and all the additional computing power, but we're depending very much on where we're trusting that the physics within the individual simulation and we're also trusting that the calibrations we're using.

Joshua (suggestion):

So, the problem at urban scales is you don't have access to building specific energy use at that scale unless you have some really strange and unusual relationship with the utility.

Guideline 14 has really talked about getting into sub-hourly data: electrical energy use, natural gas.

Should be different error rates in terms of CV (RMSE) and NMBE?
What is considered good with those indicators?
...more granularity and fuel type sub-metering in different locations within the building...

Urban scale modeling, all 125 million buildings in the U.S., what constitutes a good CV (RMSE) and NMBE? Are those even the right metrics?

Another thing I'd add is that we need something that tests more than ANSI 1206.
We need something that tests the inputs to the buildings.

Tianzhen:

When we talk about urban scale, it's not just linear.
...instead of one building, I'm talking about one million building in Los Angeles, New York City, the physics is also different when you have a group of buildings, and they have interactions...
...they share each other, heat island...

How buildings influence the urban environment...buildings absorb and emit heat...

Ron (question to Joshua):

...a connection to 140, there's definite physics there to interrogate...

...probably harder to do empirical validation at least at physics level at city level...

...the inputs to all these thousands or tens of thousands or even millions of buildings and I don't have a clue as to how you do it?

Joshua (answer):

So, I can give you some examples: there's a competition from Top Coder called Spacenet and what they do is they give you satellite imagery they give you cloud processing, and they say, "try your own algorithms at extracting the building footprints".
...reward $$...

...a very specific example where you're just looking at footprints from satellite imagery...

Ron:

What's the elevation of the building, wall ratio, what's the facade...?

…but what you're trying to do with all those pieces of information is to in the end calibrate an inverse model...

...imaginary buildings or statistical buildings that are supposed to represent many buildings...
...this big black box has got a million little pieces in it, but are there some kind of testing that I can do to see what comes out of it without worrying about each little piece that goes into it...

Because I think it's a near infinite number of little pieces that go into it.

...you guys deal with big data, but I'm somebody that kind of started out with the laws of thermodynamics, built things up from there...

...It's a big data problem, I think that goes beyond the level of or the expertise that exists within STD 140.

Ralph (suggestion):

...microclimate in urban settings where you have two or three input files that come from weather stations...
...this would be working a lot with TC 4.2 information…
As to how do we do a better description about what the urban climate's going to be...

10-story 20-story 30-story 40-story buildings in a downtown area that produce lots of the carbon emissions and consume energy...

...weather files from airport and try to do a translation to the city by making some changes...

...recreate the different climate 40 stories up...

...So, coming up with standardized ways to do that sort of variation or to expand the input and the data...

...re-analysis and to doing more weather generation...
(suggestion)...connecting TC 4.2 and TC 4.7 together better, I think is an important and could be a really good task...

Joshua (confirmed Ralph):

I'm still chair of TC 4.2. We recently released Standard 169-2020. We included climate zone designations for every county updated using 920 meteorological stations across the U.S., but the location and elevation or things that aren't taken into account.

There was an ASHRAE project that was seeking the instrument and look at not just the temperature but the pollutant variation as you move up in elevation in different cities.

That was actually privately funded and moved outside ASHRAE.

It was Luke Long that got involved.

You're right there is no standard for how to take weather data and translate it to a building specific location, at 20, 40 stories.

Ralph (suggestion):
Guideline for best practice of adjusting weather files to microclimate that fits into an ASHRAE project.

Jeannie (suggestion):
…need tools within one platform.

Jeff (question to Tianzhen):
Do you have a wish list you'd like to see ASHRAE develop?

Tianzhen (answer and suggestion):
…needs to sponsor new city data models: BIM? CIM (City Information Modeling)? GBXML?...
…Europe working on city level models…
…Calibration on urban scale important…
…how to use available data to do calibration on urban scale…
…who are stakeholders?

Joshua (add):
I would like to add one more thing:
We talked a lot about research, but we should also consider program elements for MBEM.

TC 1.5 has asked me to lead a digital twin seminar.

TC 4.2 looking at urban scale modeling that is used to assess climate change impacts.

