Validation process of energy performance simulation: A Turkish school building case

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Abstract. Buildings produce one-third of the world's carbon emissions. It is estimated that the energy needs of buildings will increase by 40% until 2040 unless measures are taken. A significant portion of the energy in Turkey is consumed by non-residential construction sectors such as educational buildings. Therefore, efforts to improve the energy performance of educational buildings are essential to minimize the environmental impacts of the building stock. Building's energy simulation provides the possibility of testing various scenarios to define their pros and cons. However, the difference between the simulation results and the actual energy consumption should be minimized in practice. The study aims to monitor energy consumption and validate the simulation results of typical school buildings in Istanbul, Turkey. The approach consists of creating dynamic energy performance simulation models and validating with onsite measurements, energy bills and climatic data of the measurement period. At the first step, the detailed schedule of the occupants and mechanical systems, the building envelope materials, the lighting system, devices information, capacity, and efficiency values of mechanical systems and electrical equipment were obtained and defined in the DesignBuilder software. The U-values of the exterior walls were obtained through in-site measurements. In the next step, interior temperature, relative humidity, and CO2 in the building was measured based on related standards and regulations (ISO 7726 and ASHRAE Guideline 14). As a result, the validated energy model based on a comparison of simulation and measured data can be applied and tested to achieve a high energy performance level in the school building.

Keywords. validation, energy consumption, educational buildings, energy performance, simulation
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1. Introduction

According to IEA's 2021 energy report, Turkey's current energy demand mostly relies on imported gas and oil. For improving energy security and decreasing the high imported energy demand, there are important steps taken by the Turkish government such as National Energy Efficiency Action Plan (NEEAP), which targets to reduce Turkey's energy consumption by %14 in different sectors, including buildings, power and heat, in 2017-2023 [1]. The non-residential buildings account for 41% of the construction sector's energy usage, and the educational facilities have a significant share. It has become crucial to study on school buildings since they are one of the most used public buildings on a daily basis [2]. Therefore, this study focuses on how to improve existing school buildings' energy performances in Turkey. One of the steps to be taken is to determine the correct reference building data by examining the national building stock. Validation is done with the model's intended purpose in mind. For instance, various purposes may need varying degrees of forecast accuracy. Comparing simulated and observed values in model validation necessitates evaluating uncertainty in these data [3]. The current situation of energy performance in educational buildings is examined [4], as well as existing simulation tools for building energy retrofit, gaps, and difficulties in measuring instruments [5].

To achieve national energy efficiency action plans, retrofitting has gained importance. Therefore the simulations' accuracy has become more significant. A study in Ireland aims to close the gap between measured data and energy performance simulation results for the home prototypes, providing new approaches on future building performance measurements, as well as monitoring and updating energy simulation softwares [6]. The study on analyzing the gap between simulation and measurements provides new information about predicting the performance gap using a probabilistic approach by evaluating the correctness and precision of the simulated results compared to the reference values [7].

This study is a preliminary part of a project funded by the Scientific and Technological Research Council of Turkey (TUBITAK) that aims to verify the current buildings' energy performances by conducting an energy simulation of two educational buildings in Istanbul. The study aims to validate the chosen two educational case study buildings' energy simulation with onsite measurements. By validating the energy efficiency simulations, this research may be an important step as a reference study for future studies on the energy efficiency of educational facilities.

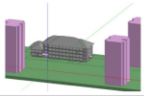
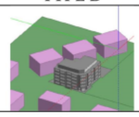
2. Methodology

The methodology consists of four steps. Firstly, two case studies were selected. Secondly, by making onsite observations and field measurements, data for energy performance simulations was collected, such as consumption habits and user-related variables. After that, the buildings were modeled, and the collected data were transferred to the simulation program. Then, the existing bills and measured interior temperatures were compared with simulation results and analyzed. The error rate between the indoor air temperatures obtained from the simulation and the measurement results were calculated by the Root Mean Square Error (RMSE) method [8].

2.1 Case Study Buildings

Existing educational buildings in Istanbul were selected (Table 1). Among the factors that played a role in selecting the buildings, they were chosen because they have typical plan types and materials, can be generalized in terms of user calendars, and allow for detailed analysis of the data collection process. Both buildings have no insulation layers on the exterior walls. The main difference is that Type A building's exterior walls consist of cast concrete, whereas Type B building has brick material in external walls.

