DOI: 10.38027/ICCAUA2023EN0262

Chapter 5

Urban Building Energy Modeling (UBEM) and Analysis

* Sinem Esen and Melik Ziya Yakut

Introduction

Cities, which have a large share in energy consumption, have been expanding at an increasing rate in recent years. Today, more than half of the world's population (57%) lives in urban areas, and the proportion of people living in urban areas is projected to reach 68% by 2050 (Demographia, 2022; UN-Habitat, 2022). Especially in big cities, energy demand is increasing rapidly with the increase in population. The energy demand in these areas corresponds to the sum of the energy used in various sectors such as heating, cooling, lighting, transportation, and industry. Globally, 30% of total final energy consumption and 27% of total energy sector emissions originate from the buildings and building construction sectors (IEA, 2022). Urbanization is thus one of the biggest challenges of this century, about climate change and the need to improve the sustainable use of energy and other natural resources (Hong et al., 2020). As the demand for energy in urban areas increases, so does the impact on the environment. Globally, urban areas have an energy consumption rate of between 60% and 80% and are the source of 75% of greenhouse gas emissions (UNEP, 2023). The fact that the use of fossil fuels causes the release of carbon dioxide and other greenhouse gases into the atmosphere, which leads to air pollution and global climate change, shows the importance of switching to renewable energy sources and developing energy-efficient strategies in urban areas. For this purpose, various steps should be taken to increase energy efficiency in urban areas. Accordingly, buildings need to be adapted to minimize the passive, negative effects of climatic factors on heating and cooling energy demand (Rahbarianyazd & Raswol, 2017).

Urban areas have great potential in terms of reducing global climate change with the steps to be taken toward the efficient use of energy. Urban Building Energy Modeling (UBEM), one of the methods to evaluate this potential, is a valuable methodology that can overcome these challenges as it provides users with the energy demand of the building stock, peak loads, scenario evaluation, and other useful analysis (Maccarini et al., 2021). UBEMs are a relatively new development that allows the simulation of multiple buildings using extensive information about the building stock (Buckley et al., 2021). Accordingly, UBEMs are formal systems that represent the processes of obtaining and using energy to meet the energy demands of a particular urban area (Keirstead et al., 2012). UBEM aims to evaluate strategies for optimizing building energy use at the urban scale to support a city's building energy goals (Carnieletto et al., 2021 The energy modeling at scale, that is, the urban zone, is considered UBEM from the neighborhood to the street block level (Reinhart & Davila, 2016; Yang & Jiang, 2019). A correct UBEM is the basis for supporting the design of energy-efficient communities (Hu et al., 2022).

Modeling urban energy use is a challenging task due to the complex nature of cities and the fact that it depends on a wide variety of factors to provide an accurate representation of real-world urban energy systems. Obtaining a realistic representation of these systems is time-consuming and computationally costly because they are in complex relationships with many factors (Abbasabadi & Ashayeri, 2019). Cities, therefore, require a lot of effort for manual modeling, data collection, and generation of urban energy models (Schiefelbein et al., 2019).

This study, it is aimed to create an applicable and practical model framework for modeling urban areas and estimating energy demand at the urban scale. The model framework created is intended to be applicable for urban areas in countries experiencing situations such as lack of building stock systems and datasets, the

---

Corresponding Author: * S. Esen
Faculty of Technology, Isparta University of Applied Sciences, Isparta, TR
e-mail: snemesen@gmail.com

How to Cite This Chapter:
Esen, S. & Yakut, M. Z. (2023). Urban Building Energy Modeling (UBEM) and Analysis. In H. A. Nia & R. Rahbarianyazd (Eds.), *Convergence of Contemporary Thought in Architecture, Urbanism, and Heritage Studies*, (pp. 56-69) Cinius Yayınları. https://doi.org/10.38027/ICCAUA2023EN0262

need to create extra algorithms, difficulties in obtaining real energy consumption data, etc. In this direction, three separate UBEM frameworks were created with the City Energy Analyst (CEA), Spacemaker-Revit, and UBEM.IO tools. These UBEM frameworks were examined in terms of analyzing the energy demand of a TOKİ site consisting of 13 blocks located in Ankara's Mamak district. The energy demand analyses made within the UBEM frameworks created for the application area were compared with the annual energy consumption data of the area and the most applicable UBEM framework was determined for the specified situations.

UBEM Approaches

UBEMs used to model the energy consumption of buildings can generally be grouped into two categories: "top-down modeling approach" and "bottom-up modeling approach". The top-down modeling approach is divided into the econometric model and the technological model (Swan & Ugursal, 2009). The bottom-up modeling approach is divided into three as physics-based dynamic simulation method, reduced-order method, and data-driven method. Of these, the data-driven method is divided into a statistical model and artificial intelligence (AI)-based model (Abbasabadi & Ashayeri, 2019; Ali et al., 2021). Figure 1 shows the hierarchy of the urban building energy modeling approach.

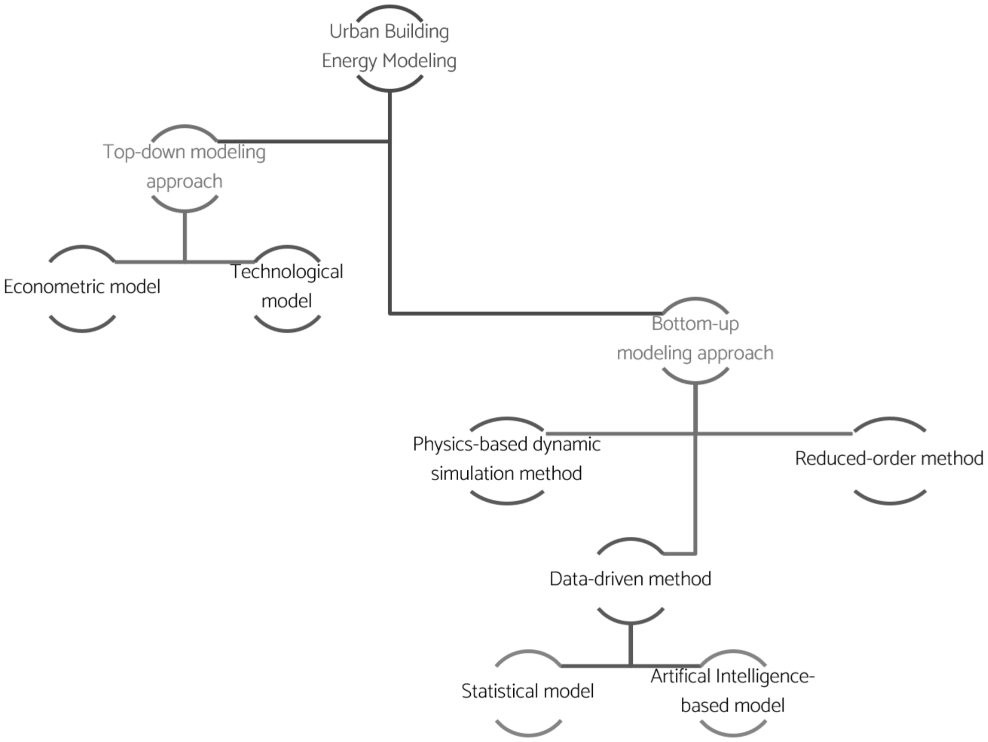


Figure 1. The hierarchy of the urban building energy modeling approach (Swan & Ugursal, 2009; Abbasabadi & Ashayeri, 2019; Ali et al., 2021).

