UNIVERSITY CAMPUS BUILDING ENERGY MODELING: A CASE STUDY

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ABSTRACT

Several universities in Turkey are implementing efforts to make their campuses more sustainable. Typically, their sustainability initiatives focus on improving the energy efficiency of new and existing buildings. There are several ways to improve building's energy efficiency and building energy models may be used to evaluate these strategies. While energy models are frequently utilized during the design of new buildings, they are rarely utilized to analyze the actual performance of those buildings. This paper presents a case study in which a prominent energy modeling software (Energy Plus) was used to assess the performance of a 12000-square-meter university building. The building was built in 1995 and has undergone significant alterations over the years. The aim of the research is to utilize energy modeling software to estimate the building's energy use and compare it to actual utility data. This paper discusses the data collection method, the modeling process, and the analysis of modeling outputs.

Keywords*: Building Energy Modeling, Energy Use, Existing Buildings.*

1. INTRODUCTION

Several universities in Turkey are implementing efforts to make their campuses more sustainable [1]. Universities have a special responsibility for their societies and for educating the individuals who will develop the social, economic, and technical solutions necessary to reverse global warming and contribute to the development of a healthy and sustainable society [2]. The buildings and buildings construction sectors combined are responsible for over one-third of global final energy consumption and nearly 40% of total direct and indirect CO_2 emissions [3]. Thus, every efficient climate change mitigation strategy should include measures to dramatically reduce building energy use.

Increasing the energy performance of the buildings is one of the most effective strategies to significantly reduce GHG emissions. At present, about 35% of the European Union's buildings are over 50 years old and almost 75% of the building stock is energy ineffi-

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cient. At the same time, only about 1% of the building stock is renovated each year. Renovation of existing buildings can lead to significant energy savings, as it could reduce the EU's total energy consumption by 5-6% and lower CO_2 emissions by about 5% [4]. Therefore, there is an increasing demand for energy modeling tools to assist in the study of an existing building's energy use.

Building Energy Modeling (BEM) is the practice of using computer-based simulation software to perform a detailed analysis of a building's energy use and energy-using systems. The simulation software works by enacting a mathematical model that provides an approximate representation of the building. BEM offers an alternative approach that encourages customized, integrated design solutions, which offer deeper savings. Using BEM to compare energy-efficiency options directs design decisions prior to construction. It also guides existing building projects to optimize operation or explore retrofit opportunities [5].

By accounting for actual construction materials and HVAC systems, BEMs can estimate a building's energy use. BEMs also take into consideration the impact of occupants on energy use by setting occupant schedules. Occupants have a major impact on thermal load and ventilation needs, which in turn affects the demand on HVAC systems and fans [6].

While energy models are frequently utilized during the design of new buildings, they are rarely utilized to analyze the actual performance of those buildings. For existing buildings, every effort to find optimal energy efficiency methods should begin with an understanding of how the building presently consumes energy through the use of an energy model that accurately simulates real building performance. Actual system performance fluctuates throughout the course of a building's life cycle since buildings' systems deteriorate and their efficiency decrease with time, especially if they are not properly maintained. Failures in mechanical systems and lighting equipment alone can account for between 2% and 11% of a commercial building's overall energy use [7].

This paper presents a case study in which a prominent energy modeling software (Energy Plus) was used to assess the performance of a 12000 square meter university building. The building was built in 1995 and has undergone significant alterations over the years. The aim of the research is to utilize energy modeling software to estimate the building's energy use and compare it to actual utility data. This paper discusses the data collection method, the modeling process, and the analysis of modeling outputs.

2. DATA COLLECTION

With the advancement of building energy modeling technologies, the quantity of user input and data necessary to develop the models increased. While some of the needed data is readily available, some require greater effort to collect with sufficient accuracy. Accurately obtaining the needed data is particularly difficult in older buildings, as the information contained in designs may be out of date because of renovations undertaken. The following data are required for creating an energy model for a building.

Architectural Data: The architectural design of a building has a significant impact on its energy use. When architects and designers have a solid understanding of the complicated interactions between building design and energy use, they can make educated and cost-effective decisions regarding energy-saving measures in their buildings

[8]. The architectural data required for modeling are mostly the following:

- The building's orientation, the city in which it is located (for weather details), and the building's relative location in relation to any tall building that throws a shadow on it.
- The number of floors, the total square meter of conditioned, unconditioned, and ventilated spaces (m2) on each floor.
- The materials used to create all external walls, roof and floor slabs, windows and doors, the thickness and type of insulation used in walls, the flooring material used in walls, and the kind of wall-slab construction connection.
- The total number, size, and location of external doors and windows, as well as any overhangs, fins, blinds, or curtains on windows.
- U-value (conductance) and shading coefficient (SC) of external window and door materials.