Tab.1-Case Study Buildings Properties

Building Properties		TYPE A	TYPE B
Picture of building geometry			
U value of the building envelope (W/m2-K)	External	1.55	1.74
	Roof	0.507	0.537
	Window	2.7	2.8
Heating system		Gas Boiler (Non-condensing) and radiators	Gas Boiler (Condensing)and radiators
Nominal thermal eff (%)		81	85
Cooling system		PTAC air conditioner	PTAC air conditioner
Hot water system		Electric water heater	Electric water heater
Set Point °C	Heating	22	21
	Cooling	24	24
Air change rate (1/h)		0.6	0.7

The obtained data were transferred to the DesignBuilder and EnergyPlus program for performance analysis. The simulations were made using the real climate data of the measurement period. Internal heat gains data, the physical properties, and the materials used were defined. To calculate the energy performance correctly, data such as the number of people and electrical equipment that can generate heat gain inside, the activity schedule, indoor temperatures, and the power of the devices were transferred to the program by making onsite observations and measurements.

3. Data Collection and Field Measurements

The thermal characteristics of external walls greatly impact total building energy performance. Therefore it is crucial to measure the actual U-value of the external walls onsite as the performance of the buildings may change over time. The U-value measurement was held on Feb 15 in both school buildings (Figure 1). The outdoor temperature was relatively cold, and the heating system was active. In order to achieve high accuracy the recommended difference between interior and exterior air temperature is 10 °C [9]. The interior temperature in the selected room in Type A was 20.9°C. It was 21°C in Type B while the outside temperature was 10.8°C. The observed U value for Type A is 1.55 W/m^{2}K and for Type B is 1.74 W/m^{2}K, and both of them are inappropriate for the Istanbul (Region 2) region [10].

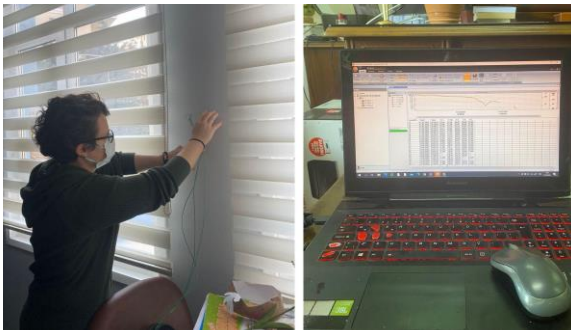


Fig. 1 - Onsite U-Value Measurements of the external wall

Fig. 2 - Placement of Testo 160 Indoor Air Quality (IAQ) Data Logger

To measure indoor temperature, relative humidity, and CO2, DataLogger devices were used (Figure 2). The selection of the device's location is based on several parameters, such as the room should be in the middle floors and the device should be placed on an internal wall. The inner walls of the selected rooms were examined with a thermal camera, and the inner wall that did not receive direct sunlight was selected. Façade photographs were taken with a thermal camera to detect the leaks and thermal bridges that may occur in the systems carrying steam, hot water, and hot air (Figure 3).

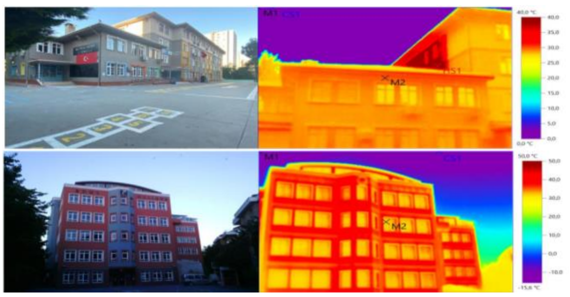


Fig. 3 - Thermal Exterior Photos of the Buildings (Building Type A on up and Building Type B presented below)

4. Modeling and Simulation

The energy efficiency of two school buildings is investigated by using DesignBuilder and EnergyPlus for the simulations (Figure 4). EnergyPlus is used to run several annual and monthly simulations, and the monthly gas and electricity consumption rates from the ESO file are noted as results for calibration.