The top-down modeling approach is suitable for assessing energy at the national level and exploring the interrelationships between the energy sector and economic outputs to fit historical time series datasets of energy consumption or carbon dioxide emissions (Swan & Ugursal, 2009; Kavgic et al., 2010; Lim & Zhai, 2017). Econometric models are based primarily on energy use about variables such as income, fuel prices, and gross domestic product to express the link between the energy sector and economic output. Technological models consider factors such as saturation, technological growth, and structural reforms that affect energy use (Swan & Ugursal, 2009; Kavgic et al., 2010).

Bottom-up models consider the energy consumption of individual buildings or groups of buildings and then, based on the representative weight of the modeled sample, evaluate these results in an integrated framework and estimate them to be representative at the urban, regional, or national scale (Swan & Ugursal, 2009; Li et al., 2017; Ferrando & Causone, 2020). Since the bottom-up modeling approach is based on the energy calculation of individual buildings, they are more stable and accurate and more widely used than the top-down modeling approach (Li et al., 2020). Physics-based dynamic simulation method considers heat transfer in buildings and their interrelationships between systems. It uses thermodynamic principles and construction, climate, and systems data to predict energy consumption. Accordingly, this method, which deals with the numerical representation of structures and their relationships with the surrounding environment, can analyze the energy consumption of structures with detailed spatiotemporal precision (Abbasabadi & Ashayeri, 2019; Ferrando et al., 2020). The reduced-order method, which is another UBEM method for the bottom-up modeling approach, is a method that provides the evaluation of urban building energy performance, which requires simple inputs compatible with the normatively configured model parameter values (Hong et al., 2020). The data-driven method is used to estimate building energy consumption using simple benchmarking or more complex regression modeling and to correlate building design and operational parameters with energy consumption. This method uses measured data, such as hourly electricity data and energy usage density databases, for modeling (Hong et al., 2016). Statistical models for this method are based on the analysis of time series or cross-sectional actual energy use data based on end-use information and give an estimate of energy demand. This means that similar to top-down models, statistical models can capture consumption patterns based on variables related to end-use (Johari, 2021). In addition to the statistical model, the artificial intelligence (AI)-based model is also widely used in models using the data-driven method. An AI-based model is essentially based on Machine Learning (ML) techniques that model the energy use of urban buildings by automatically learning data models. The model learns and trains the historical dataset to find the mathematical relationship between building energy use and influencing factors such as building features, urban features, and occupancy characteristics (Abbasabadi & Ashayeri, 2019). In light of the information explained various studies on the UBEM approach are summarized in Table 1.

Table 1. Summary of UBEM studies.

Source	Platform/ tool	City/ Region	UBEM objective
Pedersen et al., 2008	Regression	Norway	Build a load estimation method that estimates heat and electrical load profiles across various building categories
Zhao et al., 2011	CoBAM, Statistics	United States	Establishing an ABMS simulation method to predict multiple building stock energy performance
Kaden & Kolbe, 2013	Energy Atlas Berlin	Berlin, Germany	To estimate the energy demands of buildings on an urban scale using statistical data integrated with Energy Atlas Berlin
Reinhart et al., 2013	UMI	Boston, Massachusetts	Examine UMI, which enables operational energy, daylight, and walkability assessments at the urban scale
Vermeulen et al., 2013	CitySim	Paris, France	Using the urban energy simulation tool CitySim with a hybrid evolutionary algorithm
Mastrucci et al., 2014	Multiple linear regression	Rotterdam, Netherlands	To determine the energy consumption profile and savings potential of large housing stocks with a GIS-based statistical approach
Fonseca & Schlueter, 2015	GIS	Zug, Switzerland	To create an integrated model for the characterization of spatial-temporal energy consumption patterns at the urban scale
Nouvel et al., 2015	SimStadt	Ludwigsburg, Germany	Examining the urban energy simulation platform SimStadt in planning the urban-scale energy transition
Fonseca et al., 2016	CEA	Zug, Switzerland	Examine CEA for analysis and optimization of energy systems at the urban scale
Hong et al., 2016	CityBES	Manhattan, New York	Examining CityBES, which focuses on energy modeling of a city's building stock for urban-scale energy efficiency
Ma & Cheng, 2016	GIS, Big Data, Regression	New York	Develop a GIS-integrated data mining methodology to predict building EUI at the city scale
Muehleisen & Bergerson, 2017	UrbanSim	San Francisco, California	Enabling UrbanSim to be combined with the ISO model to predict energy use and GHGs at the urban scale
Heidarinejad et al., 2017	OpenStudio	United States	Rapidly create urban scale reduced-ordered building energy models
Nageler et al., 2017	IDA ICE	Gleisdorf, Austria	Establishing a validated methodology for urban scale building modeling based on publicly available data

Alhamwi et al., 2018	GIS, Regression	Oldenburg, Germany	Modeling urban-scale energy demand using only open-source data and models
Remmen et al., 2018	TEASER	Bonn, Germany	Examining TEASER at building, neighborhood, and urban scales
Papadopoulos & Kontokosta, 2019	XGBoost, GREEN	New York	Establishing a building energy performance rating methodology using urban-scale energy use and building data
Pasichnyi et al., 2019	Statistics, EPC	Stockholm, Sweden	Establishing an approach to use rich datasets to develop different building archetypes based on urban energy problems
Schiefelbein et al., 2019	OSM, TEASER	Bottrop, Germany	Establishing an urban energy modeling approach based on GIS datasets
Lu et al., 2021	UMI	Vancouver, Canada	Integrating outputs from CIMS with buildings at UMI, a spatially open UBEM
Maccarini et al., 2021	Modelica	Køge, Denmark	To create an open-source tool for use in automatically converting 3D building models to Modelica models for urban energy simulations
Nutkiewicz et al., 2021	Deep learning	Sacramento, California	Extending a DUE-S model by estimating the urban-scale impact of building energy retrofits
Prataviera et al., 2021	EUReCA	Padua, Italy	Building a new open-source tool for urban scale simulations
Perwez et al., 2022	GIS, BSEM, Ml	Japan	Creating a new hybrid model to facilitate the simultaneous handling of multiple building-oriented elements