Digital twin is just a popular term or buzzword these days for creating a digital representation of all the buildings in an area.

B.2 Sources and Papers Mentioned in the ZOOM Meeting Chat Box During the First Conference Call

https://www.sciencedirect.com/science/article/pii/S0306261920312289
Christoph's UBEM use cases (above)

NREL's standards-gem can generate buildings procedurally according to building type/vintage/climate zone: https://github.com/NREL/openstudio-standards

ResStock data is available here: https://resstock.nrel.gov/

Ten questions on UBEM -
https://www.sciencedirect.com/science/article/abs/pii/S0360132319307206

Microclimate from earth-system to local area shows 5F cooling potential by designing small area southwest of Chicago's loop area:

Allen-Dumas, Melissa R., Rose, Amy N., New, Joshua R., Omitaomu, Olufemi A., Yuan, Jiangye, Branstetter, Marcia L., Sylvester, Linda M., Seals, Matthew B., Carvalhaes, Thomaz M., Adams, Mark B., Bhandari, Mahabir S., Shrestha, Som S., Sanyal, Jibonananda, Berres, Anne S., Kolosna, Carl P., Fu, Katherine S., and Kahl, Alexander C. (2020). "Impacts of the Morphology of New Neighborhoods on Microclimate and Building Energy Use." Renewable & Sustainable Energy Reviews, volume 133, 110030, ISSN 1364-0321, doi.org/10.1016/j.rser.2020.110030, November 2020.

http://web.eecs.utk.edu/~jnew1/publications/2020_RESR_Microclimate.pdf

https://www.sciencedirect.com/science/article/abs/pii/S0378778818316852

Analysis of savings at urban-scale:
Bass, Brett, New, Joshua R., and Copeland, William (2020). "Potential Energy, Demand, Emissions, and Cost Savings Distributions for Buildings in a Utility's Service Area." Energies journal, Special Issue "Designing, Modeling and Optimizing Energy and Environmental Systems for Buildings," volume 14(1), issue 132, doi.org/10.3390/en14010132, Dec. 29, 2020.

https://www.mdpi.com/1996-1073/14/1/132

New, Joshua R., Adams, Mark, Garrison, Eric, Bass, Brett and Guo, Tianjing. (2020). "Scaling Beyond Tax Assessor Data." ASHRAE/IBPSA-USA 2020 Building Performance Analysis Conference & SimBuild (BPACS), Chicago, IL, Sept. 29 - Oct. 1, 2020.

http://web.eecs.utk.edu/~jnew1/publications/2020_BPACS_ScalableData.pdf

Spacenet competition:

https://go.topcoder.com/spacenet/

Climate change converted to EPW files for long-term building energy impacts:
Bass, Brett and New, Joshua R. (2020). "Future Meteorological Year weather data from IPCC Scenarios." ASHRAE/IBPSA-USA 2020 Building Performance Analysis Conference & SimBuild (BPACS), Chicago, IL, Sept. 29 - Oct. 1, 2020.

http://web.eecs.utk.edu/~jnew1/publications/2020_BPACS_FMY.pdf

Xiaobing Liu - Heat Pumps

Appendix C: Second Call Notes

This appendix presents the detailed content of the second conference call. Table C-1 shows the conference call agenda sent to the participant before the call. Table C-2 shows the roles, names, and affiliations of hosts and the participant.

Table C-1: Conference Call Agenda Sent to the Participant Before the Call

Multi-Scale Building Energy Modeling (MBEM) Subcommittee of TC4.7
Notes of the Conference Call
Friday 1/29, 2021
1:00-2:00pm CST

Purpose of the Call

- To survey work being performed by TC 4.7 MBEM Subcommittee members to determine research needs.

Possible Questions

- What work are you doing using BEM for Urban-scale Building Energy Modeling (UBEM)?
- What simulation programs are you using?
- What documentation is available regarding the work?
- What potential research do you see that needs to be done to improve the BEM for UBEM?