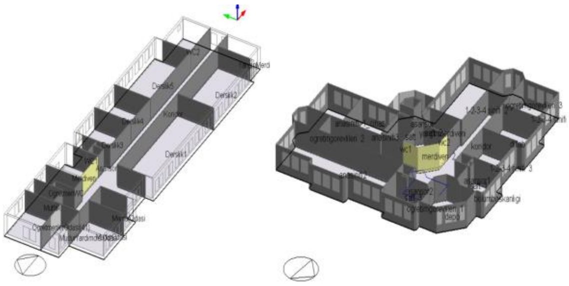


Fig. 4 - Building Modelings in DesignBuilder (Building Type A on the left and Building Type B presented on the right)

4.1 Climate data

The buildings are located in Istanbul, in which summers are hot and dry, and winters are rainy and warm. Weather information was requested from the General Directorate of Meteorology (MGM) and the files were arranged using the Elements software program to generate EPW files for EnergyPlus.

4.2. Building zoning and construction input

Building geometry was modeled with architectural plans obtained from the school administration. The real-life application can be different; hence field observations and measurements were conducted in both schools, and several alterations were observed. After revising the plans and elevations, zoning was made according to several parameters such as function, user schedule, and mechanical system. Rooms with the same parameters and adjacent to each other were combined into one zone. Construction details are obtained from field measurements and detailed sections. A measured U-value was used to determine the materials of the external wall. Material properties for other construction elements such as slab, roof and internal walls are obtained from TS 825 [10]. The label information was used for the glazing system, and the performance details were calculated for the Tvis, SHGC and U-value of the windows.

4.3 Internal heat gains and losses

The main parameters that are critical for the validation process are variables that cause heat gains, and losses are explained below in detail.

Occupancy input: The maximum number of people using a zone is determined from occupancy activity information obtained from observations and defined in DesignBuilder. The occupancy schedule is determined by the education period and holidays in 2019 and lecture-break hours. The school year of 2019 started on 09.09.2018 and ended on 14.06.2019. The semester holiday was between Jan 27 and Feb 4. The mid-holiday was between 18 November-22 November [11]. The lecture-break hours in Type A are 09:00-16:20 from Monday to Thursday and 09:00-14:40 for Friday.

For Type B, it is 09:40-16:00 for weekdays. The fraction for student occupancy in a classroom zone during the lecture hours is assumed as 1, whereas it is 0.1 for break-time as the majority of the students leave the classroom on break. For occupancy in circulation areas such as corridors, the fraction during lesson hours is entered 0 and 0.25 in the break times.

Lighting input: Each armature in a zone was counted and the power (Watts) was determined by observations. The values were defined by Watt/h in DesignBuilder. It is assumed that the lighting is on during school hours if the illuminance is under 400 lux in rooms [12]. For circulation areas such as corridors and stairs, lighting is always on during school hours, while for toilets and kitchen, it is on only during the usage hours.

Electrical equipment input: Electrical equipment such as split air conditioners, interactive whiteboards, computers, kitchen utensils etc., affect internal gains. These were counted and label information was observed on the site to obtain power values (Watts). The usage schedule was made according to the fraction method. For instance computers are being used for 2 hours a day on average in an office during school hours in Type B, hence the fraction is 0.3.

Natural ventilation: Natural ventilation depends on the window opening/closing habits of the occupants. According to ASHRAE Standard 62-1 [13], there is no fixed value for air changes per hour (ACH); however, it is recommended that ACH can be accepted in a range between 5-6 for school buildings. Based on this standard, several simulations were conducted with different ACH values within this range for both school buildings to observe the difference between consumption rates and interior temperature values.

Air infiltration: Air infiltration depends on the quality of construction and maintenance of the buildings and it is one of the main reasons for heat losses and affects energy performance. Values in an appropriate range that is recommended in the CIBSE standard [14] were defined in several simulations in order to reduce the differences between simulation results and energy bills. For Type A the infiltration rate of 0.6 1/hr is found to be suitable and for Type B it is 0.7 1/hr.

4.4 Mechanical System

The mechanical system information was obtained during the field observations. Type A school has a heating system working with a single natural gas-fired non-condensing boiler with radiators. There are split air conditioners for cooling in several zones, such as the principal's room and some of the classrooms that are located in the southern part of the building. There is a natural ventilation system in the building; the below-grade storey has windows that are opened by areaway. In Type B school, the heating system consists of a condensing boiler with radiators. There is a natural ventilation system, and in below-grade storeys with no windows, the fresh air is supplied by outlets located on the ceiling. The cooling system is dependent on the split air conditioners in several rooms. There is a theater hall that has a duct-type split air conditioner and a dining hall on the top floor which has a fan coil unit.