In line with the studies summarized in Table 1, studies in the field of UBEM are generally on bottom-up UBEM approaches and physics-based dynamic simulation method, reduced-order method, and data-driven method. In addition, there are studies conducted to produce solutions for problems such as the supply and standardization of the data required for the specified methods, and model accuracy. In line with these studies, current approaches have some limitations in representing a realistic UBEM and assessing energy use for urban scales, and a fully detailed simulation is not yet possible for UBEM, which deals with the complex representation of large areas (Swan & Ugursal, 2009; Abbasabadi & Ashayeri, 2019). While the supply of data required for UBEM and the complexity of the city are the main problems, the use of mixed databases that prevent the rapid creation of large models and the use of a different terminology from one tool to another that prevents comparison between tools are also among the current problems (Schiefelbein et al., 2019; Ferrando et al., 2020, Wang et al., 2022). Data quality, privacy, access, and security are issues that need to be addressed (Hong et al., 2020). Although actual consumption values are available at different energy companies, these data are often not shared due to privacy regulations and economic interests (Kaden & Kolbe, 2013). Readily available public building information datasets provide a good starting point for UBEM, but many cities do not provide such detailed building information (Deng et al., 2021). Simulating all buildings in cities, which are complex systems, also requires significant computing resources. Modeling the annual energy performance of a large number of buildings in a reasonable time poses a large-scale computational challenge that requires next-generation supercomputers (Hong et al., 2020). However, in many cases, licensing costs, lack of transparency, reduced capabilities of selected computational methods, and the need for advanced computing capabilities have restricted the wider adoption and use of various advanced programs, particularly in the regions of the Global South and more specifically in South America, South Asia, and low- and middle-income countries (Amrith et al., 2022). Studies conducted and UBEMs created provide validity for certain fields. In areas other than this, there are problems such as the lack of building stock systems and data sets, the need to create extra algorithms, difficulties in obtaining real energy consumption data, etc. This study contributes to the literature by creating a valid UBEM framework that is applicable to urban areas experiencing these situations and analyzing the energy demand of urban buildings through the model. In general, the use of UBEM tools is challenging in terms of the need for hard-to-find individuals with training in multiple fields, standardized building energy use data and the lack of construction databases, and requires a great deal of time for such reasons (Ang et al., 2022).

Material and Methods

This study, it is aimed to create an applicable and practical model framework for modeling urban areas and estimating energy demand at the urban scale. The model framework created is intended to be applicable for urban areas in countries experiencing situations such as lack of building stock systems and datasets, the need to create extra algorithms, difficulties in obtaining real energy consumption data, etc. In this direction, three separate UBEM frameworks were created with the City Energy Analyst (CEA), Spacemaker-Revit, and UBEM.IO tools. These UBEM frameworks are examined in terms of analyzing the energy demand of an urban area in Turkey. The flow chart of the study is shown in the Figure 2.

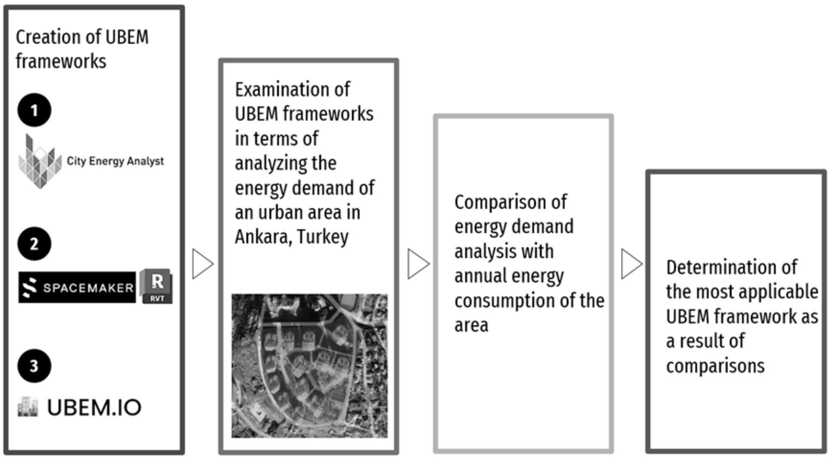


Figure 2. Flow chart of the study.

CEA, one of the tools selected to be examined in the study, is a program that can provide energy demand analysis for the determined urban implementation area within its structure. Apart from this, energy analysis can be performed with auxiliary tools for the other two tools selected for examination. Flowcharts of UBEM frameworks created from Spacemaker-Revit, UBEM.IO, and its auxiliary tools are shown in Figure 3 and Figure 4, respectively.

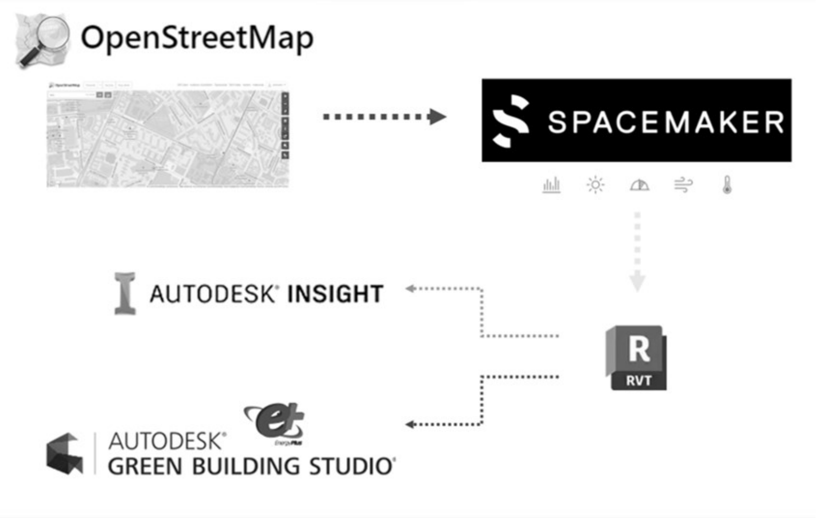


Figure 3. Spacemaker-Revit UBEM flowchart.

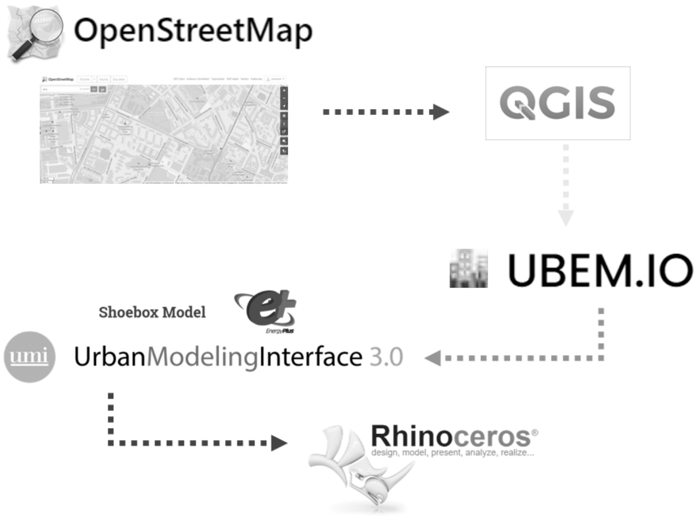


Figure 4. UBEM.IO flowchart.

In order to create the determined UBEM frameworks, a TOKİ site consisting of 13 blocks located in the Mamak district of Ankara was chosen as the implementation area, and energy analyzes were carried out for this area. The satellite location and residences of the implementation area are shown in Figure 5.

Figure 5. Satellite location and residences of the implementation area.

4 of the blocks in the selected area have 8 floors, and 9 of them have 10 floors. The energy demand analyses made within the UBEM frameworks created for the implementation area were compared with the annual energy consumption data (fuel, electricity) of the area. Accordingly, the usability of the UBEM frameworks created for the countries experiencing the above-mentioned situations was examined. In determining the energy consumption data of the area, limited data obtained from the site, Başkent Doğalgaz Dağıtım GYO A.Ş (2023) and Enerjisa (2023) were used. Accordingly, the annual energy consumption data per square meter of the implementation area is shown in Table 2 and the Energy Use Intensity (EUI) of the area is 232.78 kWh/m^2.