Mechanical Data: HVAC systems are among the most energy-intensive systems in many buildings [9]. As a result, precise information on their size and zoning is critical.

- The division of conditioned floor area into separate areas (zones) based on the AHUs that serve them.
- Each HVAC zone is designated to a certain activity (e.g., classroom, library, office, etc.) and is assigned a m2/person and a minimum m3/person.
- Each AHU is established with a Minimum Design Flow (m3/m2) and a minimum design flow for the core and perimeter zones.
- System and equipment description, the cooling and heating sources, the hot water supply, and the return air channel.
- Each zone has a set maximum and lowest set-point temperature for both occupied and unoccupied states.

Electrical Data: Another significant user of power in buildings is electrical equipment.

- Lighting types present in buildings (including interior and exterior end uses), interior lighting, office equipment, and exterior lighting loads and profiles (W/m2).

Internal Loads Data:

- Calculate maximum occupancy (m2/person)
- Wattage per square meter (W/ m2) of all lighting fixtures installed in the building

- W/m2 of all electrical equipment installed in the building.

Operations Data: Because operation schedules have a significant impact on energy use, it is critical to have precise information about them.

- The number of seasons in the year, their beginning and ending dates, building opening, and closing times, and occupancy, lighting, and miscellaneous (office) equipment schedules.
- Set-point temperatures for both occupied and unoccupied circumstances.
- Data on the size (kilowatts) and quantity of all sorts of fans (exhaust, ventilation, return) in the building.

3. ENERGY MODELING

Design Builder is used to create full three-dimensional architectural models that are exported to EnergyPlus (v9.4) as an input file which is used for analysis of existing building energy performance.

Energy Plus implements detailed building physics for air and heat transfer including treating radiative and convective heat-transfer separately to support modeling of radiant systems and calculation of thermal comfort metrics; calculates lighting, shading, and visual comfort metrics; supports flexible component-level configuration of HVAC, plant, and refrigeration systems; includes a large set of HVAC and plant component models; simulates sub-hourly time steps to handle fast system dynamics and control strategies; and has a programmable external interface for modeling control sequences and interfacing with other analyses [10].

The case building, located in the main campus of Marmara University, Istanbul, Turkey, consists of two connected buildings which are rectorate building and library building. The building has a reinforced concrete building with filled in brick walls and with heat insulation. The fenestration of the building consists of aluminum frames without thermal break and double-pane clear glass with U-value of 3.2 W/m2K. Heating demand is met by an old non-condensing boiler with 500 kW heating capacity using natural gas as the primary energy source. Cooling demand is met by an old air-cooled chiller with 650 kW cooling capacity for library building and 20 air conditioning split units for administrative building spaces. Air Handling Unit (AHU) provides outdoor air for library building spaces. The AHU total supply air flow rate is 19500 m3/h, heating and cooling coils are supplied by boiler and chiller. There are no individual indoor thermostats for different parts of the building. Main thermostat setpoint temperatures were designed as 23 ºC for heating season and 24 ºC for cooling season. The library building lighting system has recently been renovated with LED lamps, while most of the administrative building office areas have fluorescent lamps. The performance of a 12000-square-meter university facility was evaluated using Energyplus. The building was built in 1995 and has undergone significant alterations over the years. The building includes offices, meeting rooms, corridors and has a library with reading areas. The administrative building is used between 8am and 6pm on weekdays, while some part of the library building is used 7/24. For energy simulation weather data, Typical Meteorological Year (TMY) of Istanbul Goztepe region weather file is used.

General building information and building envelope elements U-values are provided in Table 1 and Table 2, respectively.