Boiler efficiency: Boiler efficiency can vary according to type, usage, maintenance, flue gas performance, fuel type and boiler insulation. In both cases boilers have been used for over 20 years and annual maintenance is not done regularly. Therefore, different boiler efficiency rates corresponding to these data were defined in simulations within the recommended value range which are 80-85% for non-condensing boilers and 85-90% for condensing boilers [15], and the value that reduces the difference between energy bills and simulation results was determined as 0.81 for Type A and 0.85 for Type B.

Heating and cooling setpoint temperature: There is no thermostat system that measures the indoor temperature in both buildings. The thermostat system located only outdoors measures the external air temperature. When the outdoor temperature is below 15 C°, the boiler starts to operate. Based on the literature and standards, the range for heating setpoint temperature is 20-23 C° and for cooling setpoint temperature is 24-28 C° for students' thermal comfort [16]. For defining accurate setpoint temperatures, values within this range were defined in various simulations and the results were compared with energy bills and measured internal temperatures. The heating setpoint is defined as 22 C° for Type A and 21 C° for Type B. The cooling setpoint is 24 C° in both school buildings.

5. Validation of the simulation

5.1 Validation with electricity and gas bills

In order to validate the actual energy consumption, the electricity and natural gas bills are compared with the simulation results. Because of the Covid-19, occupant behavior and schedule have changed due to the distance education and lockdowns. These variations inevitably lead to limitations in the comparison of actual energy consumption and simulation results. Therefore, this consumption data represents 2019 in which there was no pandemic. Simulations are conducted for both a whole year and monthly basis using weather data from 2019. The annual total and monthly electrical and gas consumptions and simulation results are presented in Table 2.

Firstly, annual simulations are performed and the total amount of consumption for a year is compared with the bills. As the case study buildings are schools, there are no students but a few administrators and teachers are present during the summer holiday months (Jun, Jul, Aug). Also, the heating system is not active between March and November. The gas

Tab. 2 - Actual electricity and gas consumptions and simulation values for Type A(left) and Type B(right)

Month	Type A-2019		Simulation			Err. (%)
			Annual		Monthly	
	Ele. (kWh)	Gas (kWh)	Ele. (kWh)	Gas (kWh)	Gas (kWh)	Monthly Gas
Jan	9,946.76	36,599.42	7,586.32	32,480.62	36,124.85	1.2
Feb	9,370.40	39,463.79	9,938.09	43,924.05	40,419.01	2.4
Mar	8,750.80	34,069.61	11,420.28	40,281.03	34,692.23	1.8
Apr	7,412.52	11,867.08	7,505.43	16,986.53	11,367.29	4.2
May	3,130.88	329.04	3,405.95	329.04		
Jun	2,287.20	6,775.00	2,485	6,775.00		
Jul	2,473.52	6,775.00	302	6,775.00		
Aug	7,383.84	242.16	225.02	242.16		
Sept	8,179.64	614.48	2,402	614.48		
Oct	6,591.12	704.88	3,457	704.88		
Nov	10,011	25,304.13	14,881.52	50,057.67	24,193.74	4.3
Dec	8,963.68	37,176.21	12,102.61	34,059.27	38,442.67	3.4
Total	84,501.36	186,384	75,711.17	186,339.21		
Annual Err (%)			10.40	0.02		