Table 2. Annual energy consumption per square meter of the implementation area.

	kWh/m^2
Fuel consumption	210.67
Electricity consumption	22.11
Total energy consumption	232.78

City Energy Analyst (CEA)

CEA (City Energy Analyst) is software with a simulation engine for calculating hourly energy flows between buildings, users, and the environment. It has a computational framework for analyzing and optimizing energy systems in neighborhoods and urban scales. This computational framework consists of a set of tools for the analysis of urban energy systems. These tools are built on standard dynamic simulation models and interdisciplinary know-how (Hong et al., 2020; The CEA team, 2022).

In order to prepare UBEM geometry in CEA, data entries were made for basic information such as location information, loading of the weather file, etc. in the urban area determined for Ankara province. After the preparation of the UBEM geometry with the basic data entries, many data entries such as building area, typology, architecture, and usage type were made through the program. After all the necessary data entries were completed, energy demand analysis was performed through the urban building energy model created by the program.

Spacemaker-Revit

Spacemaker is a cloud-based artificial intelligence software that enables the analysis and design of urban areas. It creates 3D collective models of the urban area and its surroundings using automated datasets and provides their analysis for criteria such as daylight, sun, wind, and microclimate (Loftus & Bassøe-Eriksen, 2022). Revit, on the other hand, is a BIM (Building Information Modeling) software that includes interdisciplinary tools in the fields of architecture and engineering. A transfer from Spacemaker to Revite is provided via the Spacemaker plug-in for Revit for use in measuring energy demand. This plug-in facilitates interoperability between Spacemaker and Revit (Spacemaker, 2020). After the energy demand analysis is done through Revit, the project is transferred to Insight for review. Insight is a web-based Revit plug-in that offers practical improvements to improve design through energy demand analysis (Autodesk, 2023).

In order to prepare the UBEM geometry in Spacemaker, firstly, building footprints of the selected urban area were obtained via OpenStreetMap (OSM). OpenStreetMap is an open-source, web platform that provides map data (OpenStreetMap, 2023). This area is then uploaded to the Spacemaker web interface. Basic data entries were made for the implementation area through Spacemaker's web interface. Following the completion of the basic data entries, field metrics, daylight potential, solar analysis, wind analysis, and microclimate analysis were performed. After the analysis, it is possible to transfer from the Spacemaker web interface to Revit at the stage of measuring the urban energy demand. Accordingly, the transition from Spacemaker to Revit was made through the plug-in created for Revit to create an energy analytical model. An energy analytical model of the implementation area was created to perform energy demand analysis on the project transferred to Revit via the plugin. In this direction, location and weather data were selected and data entries related to building and mass elements were provided. After the data entries were completed, the energy analytical model created for the implementation area was transferred to the web-based Insight software via Revit using the plug-in.

UBEM.IO

UBEM.IO is an open-source web tool that generates the UMI file that the energy modeler will use to run operational building energy simulations at the neighborhood level (UBEM.IO, 2020). UMI (Urban Modeling Interface) is an urban modeling interface for analyzing energy consumption at the neighborhood scale (Hong et al., 2020). It was developed by Sustainable Design Lab and is a design environment for Rhinoceros 3D (Rhino) (MIT Sustainable Design Lab, 2023). Rhino forms the CAD backbone of all environmental analysis at UMI (UBEM.IO, 2020).

In the study, building footprints of the implementation area were obtained via OpenStreetMap to prepare the UBEM geometry. Firstly, polygons for building footprints are created in the selected area. Then, a GIS file containing basic data such as building footprints heights, building ages, and building usage types was created. QGIS program was used to create the file containing the GIS data set. After creating the geometries for the implementation area and completing the data entry processes in the QGIS program, a shapefile of the area was prepared. Shapefile is prepared as a .zip folder containing .shp, .dbf, .cpg, .prj, and .shx files. Then the prepared shapefile was uploaded to UBEM.IO via the web platform. After the upload process, data such as building identity and height are assigned to the appropriate shapefile parts. After the necessary data entries were provided through the UBEM.IO platform, the resulting exchange file with the .uio extension was downloaded. This downloaded file is uploaded to the relevant part of the UBEM.IO platform for processing data such as building typology, weather, etc. The basic UBEM file, which was prepared after the operations, was downloaded from UBEM.IO with the .umi extension and transferred to the Rhino program, which was installed with the UMI plug-in, for energy demand analysis.

Results

Energy demand analyses were obtained from three different UBEM frameworks created for the implementation area determined in the study. The obtained analysis outputs were examined and compared with the energy consumption data of the implementation area. The applicability of the UBEMs created for the countries that have difficulties in creating UBEMs for the reasons stated in the study (lack of building stock system and data sets, need to create extra algorithms, difficulty in obtaining real energy consumption data, etc.)

has been evaluated. As a result, the most reasonable UBEM framework was determined in terms of applicability for the specified situations. In this direction, as shown in Table 2, the EUI of the implementation area is 232.78 kWh/m^2.year. The results of the energy demand analyses made over the UBEM frameworks created for the area are given in Table 3.

Table 3. Annual energy consumption per square meter of implementation area.

UBEM Framework	Energy use intensity (kWh/m^2.year)
CEA	108
Spacemaker-Revit	214
UBEM.IO	460

If the energy use intensity data shown in Table 3 is compared with the energy use intensity of the area, which is 232.78 kWh/m^2.year, it is seen that the closest result is obtained from the model framework created with Spacemaker-Revit with 214 kWh/m^2.year. After that, the model created with CEA follows it with 108 kWh/m^2.year, but it is the UBEM.IO model framework with 460 kWh/m^2.year that gives the furthest result. As a result of the energy demand analysis made on the model created with CEA, the energy final use intensity chart and graph of the area are shown in Table 4 and Figure 6, respectively.

Table 4. CEA- Energy final use intensity.

Building Code	Energy final use intensity (kWh/m^2.year)
B1000	107
B1001	105
B1002	106
B1003	106
B1004	106
B1005	108
B1006	106
B1007	106
B1008	105
B1009	107
B1010	106
B1011	129
B1012	109
Average energy final use intensity (kWh/m^2.year)	108

Name: B1000

REFERENCE: User - Input
category: house
descriptio: null
floors_ag: 10
floors_bg: 2
height_ag: 30
height_bg: 6

Floor Area: 516.450m²
GFA: 6197.500m²

Figure 6. CEA- Energy final use intensity.

According to the data shown in Table 4 and Figure 5, the value of the buildings in the implementation area with the highest energy end final use intensity is 129 kWh/m^2.year, and the value of the lowest one is 105 kWh/m^2.year. The average energy use intensity of the implementation area is 108 kWh/m^2.year.

As a result of the energy demand analysis made on the model created with Spacemaker-Revit, various analysis outputs were obtained on the energy use of the implementation area. In Figure 7, the sun, daylight, wind, and microclimate analyses for the implementation area are shown comparatively.