Table C-2: Roles, Names, and Affiliations of Hosts and the Participant

Roles	Names	Affiliations
Host	Jeff Haberl	Texas A&M University (TAMU)
Host	Ron Judkoff	US National Renewable Energy Laboratory (NREL)
Participant	Anthony Fontanini	National Renewable Energy Laboratory (NREL)

MBEM TC 4.7 Conf call – Anthony Fontanini:

- Recently published TMY3 files for 900 stations around the U.S. (one for every county). This may be helpful for others. Does not cover urban heat island, nor coastal (i.e., sea breeze).
- TOPIC: weather files for areas with large temp gradients, dependent on wind speed and direction, altitude.
- TOPIC: EPW files do not cover large changes in elevation – how to adjust?
- ResStock and BuildStock-Batch is now available using EnergyPlus and OpenStudio.
- NREL using hourly ERCOT load research data for analysis vs simulations.
- TOPIC: How to characterize the building stock. Europe uses R-values for walls, etc. that are fairly reliable vs in the US where very little is known about how much insulation is in a given building. Could ASHRAE survey actual wall insulation values: SF, MF, Commercial to help establish better base characteristics.
- TOPIC: what is the degradation of insulation in attics, walls, anywhere –
- TOPIC: what's the aging of windows? How does it impact performance? New windows have argon that leaks – what's the impact
- TOPIC: foam insulation – blowing gas gets replace with air … what's the impact … how to incorporate in the MBEM model? What's in the model? Might be very different in Houston vs Denver?
- TOPIC: don't have good data on shading on SF residential – impact of how much for a house, trees, shading schedule for elms vs live oaks. Fence shading? Microsoft has building footprints but not height, how to fill-in. Shading of the roofs. Effect of moss on shingles?
- TOPIC: how much insulation does each house have? Blown-in attic vs foam? How much? How much has it degraded?
- TOPIC: might have tools to estimate the building stock… however, don't have good data on moisture transfer during the through opaque material…summer … technically evaporative cooling, but how to model? What difference does it make? Need better moisture transport models?
- TOPIC: what's the installation quality? HVAC system? Ductwork? Sealing the ductwork?

- TOPIC: What's the refrigerant charge in the A/C? What's the condition of the evaporator? Condenser?
- TOPIC: How could smart thermostat better inform the models? How is actual building zoned vs how the model is zoned? How does that impact the accuracy of the MBEM model? What about two-story houses with an open space – stratification? Implications on the building stock?
- TOPIC: Are the models correct? How to validate? Need better validation data? Could use more 15-minute AMI data on specific houses that are being modeled OR a representative set.
- TOPIC: synthetic data from utilities is a merger of individual house data … use tool to join data files – don't know where the house. ANN synthetic data – is an ANN that trains network to produce time series that identical to the real data but has been de-identified. Need way to better streamline validation data for building stock analysis.
- TOPIC: simple problems still exist in many datasets … example: daylight savings causes problems ... need to have standard data protocol.
- TOPIC: missing data is problem with AMI meters … causes meter to accumulate data then feeds forward.
- TOPIC: how to deal with bias in small AMI sets for validation? Wealthy neighborhood versus average housing neighborhood … how to classify and how to get statistically valid data. Example: hourly profile: SF vs MF, electric vs non-electric heating … trying to validate model… data is biased toward electric heating … not identified by utility companies …

Appendix D: Third Call Notes

This appendix presents the detailed content of the third conference call. Table D-1 shows the conference call agenda sent to the participant before the call. Table D-2 shows the roles, names, and affiliations of hosts and the participant.

Table D-1: Conference Call Agenda Sent to the Participant Before the Call

Multi-Scale Building Energy Modeling (MBEM) Subcommittee of TC4.7
Notes of the Conference Call
Wednesday 2/3, 2021
4:00-5:00pm CST

Purpose of the Call

- To survey work being performed by TC 4.7 MBEM Subcommittee members to determine research needs.

Possible Questions

- What work are you doing using BEM for Urban-scale Building Energy Modeling (UBEM)?
- What simulation programs are you using?
- What documentation is available regarding the work?
- What potential research do you see that needs to be done to improve the BEM for UBEM?