Month	Type B-2019		Simulation			Err. (%)
			Annual		Monthly	
	Ele. (kWh)	Gas (kWh)	Ele. (kWh)	Gas (kWh)	Gas (kWh)	Monthly Gas
Jan	15,754.92	57,755.07	11,955.98	53,436.46	57.599.90	0.27
Feb	16,006.86	52,550.42	11,816.91	56,753.94	54.983.50	4.62
Mar	16,613.82	47,081.76	13,217.46	47,459.00	47.938.78	1.82
Apr	15,651.36	37,394.40	13,121.02	32,921.87	39.049.96	4.42
May	14,676.60	11,625.95	13,611.71	11,625.95		
Jun	9,457.68	2,595.81	10,854.94	2,595.81		
Jul	6,878.28	2,320.06	9,019.58	2,320.06		
Aug	7,972.62	2,320.06	8,977.82	2,320.06		
Sept	7,383.84	269.28	11,687.39	269.28		
Oct	13,502.58	4,154.96	13,631.15	4,154.96		
Nov	12,561.36	5,193.02	12,591.11	10,126.98		
Dec	17,922.42	40,075.06	13,570.13	47,233.37	38.842.16	3.07
Total	154,382.34	263,335.85	144,055.20	271,217.74		
Annual Err (%)			6.68	2.99		

consumption available in the bills for May, June, July, August, September, and October represents mainly the consumption of kitchen appliances. To find the gas usage of the kitchen, the gas bill of October is used in which the heating system is closed, but the kitchen is active. Accordingly, it is ~700 kWh in Type A, and ~4000 kWh in Type B. These consumption rates are added to the corresponding months of simulation results. For Type A, the annual error rate for electricity is %10.04 and for natural gas is %0.02. For Type B, the annual error rate for electricity is %6.68 and for natural gas is %2.99. According to the ASHRAE Guideline 14 [18], these error values are in an acceptable range. Secondly, the monthly simulations are conducted and results are obtained and validated only for natural gas consumption. Monthly inspection of electricity consumption is an ongoing study. For monthly validation of natural gas consumption, simulation results are available only for the time and months that the heating system is active; therefore, the error rates are presented for January, February, March, November, and December. However, in Type B, the date of the gas bill of November does not contain the time interval in which the heating system is active and it has not been included in monthly gas validation. All monthly gas error rates are in an acceptable range that is %5 for both schools [18].

5.2 Validation with indoor temperature

The indoor air temperature was measured in hourly intervals from Apr 29 2021 until Jan 9 2021. Due to the lockdowns and distance education there were no occupants, and mechanical systems were not active. It inevitably caused several limitations such as the effect of user behavior and internal gains cannot be obtained correctly. However, measuring indoor air temperature while lockdown has several benefits such as it is possible to validate the thermophysical and geometrical properties of the model more accurately without human-based parameters, which highly affects the error rates in simulation. Hence internal air temperature measurement results from lockdown dates (Apr 29- May 17 2021) [17] are selected to compare with the simulation (Figure 6). Firstly, simulation input data was revised by changing schedules for people, lighting, electrical equipment, mechanical systems, and natural ventilation to be off 24/7. The simulation run period was arranged for April 29th to May 17th. The weather data obtained from MGM is applied. Fig. 5 presents the differences between measurement and simulation. The simulation's max, min and average temperatures are 26.7, 18.44, 21.39 C° and in observed data are 22.5, 18.9, 20.6 C° for Type A. For Type B the max, min, and average temperatures in the simulation are 25.11, 18.34, 21.72 C° and in observed data are 24.2, 20, 21.73 C°. Considering the measurement tools have ±0.5°C error rate, the differences between the measured and the simulated temperature show that there is no significant error.

$$\text{RMSE}(\hat{O}) = \sqrt{MSE(\hat{O})} = \sqrt{E((\hat{O} - O)^2)}$$

(1) Root mean square error (RMSE) equation Obtained from Sedki et al. [18]

The Root Means Square Error (RMSE) (1) was used for an hourly basis to calculate the error between the simulation and measured values [8]. The error rate for Type A is 1.53 and for Type B is 0.6. According to Maamari et al. [19] the difference between the actual and predicted values should be between 10-20%. As results show, the error rates obtained in Type A and B schools are satisfactory. In addition to the measurement during the pandemic period and without internal gains, another measurement was held on November 25th 2021. During this time, the school was open and the training was face to face. Internal gains, human factors, and climate data inputs were revised in the simulation. The measured internal air temperature is 24.1 C°, and it is 24.5 C° in the simulation for Type A (Figure 5). For Type B measured internal air temperature is 21.9 C° and 21 C° in simulation, which shows no significant error**.**

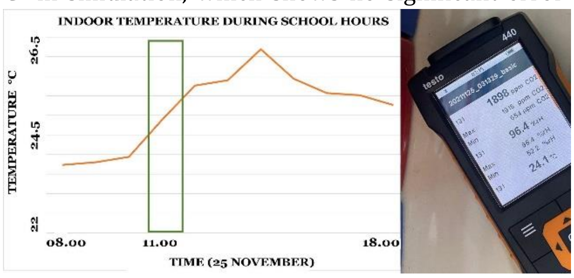


Fig. 5 -Example of indoor temperature measurement on November 25th 2021, Type A Building.