Table 1. Building information

Building Information	
Building Area (m^2)	12000
Conditioned Building Area (m^2)	8610
Façade Surface Area (m^2)	4690
Roof Area (m^2)	2300
Glazing Area (m^2)	820
Glazing Ratio (%)	17.5

Table 2. Building Envelope Elements and U-values

Building Elements	**U-Value (W/m^2K)**
External Walls	0.60
Roof	0.42
Slab On Grade Floor	0.56

Authorized personnel from the Department of Construction and Maintenance provided the necessary data, which included CAD drawings of all levels, floor plans, HVAC designs and final energy audit report dated December 2020. Provided energy audit report includes general building information, building occupancy patterns, HVAC, and lighting system/equipment description. Building energy model generated through observations from site visit and measurements taken from 2020 energy audit. The building depicted in Figure 1 is one utilized in the case study.

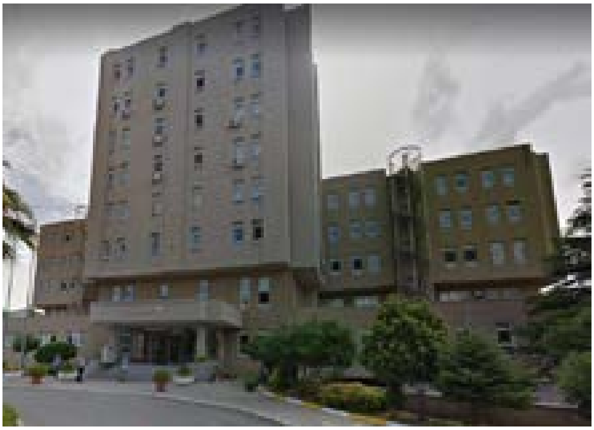

Figure 1. The building used in the case study

Additionally, the building had been visited twice with the assistance of university authorized personnel, who discussed the configuration of the building's HVAC systems and any modifications made since their initial installation. Moreover, university authorized personnel provided utility bills for 2018, 2019, and 2020, broken down by natural gas and electricity use.

As seen in Figure 2 and Figure 3, Energy Plus model was generated with the following input:

- Computer-aided design (CAD) drawings of all floors,
- The orientation of the building and its geographical location – the floor-to-floor heights
- Construction of the external and interior envelopes of buildings (roofs, walls, slabs) – materials and insulation,
- Fenestration details, HVAC zoning of all floors, assigning these zones to various activities,
- Building operating schedule, building occupancy details, lighting and office equipment load details, details of all HVAC systems, settings for ventilation and airflow in all areas

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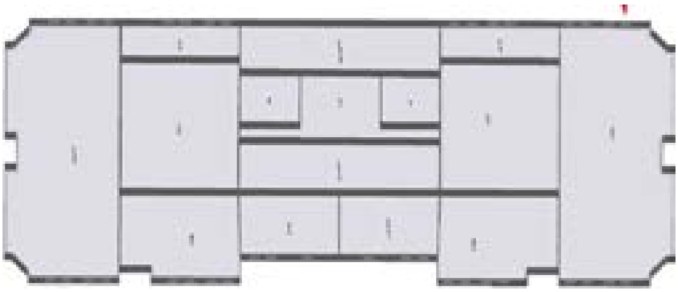
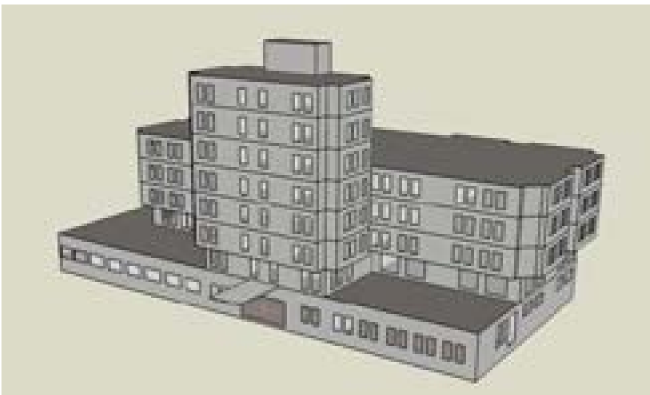