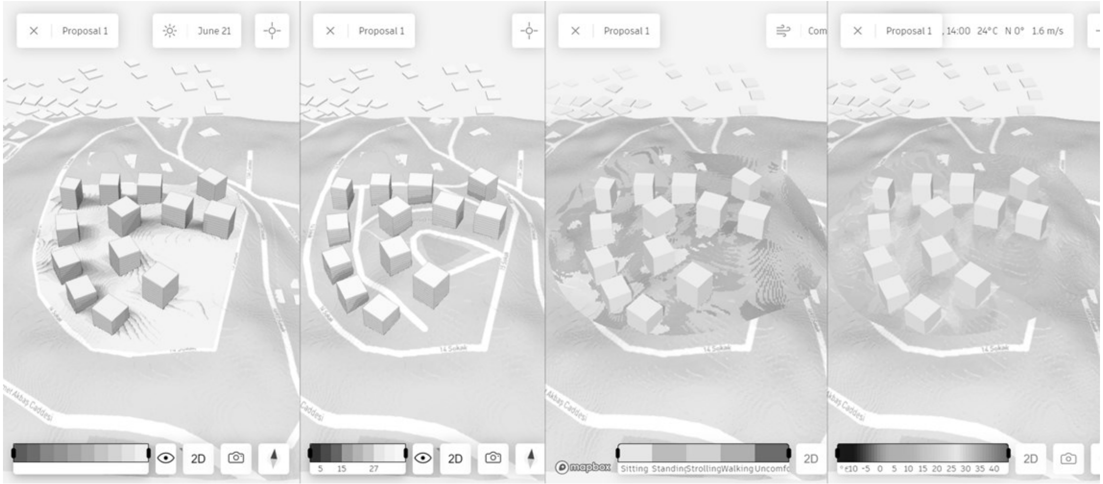
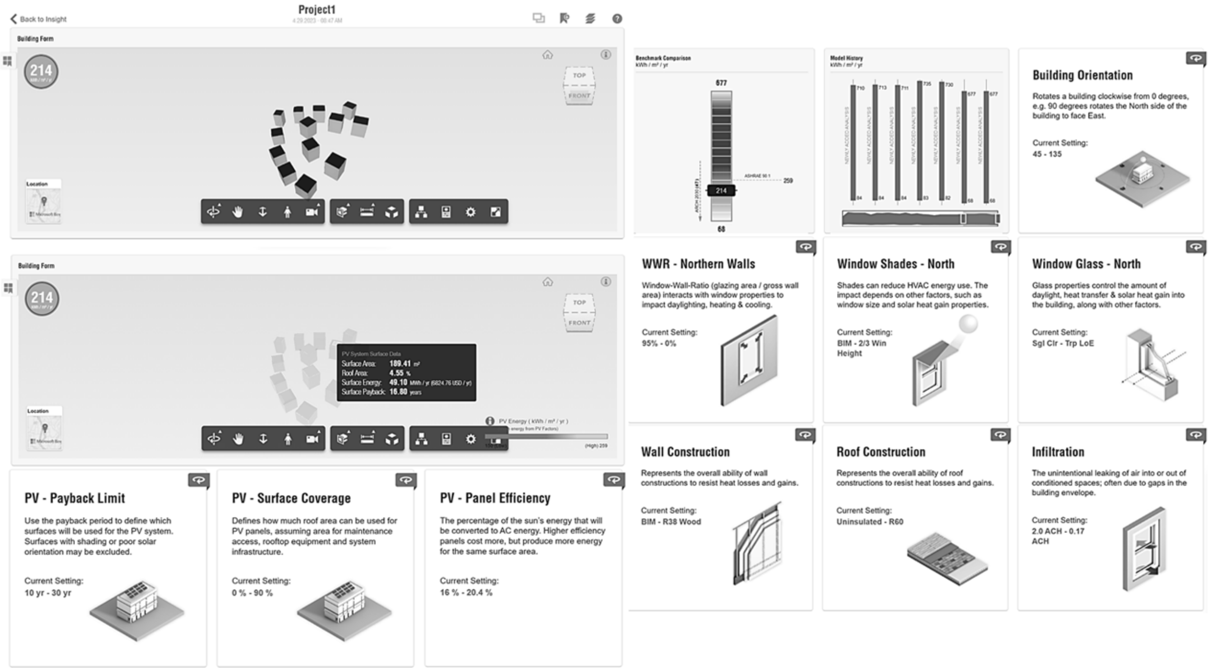


Figure 7. Spacemaker-Comparative view of the sun, daylight, wind, and microclimate analysis.

Solar analysis, which is the first of the analyses shown comparatively in Figure 7, uses sun position tracing and ray tracing techniques throughout the day for location and selected date in calculating sunlight hours on sites and buildings. In this calculation made for the implementation area, the dates of 21 December and 21 June were selected. Daylighting potential analysis provides information about the daylighting performance of buildings. This analysis evaluates which parts of building facades have less access to daylight with the help of the VSC (Vertical Sky Component) score. This component, expressed as a percentage, indicates how much daylight illuminates a horizontal surface. Wind analysis examines how wind conditions affect the design, with different wind directions and speeds in real-time. Two different analysis outputs, comfort, and direction, are obtained over the wind analysis. Figure 7 shows the wind analysis in terms of comfort. In terms of comfort, the wind analysis shows how the wind conditions in the application area will be experienced by pedestrians at ground level. Wind analysis in terms of direction shows the wind conditions in the implementation area in terms of direction and speed. Microclimate analysis to calculate the perceived temperature in the implementation area also evaluates the sun, daylight, and wind analyses with local weather conditions to determine the local microclimate conditions in the selected urban area (Spacemaker, 2020). The results of the selected points through the analysis can be seen with the examination tool.

In line with the analyzes made in Spacemaker, the energy analytical model of the model transferred to Revit was created. Various aspects of the model imported to the Insight plug-in through the energy analytical model created in Revit, related to energy use intensity, PV potential, and energy demand, are shown in Figure 8.



PV System Surface Data
Surface Area: 189.41 m²
Roof Area: 4.55 %
Surface Energy: 49.10 MWh / yr (6824.76 USD / yr)
Surface Payback: 16.80 years

Building Orientation
Rotates a building clockwise from 0 degrees, e.g. 90 degrees rotates the North side of the building to face East.
Current Setting:
45 - 135

WWR - Northern Walls
Window-Wall-Ratio (glazing area / gross wall area) interacts with window properties to impact daylighting, heating & cooling.
Current Setting:
95% - 0%

Window Shades - North
Shades can reduce HVAC energy use. The impact depends on other factors, such as window size and solar heat gain properties.
Current Setting:
BIM - 2/3 Win Height

Window Glass - North
Glass properties control the amount of daylight, heat transfer & solar heat gain into the building, along with other factors.
Current Setting:
Sgl Clr - Trp LoE

Wall Construction
Represents the overall ability of wall constructions to resist heat losses and gains.
Current Setting:
BIM - R38 Wood

Roof Construction
Represents the overall ability of roof constructions to resist heat losses and gains.
Current Setting:
Uninsulated - R60

Infiltration
The unintentional leaking of air into or out of conditioned spaces; often due to gaps in the building envelope.
Current Setting:
2.0 ACH - 0.17 ACH

PV - Payback Limit
Use the payback period to define which surfaces will be used for the PV system. Surfaces with shading or poor solar orientation may be excluded.
Current Setting:
10 yr - 30 yr