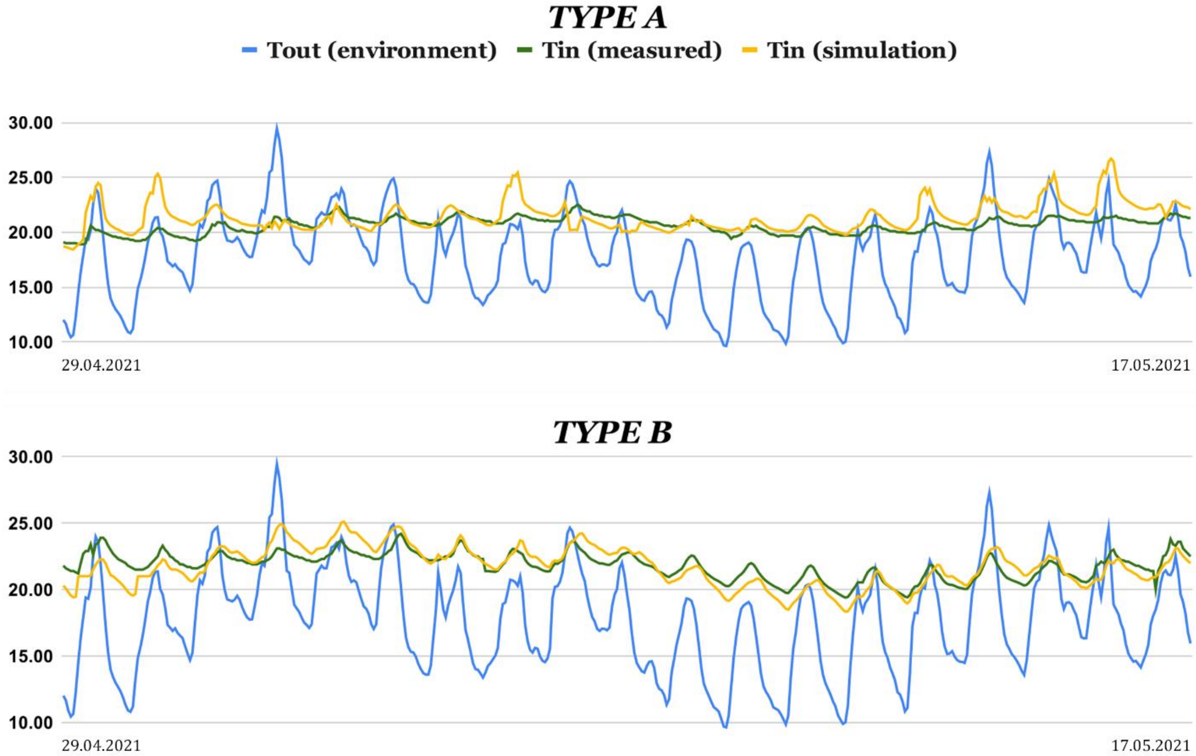


Fig. 6 - Measured and simulated indoor air temperature comparison

6. Discussion

Minimizing the challenges encountered while validating the model and calculating the energy performance of buildings as close to reality is critical for the transition to the next phase of the project that proposes retrofit strategies to reduce the energy consumption of the school buildings. The most significant parameters that risk the validation of energy simulation models are discussed below.

-*Climatic and environmental data:* Weather data directly affects the energy needed to provide the appropriate indoor temperatures for the users' comfort in the simulations. Although the climatic data were obtained through meteorology, missing data emerged in several days and hours. This challenge was resolved by taking the average values of the former and latter that day and hour. Still, some parameters such as radiation gain could not be obtained. Problems with these parameters can cause errors in simulations.