Table D-2: Roles, Names, and Affiliations of Hosts and the Participant

Roles	Names	Affiliations
Host	Jeff Haberl	Texas A&M University (TAMU)
Host	Ron Judkoff	US National Renewable Energy Laboratory (NREL)
Participant	Wangda Zuo	University of Colorado Boulder (CU Boulder)

TC 4.7 MBEM – Wangda Zuo:

- Has 2 categories:
    1. Modelica modeling of community scale, district heating, cooling and to integrate micro-grid into system.
    2. OpenStudio for city scale energy prediction.
- When the focus is energy flow from district heating, we use reduced model to predict heating load.
- Working with NREL to develop URBANopt. The building load information can be calculated by EnergyPlus model.
- Has RP1771 ASHRAE project to support open studio large scale analysis for BEQ stds. Allows for CU to apply technology to analyze the impact of dynamic electricity pricing, etc.
- Major challenge is to find qualified students to do the research. Hard to find students with skills in both HVAC system and numerical modeling.
- Majority of students want to work on real buildings, not developing simulation tools, which makes recruiting difficult.
- TC 4.7 could help attract more ASHRAE YEA members to modeling.
- For Open Studio used supercomputer. NREL developed platform for Amazon cloud computing. However, was expensive for academic research. It took a lot of effort to debug and use CU's computer. It would be good if NREL has platform for supercomputer research computing.
- Large scale simulations need 1,000,000s of simulations.
- Need to do sensitivity analysis as well.
- ORNL also has state-of-art supercomputers.
- Modelica work also includes model predictive control. Use physical-based model for controls design and evaluation and reduced order models for MPC.
- Open Studio has good graphical interface – very flat learning curve.
- However, Modelica is very flexible, but students must have good understanding of physical systems. Typically, using Modelica requires 1 year to train students.
- Most Modelica work is limited to either buildings or small communities, have not used on US scale.

- Weather data in use is from airport, not always useful. Would like to have weather data from local city. Had to rely on local weather station in Boulder to do this.
- Have project in Indonesia, had problem getting weather data.
- In US weather data is available, but may not be outside the U.S.
- Models at district scale is highly coupled. It is too complex to model every detail of the system and the computing time is also too long. We must decide the details of modeling and make some simplifications on application needs. Current urban project is trying to model district heating/cooling at CU Boulder. Effort to model individual buildings is large. Using measured data build regression model. Then focus on district heating system. Use this to calculate heating/cooling for campus plant.
- Currently trying to generate EP+ models for each building. Trying to find balance for amount of information vs. project timeline.
- Another team is testing open studio models, testing inputs for a large complex building, takes few months.
- Previous work by others is not enough detail to be useful for CU Boulder model.
- Current district model is loop. Models ChW loop and have detailed model of plant. Heating side models steam. Modeling steam pressure balance over the heating network and phase change from steam to water is challenging. Using Modelica models in plant and the loop.
- Still working to create load models. Working towards coupled models. Started with R/C models and measured models.
- Have used Modelica dynamic model for inverse model. TC 4.7 needs to try to connect inverse models better with forward models… very important for urban scale models.
- Heat island is important in large cities. TC 4.7 need to reach out to work on this. Maybe TC 4.2 and TC 4.10 CFD modeling for air flow modeling outside the building might approach some of these issues.
- Need extensive pressure coefficient models around the outside of buildings, might drive infiltration models better.
- CFD inside would yield the pressure coefficients for inside the building. May need similar coefficients outside the building to simplify this.

- Still working with CFD. Recently completed coupled CFD and Modelica for data center. Modelica models the cooling equipment and CFD models the computer room airflow distribution. Schneider Electric commercialized the CFD tool.
- Using CFD for COVID analysis. Would like to see coupled models CFD with building energy simulation.
- It is feasible to have CFD and mechanical ventilation. But harder for CFD and natural ventilation.
- Programming languages for TC 4.7? What to use? Modelica? C++? Python? Spreadsheets?
- Maybe TC 4.7 could create one model in FORTRAN, Modelica, C++, Python.

Appendix E: Fourth Call Notes

This appendix presents the detailed content of the fourth conference call. Table E-1 shows the conference call agenda sent to the participant before the call. Table E-2 shows the roles, names, and affiliations of the host and the participants.