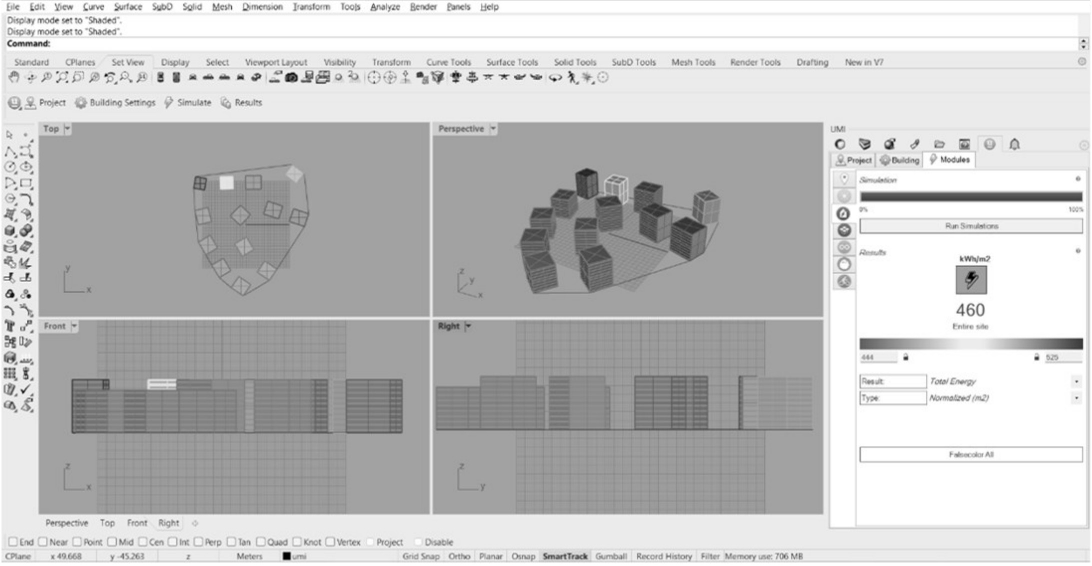
PV - Surface Coverage
Defines how much roof area can be used for PV panels, assuming area for maintenance access, rooftop equipment and system infrastructure.
Current Setting:
0 % - 90 %

PV - Panel Efficiency
The percentage of the sun's energy that will be converted to AC energy. Higher efficiency panels cost more, but produce more energy for the same surface area.
Current Setting:
16 % - 20.4 %

Figure 8. Revit, Insight- Various aspects of the implementation area related to energy use intensity, PV potential, and energy demand.

In line with the data shown in Figure 8, the energy use intensity of the implementation area is 214 kWh/m^2.year. In line with the analysis made for the model, various aspects of the project related to PV potential and energy demand are listed on the Insight panel. Information such as the PV potential of the implementation area and the PV system surface data for the selected building, and payback period can be seen. Examining the project from various aspects of energy demand helps to understand how decisions will affect energy use and shows alternatives that can be made for performance improvements. The general capabilities of various parameter options such as the presented building orientation, roof, wall, and window construction, the use of window shades can be seen against heat losses and gains, and the relative effects on energy consumption types such as heating and cooling, and lighting.

Finally, the model created with UBEM.IO for the implementation area was transferred to Rhino via the UMI plug-in, and energy demand analysis was performed. The energy use intensity of the implementation area for UBEM.IO is shown in Figure 9.



```
Display mode set to "Shaded".
Display mode set to "Shaded".
Command:
```

Result: Total Energy

Type: Normalized (m2)

Figure 9. UBEM.IO- Energy use intensity of the implementation area.

In line with the data shown in Figure 9, the energy use intensity of the implementation area is 460 kWh/m^2.year. As a result of the energy demand analysis made over the model frameworks created, it was determined that the energy demand analysis result, which is the furthest from the real energy consumption data of the implementation area, belongs to the model framework created with UBEM.IO.

Discussion

Among the UBEM frameworks created in the study, it was seen that the analysis result obtained for the Revit-Spacemaker UBEM framework gave the closest result to the energy consumption of the implementation area. In this direction, it was determined that the most applicable model framework for urban areas in countries that have difficulties in creating UBEM due to the lack of building stock systems and data sets, the need to create extra algorithms, the difficulty in obtaining real energy consumption data, etc. are the UBEM framework created with Spacemaker-Revit. It has been determined that the analyzes performed within the framework of this model will give results closer to the actual consumption data when the level of detail is increased, and Revit provides more flexibility in data entry than other examined tools. The fact that the standards used in the program are more common than valid in a specific area and that they allow for easy export and connection between various analysis tools makes this model framework stand out from the other two model frameworks. In addition, the fact that it enables effective analyses such as measuring daylight potential and wind and microclimate analyses through the Spacemaker platform shows that this UBEM framework is the most effective model framework among those examined.

With the energy demand analysis outputs made through the model framework created, the energy performance of the selected urban area can be examined from various aspects, the microclimate conditions in the area and the effects of the project on the physical environment can be evaluated, and it can be ensured that decisions to improve the design can be taken while there is no financial damage for the projects in the design stage. These are all steps that need to be taken toward an energy-efficient future. Considering the emission reduction targets in urban areas required by the Paris Agreement, it confirms the necessity of benefiting from UBEM approaches, which are an effective method to create solutions to the local problems of urban areas.

Conclusion

Urban areas accelerate global warming by releasing carbon dioxide and other greenhouse gases into the atmosphere and increasing the environmental temperature by creating heat islands. Therefore, practices such as UBEM, which will increase energy efficiency in urban areas, are important steps to reduce the effects of global warming and create a healthier, more sustainable urban environment.

This study, it is aimed to create a feasible and practical model framework to model urban areas and predict energy demand at the urban scale. The model framework created is intended to be applicable to urban areas in countries experiencing situations such as lack of building stock systems and data sets, the need to create extra algorithms, difficulties in obtaining real energy consumption data, etc. In this direction, three separate UBEM frameworks have been created with City Energy Analyst (CEA), Spacemaker-Revit, and UBEM.IO tools. These UBEM frameworks were examined in terms of analyzing the energy demand of a TOKİ site consisting of 13 blocks located in the Mamak district of Ankara. The energy demand analyses made within the UBEM frameworks established for the application area were compared with the annual energy consumption data of the area and the most applicable UBEM framework was determined for the specified situations. The energy use intensity of the implementation area is 232.78 kWh/m^2.year and the closest result was obtained from the model frame created with Spacemaker-Revit with 214 kWh/m^2.year. The model created with CEA follows it with 108 kWh/m^2.year, but it is the UBEM.IO model framework with 460 kWh/m^2.year that gives the furthest result. The Spacemaker-Revit UBEM framework was found to be the most effective among those examined for reasons such as being relatively flexible in data entry, allowing the evaluation of urban microclimate conditions, and allowing easy export and connection between various analysis tools. In this respect, it was determined that the most applicable model framework for urban areas in countries experiencing difficulties for the reasons stated in the creation of UBEM is the UBEM framework created with Spacemaker-Revit.

The UBEM framework created as a result of the study can contribute to the accumulation of knowledge in the field of UBEM, which will be widely used in the future, and offer solutions for countries experiencing various problems in creating UBEM. At the same time, the model framework created can contribute to the determination of policies and pre-investment decision-making issues by concretely revealing the energy consumption trends in a particular urban area. In this direction, it is of great importance to benefit from UBEM approaches to reduce the dependence on fossil fuels in cities and to prevent global warming. Reducing energy consumption and dependence on fossil fuels contributes to the progress of cities towards a cleaner and more sustainable future by enabling more efficient use of energy resources.

Acknowledgement

This research has been produced from the Ph.D. Dissertation. In addition, this study is based on studies supported within the scope of Turkey’s The Council of Higher Education YÖK 100/2000 Ph.D. project. We offer our gratitude.

Conflict of Interests

The authors declare no conflict of interest.