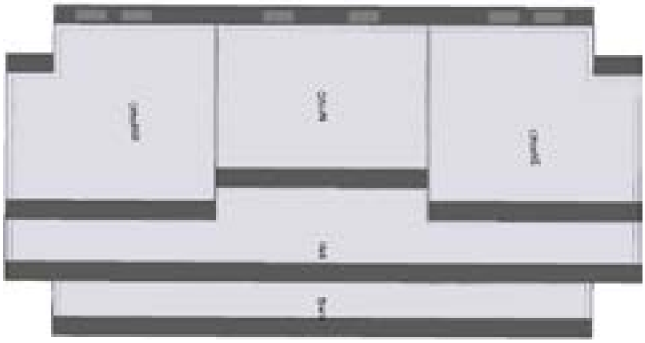


Figure 2. Design Builder rendering of the building and floor plans

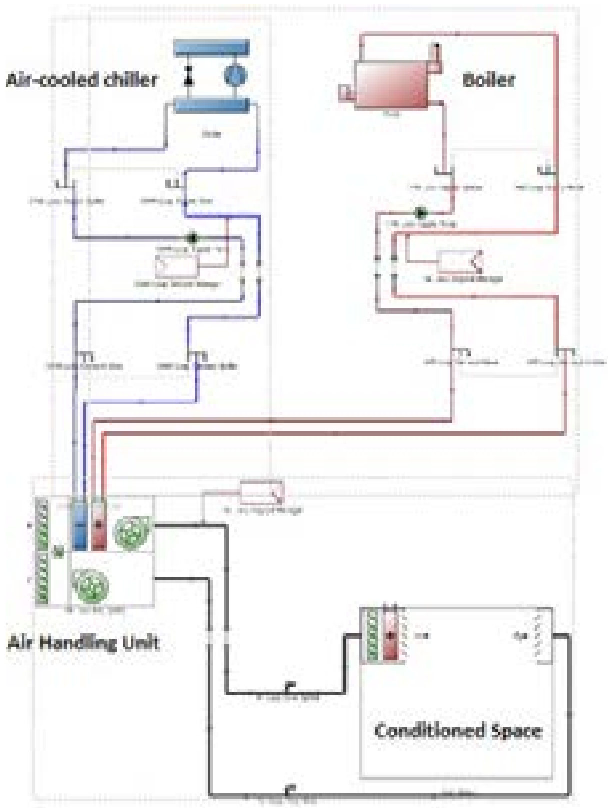
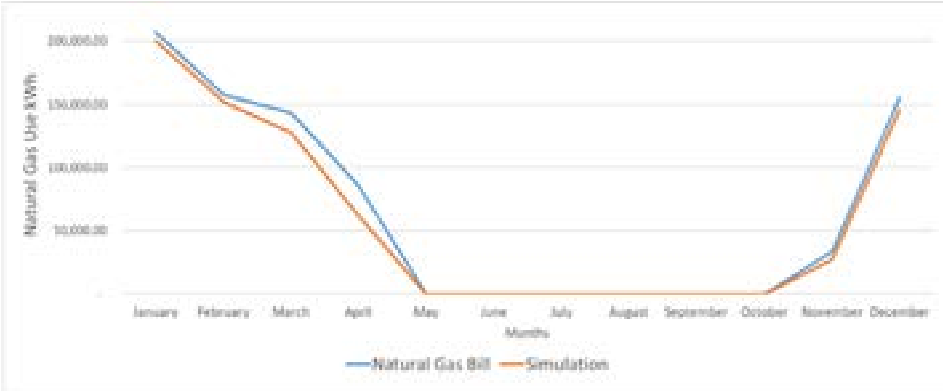


Figure 3. HVAC system schematic view for library building

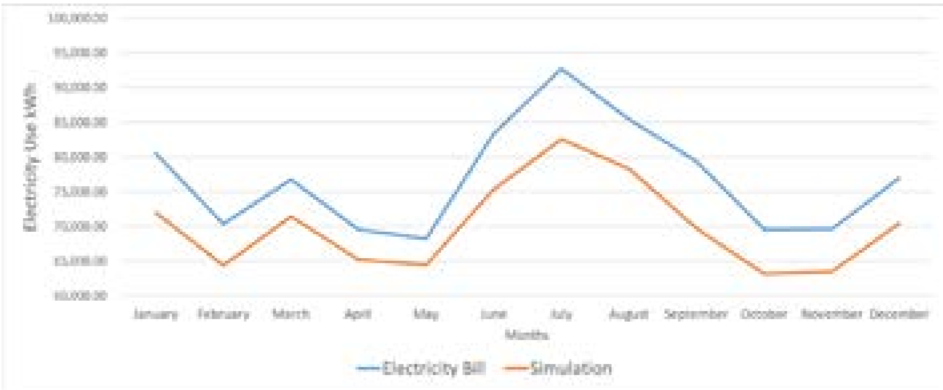
4. RESULTS AND DISCUSSION

The results of the simulation are depicted in Figure 4 and Figure 5. The numbers depict both actual and modeled energy use for natural gas and electricity, respectively. As seen in the images, while the modeled total yearly utility consumption is similar to the actual energy use, there are significant energy use differences in terms of month-to-month utility use. These differences are due to a variety of variables, which are discussed in further detail in the next section.