Table E-1: Conference Call Agenda Sent to the Participant Before the Call

Multi-Scale Building Energy Modeling (MBEM) Subcommittee of TC4.7
Notes of the Conference Call
Friday 9/2, 2022
2:00-3:00pm CST

Purpose of the Call

- To survey work being performed by TC 4.7 MBEM Subcommittee members to determine research needs.

Possible Questions

- What work are you doing using BEM for Urban-scale Building Energy Modeling (UBEM)?
- What simulation programs are you using?
- What documentation is available regarding the work?
- What potential research do you see that needs to be done to improve the BEM for UBEM?

Table E-2: Roles, Names, and Affiliations of the Host and the Participants

Roles	Names	Affiliations
Host	Jeff Haberl	Texas A&M University (TAMU)
Participants	Peter Ellis and Neal Kruis	Big Ladder Software LLC

TC 4.7 MBEM – Peter Ellis and Neal Kruis:

Jeff (question):
What work are you doing using BEM for Urban-scale Building Energy Modeling (UBEM)?

Peter (answer):
We have been working on a web-based application in collaboration with the Army Corps of Engineers since 2011. Since then, it's evolved into the second complete rewrite. The one in 2011 was called Net Zero Planner. What we were trying to do was to automate a significant portion of the modeling and analysis required for energy master planning at DOD installations. For example, when doing renovation plans and setting energy goals, it's the master planning which looks 10-20 years ahead.

Jeff (question):
Are there different kinds of buildings? Different types of army buildings or what?

Peter (answer):
There are various types of commercial buildings and then there are a number of army specific buildings and then a handful of residential buildings. We have prototype models much like the PNNL commercial prototypes or the NREL commercial reference buildings. You start with the prototype. You pick the right building type for each building on the base and then from there you can sort of customize it to make that building line up more closely with the real building.

Jeff (question):
That's interesting. Is that project near completion or is it on the way or what?

Peter (answer):
It's still ongoing. This Net Zero Planner at some point they renamed it to System Master Planner or SMPL tool. The first version of it has been used in production for a number of years. Let's say like seven years. They've done a lot of projects doing analysis of various installations with it. It's more than 100 maybe approaching 200 different studies.

Jeff (question):
That's interesting. What simulation programs are you currently using in these tools?

Peter (answer):
It uses EnergyPlus under the hood. The prototype models are based on the NREL commercial reference models but those are in the process of being updated to align with the PNNL commercial building models. Then there's all the army specific ones.

Jeff (question):
Are these models with fixed parameters or do they have variable selected parameters? So, you could make it a longer building or a square building or you can add floors to it?

Peter (answer):
You can change just about everything except the geometry. It's sticking with the original prototype sort of configuration, but you can swap out for different HVAC systems. There's a whole set of different HVAC system types that are available. All different kinds of control parameters, set points, schedules, all your internal loads, all the envelope properties. Except for geometry, there is an incredible range of parameters you can play with.

Jeff (question):
Documentation regarding the different projects and the different work that you're doing for urban scale building energy modeling.

Peter (answer):
There's a couple of papers, ASHRAE papers that I can send you references for. I think those are all calling it Net Zero Planner at that time. Ref.: Liesen, Johnson, Swanson, Stinson, and Case (2018), Ellis (2016), Case et al. (2014), Ellis, Liesen, Zhivov, and Herron (2012).

Jeff (question):
Is there any larger documentation within the army's documents?

Peter (answer):
There's not really like a user guide or anything like that. Some documentation videos on their YouTube channel, that sort of demonstrate some things. But other than that, there's not really documentation per se.
https://www.youtube.com/channel/UC2sdFPLVc5TENXyuRL4SzNw

Jeff (question):
What other research can you see coming out of this perhaps that could lend itself to urban scale building energy modeling?

Peter (answer):
Since 2018 we got a grant from DOD to basically rewrite this original tool, essentially version two of the Net Zero Planner. One of the improvements is that it's now moved to more of a portfolio level analysis, so it's not focused on just one installation, it could be buildings all over the country.

Jeff (question):
So, you actually have a feature that combines models? It sounds like you can develop a cluster of models for a base or something like that, then it combines the results or combines the cluster with another cluster, etc.

Peter (answer):
Right, exactly! You want to be able to roll up the results at bigger and bigger scales, so DOD could see across its entire portfolio of buildings around the whole world: what's

going on with energy, what's the projected energy according to the current plan, even historical stuff.