References

Abbasabadi, N., & Ashayeri, M. (2019). Urban energy use modeling methods and tools: A review and an outlook. *Building and Environment*, 161, 1-16. https://doi.org/10.1016/j.buildenv.2019.106270.

Alhamwi, A., Medjroubi, W., Vogt, T., & Agert, C. (2018). Modelling urban energy requirements using open source data and models. *Applied Energy*, 231, 1100-1108. https://doi.org/10.1016/j.apenergy.2018.09.164.

Ali, U., Shamsi, M. H., Hoare, C., Mangina, E., & O’Donnell, J. (2021). Review of urban building energy modeling (UBEM) approaches, methods and tools using qualitative and quantitative analysis. *Energy and Buildings*, 246, 1-24. https://doi.org/10.1016/j.enbuild.2021.111073.

Amrith, S., Oraiopoulos, A., Korolija, I., & Fennell, P. (2022). Developing an Open Access Plugin for Urban Building Energy Modelling in QGIS. *BSO-VI 2022 Sixth Building Simulation and Optimisation Virtual Conference*. IBPSA, pp. 1-8.

Ang, Y. Q., Berzolla, Z. M., Letellier-Duchesne, S., Jusiega, V., & Reinhart, C. (2022). UBEM. io: A web-based framework to rapidly generate urban building energy models for carbon reduction technology pathways. *Sustainable Cities and Society*, 77, 1-12. https://doi.org/10.1016/j.scs.2021.103534.

Autodesk. (2023). *Autodesk Revit 2021*. Available at: https://help.autodesk.com/view/RVT/2021/ENU/ (Accessed: 06 Apr 2023).

Başkent Doğalgaz Dağıtım GYO A.Ş. (2023). *Bilgi edinme*. Available at: https://www.baskentdogalgaz.com.tr/tr/page/Iletisim/1 (Accessed: 06 Apr 2023).

Buckley, N., Mills, G., Letellier-Duchesne, S., & Benis, K. (2021). Designing an energy-resilient neighbourhood using an urban building energy model. *Energies*, 14(15), 1-17. https://doi.org/10.3390/en14154445.

Carnieletto, L., Ferrando, M., Teso, L., Sun, K., Zhang, W., Causone, F., Romagnoni, P., Zarrella, A., & Hong, T. (2021). Italian prototype building models for urban scale building performance simulation. *Building and Environment*, 192, 1-18. https://doi.org/10.1016/j.buildenv.2021.107590.

Demographia (2022). Demographia World Urban Areas. Wendell Cox Consultancy, Belleville.

Deng, Z., Chen, Y., Pan, X., Peng, Z., & Yang, J. (2021). Integrating GIS-based point of interest and community boundary datasets for urban building energy modeling. *Energies*, 14(4), 1-17. https://doi.org/10.3390/en14041049.

Enerjisa. (2023). *Enerjisa Sürdürülebilirlik Çerçevesi*. Available at: https://www.enerjisa.com.tr/ (Accessed: 06 Apr 2023)

Ferrando, M., & Causone, F. (2020). An overview of urban building energy modelling (UBEM) tools. *Building Simulation Conference Proceedings* 16, pp. 3452-3459. https://doi.org/10.26868/25222708.2019.210632.

Ferrando, M., Causone, F., Hong, T., & Chen, Y. (2020). Urban building energy modeling (UBEM) tools: A state-of-the-art review of bottom-up physics-based approaches. *Sustainable Cities and Society*, 62, 1-15. https://doi.org/10.1016/j.scs.2020.102408.

Fonseca, J. A., Nguyen, T. A., Schlueter, A., & Marechal, F. (2016). City Energy Analyst (CEA): Integrated framework for analysis and optimization of building energy systems in neighborhoods and city districts. *Energy and Buildings*, 113, 202-226. https://doi.org/10.1016/j.enbuild.2015.11.055.

Fonseca, J. A., & Schlueter, A. (2015). Integrated model for characterization of spatiotemporal building energy consumption patterns in neighborhoods and city districts. *Applied Energy*, 142, 247-265. https://doi.org/10.1016/j.apenergy.2014.12.068.

Heidarinejad, M., Mattise, N., Dahlhausen, M., Sharma, K., Benne, K., Macumber, D., Brackney, L., & Srebric, J. (2017). Demonstration of reduced-order urban scale building energy models. *Energy and Buildings*, 156, 17-28. http://dx.doi.org/10.1016/j.enbuild.2017.08.086.

Hong, T., Chen, Y., Lee, S. H., & Piette, M. A. (2016). CityBES: A web-based platform to support city-scale building energy efficiency. *Urban Computing*, 14, 1-9. http://dx.doi.org/10.1145/12345.67890.

Hong, T., Chen, Y., Luo, X., Luo, N., & Lee, S. H. (2020). Ten questions on urban building energy modeling. *Building and Environment*, 168, 1-16. https://doi.org/10.1016/j.buildenv.2019.106508.

Hu, Y., Cheng, X., Wang, S., Chen, J., Zhao, T., & Dai, E. (2022). Times series forecasting for urban building energy consumption based on graph convolutional network. *Applied Energy*, 307, 1-12. https://doi.org/10.1016/j.apenergy.2021.118231.

IEA. (2022). *Buildings, IEA*. Available at: https://www.iea.org/reports/buildings (Accessed: 06 Apr 2023).

Johari, F. (2021). Urban building energy modeling: A systematic evaluation of modeling and simulation approaches (Doctoral dissertation, Uppsala University).

Kaden, R., & Kolbe, T. H. (2013). City-wide total energy demand estimation of buildings using semantic 3D city models and statistical data. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 2, 163-171. https://doi.org/10.5194/isprsannals-II-2-W1-163-2013.

Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z., & Djurovic-Petrovic, M. (2010). A review of bottom-up building stock models for energy consumption in the residential sector. *Building and environment*, 45(7), 1683-1697. https://doi.org/10.1016/j.buildenv.2010.01.021.

Keirstead, J., Jennings, M., & Sivakumar, A. (2012). A review of urban energy system models: Approaches, challenges and opportunities. *Renewable and Sustainable Energy Reviews*, 16(6), 3847-3866. https://doi.org/10.1016/j.rser.2012.02.047.

Li, W., Zhou, Y., Cetin, K., Eom, J., Wang, Y., Chen, G., & Zhang, X. (2017). Modeling urban building energy use: A review of modeling approaches and procedures. *Energy*, 141, 2445-2457. https://doi.org/10.1016/j.energy.2017.11.071.

Lim, H., & Zhai, Z. J. (2017). Review on stochastic modeling methods for building stock energy prediction. *Building Simulation*, 10(5), 607-624. http://dx.doi.org/10.1007/s12273-017-0383-y.

Li, Z., Lin, B., Zheng, S., Liu, Y., Wang, Z., & Dai, J. (2020). A review of operational energy consumption calculation method for urban buildings. *Building Simulation*, 13, 739-751. https://doi.org/10.1007/s12273-020-0619-0.

Loftus, C. & Bassøe-Eriksen, A. (2022). *Iterative concept design with Spacemaker & Revit*. Available at: https://www.autodesk.com/autodesk-university/class/Iterative-concept-design-Spacemaker-Revit-2022#handout (Accessed: 06 Apr 2023).