-*Building thermophysical properties:* Envelope properties such as air infiltration is one of the critical parameters that affect natural gas consumption. Different infiltration rates within a recommended range were defined in simulation to analyze their effects on the gap between actual gas consumption and simulation outcome. It is possible to state that 0.1 change in air infiltration rate affects the gas consumption by 4-6%.

User behavior: The human factor affects the heat gain or loss in buildings such as opening windows for fresh air and occasionally turning on lights during the day. This should be observed and precisely defined into the software. In this study, onsite observations and surveys were made and parameters suitable for user behaviors were transferred to the software. For instance, more Air Changes per Hour (ACH) are expected to provide thermal comfort in the summer months. In the EnergyPlus simulation, higher values are defined compared to the winter months. However, it is not possible to determine an exact value for ACH rate for each month. Therefore, different ACH values from the range of 5-6 [20] were defined in software and the results were compared with the natural gas bills. Findings showed that 0.1 difference of ACH values affects natural gas consumption by 09% to 1.3%.

-*Mechanical System:* Boiler efficiency and heating setpoint temperature variables are the most critical parameters that affect the simulation results of natural gas consumption and internal air temperature. According to the simulation results, ±0.10 change in boiler efficiency can cause a 12-14% difference in gas consumption. Additionally, the lack of a thermostat system in both buildings has caused limitations in terms of defining proper heating setpoint temperature, which can significantly impact simulation results. Also this situation inevitably increases gas consumption. For instance, according to the different simulation results with different heating setpoint temperatures, ±1 change in heating setpoint temperature affects the natural gas consumption by 12-15%.

-*Internal air temperature:* Measuring internal air temperature and comparing the data with simulation outcome is one of the methods that was used in the study. Internal temperature is dependent on air infiltration, window opening, internal gains, mechanical systems and window to wall ratio. Based on these there are differences between Type A and Type B schools. When the internal temperatures measured during the quarantine period during April and May are compared, the internal temperatures in Type A are lower than Type B because of the fact that the window to wall ratio is higher in Type B school. Therefore, it has caused the interior spaces to become warmer. In addition, when the measurement results from November, in which the education was face-to-face, were compared, the internal temperature of Type A was greater than Type B because internal heat gain due to the occupants and equipment is high. Additionally, measured internal air temperature during the heating period is greater than the heating setpoint temperature of the system because of the high internal gains in school buildings.

-Pandemic Situation: During the pandemic, internal temperature measurements were made while switching to online education in schools. Although this has negative effects on the operation of the project, problems arising from user behavior have been eliminated by measuring when there is no user during the quarantine. It also allowed for building envelope analysis without internal gains or losses. On the other hand, more ventilation was needed to ensure fresh air flow during the training period and the user capacities of some places were different from the normal situation. It may cause some limitations between the simulation and the observed values.

7. Conclusion

In this study, simulation is the first step taken to improve buildings' energy performance, including the validation of the observed results. Necessary details for simulation were obtained by making onsite observations at two school buildings in Istanbul and analyzed using Designbuilder and EnergyPlus programs. The most important step in data collection is to gather information from schools' users. Therefore, authors had meetings with the school administration to learn user habits. Another significant matter is mechanical system information obtained from on-site visits, standards, and consultants. The simulation results were compared with the devices placed in schools that measure the indoor air quality in terms of temperature, humidity, and CO_2. Because of the Covid-19, there is a lockdown during the measurement time interval. Therefore these measurements were used to validate only the geometrical and thermophysical properties of case buildings by comparing simulation and measured internal air temperature. These outcomes present necessary information of the material properties as well as infiltration rates. The internal air temperature error rate between simulated and measured data was calculated by the REMS method and verified. To validate energy consumption, electricity and natural gas bills obtained from schools and simulation outcomes were compared in terms of natural gas consumption and confirmed monthly with ASHRAE standards [13]. Additionally, internal temperatures were observed on November 25th in schools to observe indoor temperature while the heating system is active and education was face-to-face.

Energy efficiency in buildings is becoming a more significant and critical concept day by day. The initial step of energy optimization involves validating the simulations with the actual building. Additionally, there are pandemic-related limitations in the study that cause alterations in methodology. However, studies on this subject are very limited. It is expected that this study will fill the existing gap and serve as a guide for similar studies. In addition, this work is an ongoing project and the future study is the development of energy-efficient strategies for these buildings whose next phase is validated.