The new tool is the original Net Zero Planner that also integrates water, waste, storm water and resiliency analysis. We have a very interesting resiliency modeling module that is sort of based on Monte Carlo, evaluating various potential threats and things that can happen statistically either to individual buildings or to different parts of the electrical network and any of the network systems, chilled water plant, hot water plant, etc.

Jeff (question):
You're doing this all with EnergyPlus or do you have some add-ons with that?

Peter (answer):
That's a separate engine that we've developed that does this systems level modeling and that's called ERIN right now.

Neal (answer):
ERIN: Energy Resilience of Interacting Networks

Peter (answer):
It's a network with statistical probabilities of different things happening.

Jeff (question):
What other research potential have you seen through your project? The purpose of this interview was to try to feed back to TC 4.7 and ultimately try to ask some of the experts in this area what research is needed that ASHRAE could help with.

Peter (answer):
Great! One thing I'll mention first before I answer that question is we've been developing this for years in this DOD context, but ultimately, we have the rights to try to make this a commercial product to roll this out as a software service. So, consultants can use it to model a portfolio energy master planning for university campuses, parts of cities, or commercial retail chains that have buildings all across the country: Target, Walmart, Starbucks.

Jeff (comment):
So that would mean a significant number of different types of models because the building types are going to change from the typical army bases.

Peter (answer):
Right and you'll be able to upload your own prototype model that you would create offline and then you could upload it and the tool would work the rest.

Jeff (question):
So, you would have some sort of a plug-in protocol?

Peter (answer):
Yes. Looking ahead and there's potentially lots and lots of EnergyPlus runs happening here and we are leveraging cloud computing resources, different platforms like Microsoft Azure or Amazon, but that's going to be a bottleneck for people to really use this kind of stuff efficiently. So, finding a way to make these models just run faster.

So, some stuff that I'm aware of that's been done in the past is something like surrogate modeling where you have the detailed model and then you sort of exercise it across a big parameter space and reduce that to just like a big polynomial.

Jeff (comment):
Yeah, an inverse model.

Peter (comment):
That's right. We haven't gotten to that stage where we are actively pursuing how to do that or what even has been done otherwise.

Jeff (comment):
That's a possibility where a protocol could be developed in the ASHRAE world.

Peter (answer):
If there was an established way that ASHRAE could develop or help develop, that would be fantastic.

Jeff (question):
When you work with your urban scale building energy models, typically what kinds of weather data are you using?

Peter (answer):
We're using the regular TMY3 data.

Jeff (question):
When you calibrate those models if you calibrate them, how do you calibrate the model?

Peter (answer):
Same weather file. Nothing very fancy on the calibration side, just it's a manual process.

Jeff (question):
So, you don't actually use actual meteorological data.

Peter (answer):
That would be nice. We just haven't gotten to that yet.

Jeff (comment):
Well, those are the main questions that we've been asking everybody each time.

Peter (comment):
Thinking about what ASHRAE could help with, I think of resiliency modeling. You hear about resiliency a lot and it's often like squishy, fluffy stuff, but there's actually quantitative ways to go about it that are very useful. I think we have a paper on that that I can send you. Ref.: O'Keefe et al. (2021).

Peter (comment):
I think what's unique or neat about what we're doing is that we are bringing this stuff out to the real world. Doing these mass projects whether it's through the DOD installations or ultimately with our commercial pool, we think it's going to have a big impact.

Jeff (comment):
…It's almost like the individual buildings become like DNA. You can begin to assemble an entity out of all these multiple models. So, rather than focusing one model at a time, now you can begin to look at larger issues, because you have hundreds of thousands of these models.

Peter (comment):
Yeah, part of the benefit of the prototypes is that if you don't really know a lot about each building, at least you're starting with some decent defaults.

Jeff (comment):
…In theory their basic elements are public and so they could be reviewed. So that builds trust in the foundation of the model…

Peter (comment):
Whatever we do, it's way better than what these energy master planners were doing before, which was if you're lucky you know a little bit of rule of thumb stuff in an excel spreadsheet. So, Urban-Scale Energy Modeling is making it way more quantitative and analytical than what was available to these type of planners before.