Lu, Y., Scott, A., Kim, J., Curi, C. B., McCarty, J., Pardy, A., Rysanek, A., Girling, C., & Kellett, R. (2021). Integration of an energy-economy model with an urban energy model. *Buildings and Cities*, 2(1), 114-133. https://doi.org/10.5334/bc.71.

Ma, J., & Cheng, J. C. (2016). Estimation of the building energy use intensity in the urban scale by integrating GIS and big data technology. *Applied Energy*, 183, 182-192. https://doi.org/10.1016/j.apenergy.2016.08.079.

Maccarini, A., Mans, M., Sørensen, C. G., & Afshari, A. (2021). Towards an automated generator of urban building energy loads from 3D building models. *Proceedings of 14th Modelica Conference,* pp. 659-664. https://doi.org/10.3384/ecp21181659.

Mastrucci, A., Baume, O., Stazi, F., & Leopold, U. (2014). Estimating energy savings for the residential building stock of an entire city: A GIS-based statistical downscaling approach applied to Rotterdam. *Energy and Buildings*, 75, 358-367. https://doi.org/10.1016/j.enbuild.2014.02.032.

MIT Sustainable Design Lab. (2023). *Urban Modeling Interface 3.0*. Available at: https://web.mit.edu/sustainabledesignlab/projects/umi/index.html (Accessed: 06 Apr 2023).

Muehleisen, R., & Bergerson, J. (2017). Coupling a Reduced Order Building Energy Model to UrbanSim. *Proceedings of the 15th IBPSA Conference*, pp. 521-527. https://doi.org/10.26868/25222708.2017.136.

Nageler, P., Zahrer, G., Heimrath, R., Mach, T., Mauthner, F., Leusbrock, I., Schranzhofer, H., & Hochenauer, C. (2017). Novel validated method for GIS based automated dynamic urban building energy simulations. *Energy*, 139, 142-154. http://dx.doi.org/10.1016/j.energy.2017.07.151.

Nouvel, R., Brassel, K. H., Bruse, M., Duminil, E., Coors, V., Eicker, U., & Robinson, D. (2015). SimStadt, a new workflow-driven urban energy simulation platform for CityGML city models. *Proceedings of International Conference CISBAT 2015,* pp. 889-894.

Nutkiewicz, A., Choi, B., & Jain, R. K. (2021). Exploring the influence of urban context on building energy retrofit performance: A hybrid simulation and data-driven approach. *Advances in Applied Energy*, 3, 1-17. https://doi.org/10.1016/j.adapen.2021.100038.

OpenStreetMap. (2023). *OpenStreetMap About*. Available at: https://www.openstreetmap.org/about (Accessed: 06 Apr 2023).

Papadopoulos, S., & Kontokosta, C. E. (2019). Grading buildings on energy performance using city benchmarking data. *Applied Energy*, 233, 244-253. https://doi.org/10.1016/j.apenergy.2018.10.053.

Pasichnyi, O., Wallin, J., & Kordas, O. (2019). Data-driven building archetypes for urban building energy modelling. *Energy*, 181, 360-377. https://doi.org/10.1016/j.energy.2019.04.197.

Pedersen, L., Stang, J., & Ulseth, R. (2008). Load prediction method for heat and electricity demand in buildings for the purpose of planning for mixed energy distribution systems. *Energy and Buildings*, 40(7), 1124-1134. https://doi.org/10.1016/j.enbuild.2007.10.014.

Perwez, U., Yamaguchi, Y., Ma, T., Dai, Y., & Shimoda, Y. (2022). Multi-scale GIS-synthetic hybrid approach for the development of commercial building stock energy model. *Applied Energy*, 323, 119536. https://doi.org/10.1016/j.apenergy.2022.119536.

Prataviera, E., Romano, P., Carnieletto, L., Pirotti, F., Vivian, J., & Zarrella, A. (2021). EUReCA: An open-source urban building energy modelling tool for the efficient evaluation of cities energy demand. *Renewable Energy*, 173, 544-560. https://doi.org/10.1016/j.renene.2021.03.144.

Rahbarianyazd, R., & Raswol, L. (2018). Evaluating energy consumption in terms of climatic factors: A case study of Karakol residential apartments, Famagusta, North Cyprus. *Journal of Contemporary Urban Affairs*, 2(1), 45-54. https://doi.org/10.25034/ijcua.2018.3658.

Reinhart, C. F., Dogan, T., Jakubiec, J. A., Rakha, T., & Sang, A. (2013). Umi-an urban simulation environment for building energy use, daylighting and walkability. *13th Conference of International Building Performance Simulation Association*, pp. 476-483. http://dx.doi.org/10.26868/25222708.2013.1404.

Reinhart, C. F., & Davila, C. C. (2016). Urban building energy modeling-A review of a nascent field. *Building and Environment*, 97, 196-202. http://dx.doi.org/10.1016/j.buildenv.2015.12.001.

Remmen, P., Lauster, M., Mans, M., Fuchs, M., Osterhage, T., & Müller, D. (2018). TEASER: an open tool for urban energy modelling of building stocks. *Journal of Building Performance Simulation*, 11(1), 84-98. https://doi.org/10.1080/19401493.2017.1283539.

Schiefelbein, J., Rudnick, J., Scholl, A., Remmen, P., Fuchs, M., & Müller, D. (2019). Automated urban energy system modeling and thermal building simulation based on OpenStreetMap data sets. *Building and environment*, 149, 630-639. https://doi.org/10.1016/j.buildenv.2018.12.025.

Spacemaker. (2020). *Advice and answers from the Spacemaker Team*. Available at: https://help.spacemaker.ai/en/ (Accessed: 06 Apr 2023).

Swan, L. G., & Ugursal, V. I. (2009). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable and sustainable energy reviews*, 13(8), 1819-1835. https://doi.org/10.1016/j.rser.2008.09.033.

The CEA team. (2022). The City Energy Analyst (Version 3.32.0). Zürich, Switzerland. https://doi.org/10.5281/zenodo.598221.

UBEM.IO. (2020). *Technology Pathways for Building Decarbonization*. Available at: https://www.ubem.io/ (Accessed: 06 Apr 2023).

UN-Habitat. (2022). *World Cities Report 2022*. United Nations Human Settlements Programme. Nairobi, Kenya.

UNEP. (2023). *Why do the Sustainable Development Goals matter?*. Available at: https://www.unep.org/explore-topics/sustainable-development-goals/why-do-sustainable-development-goals-matter/goal-11 (Accessed: 06 Apr 2023).

Vermeulen, T., Kämpf, J. H., & Beckers, B. (2013). Urban form optimization for the energy performance of buildings using Citysim. *Proceedings of CISBAT 2013*, pp. 915-920.

Wang, Y., Wu, T., Li, H., Skitmore, M., & Su, B. (2020). A statistics-based method to quantify residential energy consumption and stock at the city level in China: The case of the Guangdong-Hong Kong-Macao Greater Bay Area cities. *Journal of Cleaner Production*, 251, 1-13. https://doi.org/10.1016/j.jclepro.2019.119637.

Yang, F., & Jiang, Z. (2019). Urban building energy modelling and urban design for sustainable neighbourhood development-A China perspective. *IOP Conference Series: Earth and Environmental Science* 329(1), pp. 1-8. https://doi:10.1088/1755-1315/329/1/012016.

Zhao, F., Martinez-Moyano, I. J., & Augenbroe, G. (2011). Agent-based modeling of commercial building stocks for policy support. *Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association*, pp. 2385-2392.