Actual Annual Natural Gas Use (kWh)	Modeled Annual Natural Gas Use (kWh)
783,097.28	716,022.47

Figure 4. Graph comparing actual natural gas use with that simulated by the model



Actual Annual Electricity Use (kWh)	Modeled Annual Electricity Use (kWh)
922,770.81	840,878.42

Figure 5. Graph comparing actual electricity use with that simulated by the model

The parameters affecting the overall energy use of a building can be categorized as follows:

- The climate (e.g., outdoor air temperature, solar radiation, wind velocity, etc.),
- Characteristics of buildings (e.g., type, area, orientation, construction materials, etc.)
- Building services systems and operation (space cooling/heating, hot water supply, etc.)
- The behavior and activities of building occupants (e.g., time they come and leave the building, whether they turn light off when they leave, etc.)

Among these categories, predicting the behavior and activities of building occupants with sufficient accuracy is the most difficult and challenging of getting accurate data on building occupant behavior. Other studies have also found it difficult to fully characterize the influences of occupants' behavior and activities through simulation, owing to the diversity and complexity of users' behavior in real life [11].

5. CONCLUSION

It is critical that any sustainability initiative aimed at reducing greenhouse emissions includes major efforts to enhance building energy efficiency. There are several ways for improving a building's energy efficiency, and energy models should be used to compare these strategies. For existing buildings, every attempt to find optimal energy efficiency measures should begin with an energy model that depicts how the building currently consumes energy. The article discussed a case study in which an energy model of an existing university building was developed. Energy plus was utilized to assess the building's performance. Although the modeled annual energy use is comparable to the actual energy use, there are greater variances in monthly energy use between the actual and modeled results due to the current difficulties in obtaining data accurately describing building occupants' behavior/activities and building's thermal properties, temperature set points, and internal loads. A new tool that can aid in better predicting occupant behavior and activity through people counters to track the occupancy of each room and area.

REFERENCES

[1] Erten D., Kampüs Sürdürülebilirliğine Bütünleşik Bir Yaklaşım: Piri Reis Üniversitesi, ITU Vakfı Dergisi Eylül 2014, Volume 65 pp.103-104.

[2] American College & University Presidents' Climate Commitment, 2014. http://www.presidentsclimatecommitment.org/about/mission-history, Access date:13.08.2021.

[3] Global Status Report for Buildings and Construction, 2019. https://www.iea.org/reports/tracking-buildings-2020, Access date:18.08.2021.

[4] Europen Commission Energy Performance of Buildings Directive. https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en, Access date:16.08.2021.

[5] EnergyPlus Documentation, EnergyPlus Documentation Engineering Reference, https://energyplus.net/sites/all/modules/custom/nrel_custom/pdfs/pdfs_v9.3.0/EngineeringReference.pdf, Access date:10.08.2021.

[6] Ryan, E. M., & Sanquist, T. F. Validation of building energy modeling tools under idealized and realistic.Energy and Buildings, 2011.

[7] Heo, Y., Choudhary, R., & Augenbroe, G. Calibration of building energy models for retrofit analysis underuncertainty. Energy and Buildings, 2011.

[8] http://www.glumac.com/greenResources/GR_EnergyModeling.html. Access date:23.08.2021.

[9] T Fong, K., Hanby, V., & Chow, T. HVAC system optimization for energy management. Buildings andEnergy, 2005.

[10] Crawley, D.B., L.K. Lawrie, F.C. Winkelmann, W.F. Buhl, Y. Joe Huang, C.O. Pedersen, R.K. Strand, R.J.Liesen, D.E. Fisher, M.J. Witte, and J. Glazer. EnergyPlus: Creating a new-generation building energy simulation program. Energy and Buildings 2001;33(4):319-331.

[11] Yu, Z., Fung, B. C., Haghighat, F., Yoshino, H., & Morofsky, E. A systematic procedure to study theinfluence of occupant behavior on building. Energy and Buildings, 2011.