Appendix F: Additional UBEM Survey Questions/Answers

This appendix presents additional UBEM survey Questions/Answers that were asked to the participants. These additional questions were created based on the review and feedback from the 2022 ASHRAE winter conference TC 4.7 committee meeting. The following tables record answers from the participants who responded to the authors of the report.

Table F-1 shows the answers from Dr. Tianzhen Hong. Table F-2 shows the answers from Dr. Wangda Zuo. Table F-3 shows the answers from Dr. Christoph Reinhart. Table F-4 shows the answers from Dr. Ralph Muehleisen. Table F-5 shows the answers from Mr. Peter Ellis and Dr. Neal Kruis.

Table F-1: Answers emailed by Dr. Tianzhen Hong

Question: When you are working on UBEM projects, what type(s) of weather data are you using? Example: Average year weather data (i.e., TMY3) or Actual Meteorological Year (AMY) weather data for each location?
Answer: "We use various types of weather data: TMY3 for evaluating general trends of building energy demand and load profiles and how energy efficiency measures influence those results; AMY for calibrating building energy models with measured energy data; and future weather files for studying the impacts of climate change on building performance. When multiple local weather station data is available, we use them to capture the urban microclimate impacts on building performance."
Question: When/if you calibrate your UBEM model do you use average year weather data or AMY weather data?
Answer: "We use AMY, as described above."

Table F-2: Answers emailed by Dr. Wangda Zuo

Question: When you are working on UBEM projects, what type(s) of weather data are you using? Example: Average year weather data (i.e., TMY3) or Actual Meteorological Year (AMY) weather data for each location?
Answer: "We used both depending on the research needs. When we calibrate our models for real systems, we used AMY data. When we do design analysis, we tend to use TMY3 data."
Question: When/if you calibrate your UBEM model do you use average year weather data or AMY weather data?
Answer: "AMY data."

Table F-3: Answers emailed by Dr. Christoph Reinhart

Question: When you are working on UBEM projects, what type(s) of weather data are you using? Example: Average year weather data (i.e., TMY3) or Actual Meteorological Year (AMY) weather data for each location?
Answer: "That depends on the study scope. In most cases TMY data suffices but you may also use morphed weather files and/or consider urban heat island effects."
Question: When/if you calibrate your UBEM model do you use average year weather data or AMY weather data?
Answer: "Always AMY."

Table F-4: Answers emailed by Dr. Ralph Muehleisen

Question: When you are working on UBEM projects, what type(s) of weather data are you using? Example: Average year weather data (i.e., TMY3) or Actual Meteorological Year (AMY) weather data for each location? **Question:** When/if you calibrate your UBEM model do you use average year weather data or AMY weather data?
Answer: "For calibration of models, AMY. Always. For doing analysis, the use of TMY or AMY depends on the goals. Looking to understand impacts of technology, design options, standards/regulation? Then usually its TMY. Looking to compare energy/carbon between buildings and some other infrastructure, then AMY since we want to model "actual" energy use. Even if we are looking to look at impacts of design or regulation since we are likely comparing to energy use of some other specific modality (i.e., transportation) for a given year. If the analysis is for extreme weather impacts, then you would want to use an extreme AMY or XMY (eXtreme Meteorological Year). Or if you want to look at resiliency, then also AMY or XMY. If you want to look at future impacts, then it's future versions of TMY, AMY, or XMY, preferably generated from dynamic downscaling and not from "morphing" of AMY or TMY because morphing is less accurate in prediction of changes in frequency, duration, and intensity of events. And one last thing: large urban areas have distinct microclimates, and we rarely have much weather data except from the nearby airport. So, we still have to take everything with a large grain of salt."

Table F-5: Answers by Mr. Peter Ellis and Dr. Neal Kruis

Question: When you are working on UBEM projects, what type(s) of weather data are you using? Example: Average year weather data (i.e., TMY3) or Actual Meteorological Year (AMY) weather data for each location?
Answer: "We're using the regular TMY3 data."
Question: When/if you calibrate your UBEM model do you use average year weather data or AMY weather data?
Answer: "Same TMY3 weather file…"