8. Acknowledgement

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9. References

[1]Turkey 2021. IEA. [cited 2022 Feb 17].Doi:https://www.iea.org/reports/turkey-2021

[2]Aksin FN, Arslan Selçuk S. Energy performance optimization of school buildings in different climates of Turkey. Future Cities and Environment. 2021;7(1). Doi: 10.5334/fce.107

[3]Ohlsson KEA, Olofsson T. Benchmarking the practice of validation and uncertainty analysis of building energy models. Vol. 142, Renewable and Sustainable Energy Reviews. Elsevier BV; 2021. p. 110842. Doi:10.1016/j.rser.2021.110842

[4]Loreti L, Valdiserri P, Garai M. Dynamic Simulation on Energy Performance of a School. Vol. 101, Energy Procedia. Elsevier BV; 2016. p. 1026–33. Doi: 10.1016/j.egypro.2016.11.130

[5]Hu M. Existing Energy Performance and The Potential of Role of Simulation in School Building Design – A Review. Building Simulation Conference proceedings. IBPSA; Doi:10.26868/25222708.2019.210336

[6]Beagon P, Boland F, Saffari M. Closing the gap between simulation and measured energy use in home archetypes . Vol. 224, Energy and Buildings. Elsevier BV; 2020. p. 110244.Doi:http://dx.doi.org/10.1016/j.enbuild .2020.110244

[7] Ekström T, Burke S, Wiktorsson M, Hassanie S, Harderup L-E, Arfvidsson J. Evaluating the impact of data quality on the accuracy of the predicted energy performance for a fixed building design using probabilistic energy performance simulations and uncertainty analysis. Vol. 249, Energy and Buildings. Elsevier BV; 2021. p. 111205. Doi: http://dx.doi.org/10.1016/j.enbuild.2021.111205

[8] Hyndman RJ, Koehler AB. Another look at measures of forecast accuracy. Vol. 22, International Journal of Forecasting. Elsevier BV; 2006. p. 679–88. Doi:http://dx.doi.org/10.1016/j.ijforecast.2006.03.001

[9] Giebeler, M. Testo Ltd. U-value measurement on a wall of unknown materials with the testo 635.. BAU-EXPERT Engineering Consultants; 2014.Doi:https://www.testo.com/en-US/products/products

[10] Turkish Standardization Institute (2013) TS825, Thermal insulation requirements for buildings, Ankara.

[11] Turkish Republic the Ministry of Education. 2018-2019 Academic Year Calender; 2018 Jun.

[12] Chel A. Performance of skylight illuminance inside a dome shaped adobe house under composite climate at New Delhi (India): A typical zero energy passive house. Alexandria Engineering Journal. 2014 June 1st;53(2):385-97.

[13] ASHRAE Guideline 14 Measurement of Energy, Demand, and Water Savings, ASHRAE inc, 2014

[14] Chartered Institution of Building Services Engineers. Guide A - Environmental Design. 2015, London.

[15] Turkey. Ministry of Science, Industry and Technology. Regulation on amending the regulation (92/42/EC) on the efficiency requirements of new liquid and gas fueled hot water boilers 2018 (Act No. 1 of 12). Official Gazette of the Republic of Turkey. No: 30374

[16] European Standards. BS EN 16798-1:2019 Energy performance of buildings. Ventilation for buildings Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

[17] Ministry of Interior. Partial Closing Circular to 81 Provincial Governorships. Turkey: Ministry of Interior; 2021. Available from:https://www.icisleri.gov.tr/81-il-valiligine-kismi-kapanma-genelgesi-gonderildi

[18] Sedki A, Hamza N, Zaffagnini T. Field Measurements to Validate Simulated Indoor Air Temperature Predictions: A case study of a residential building in a hot arid climate. Building Simulation Cairo Conference: Towards Sustainable & Green Built Environment. Cairo: EEER - IBPSAEgypt; 2013 [cited 9 January 2022]. p. 338-347.

[19] Maamari F, Andersen M, de Boer J, Carroll WL, Dumortier D, Greenup P. Experimental validation of simulation methods for bi-directional transmission properties at the daylighting performance level. Vol. 38, Energy and Buildings. Elsevier BV; 2006. p. 878–89.Doi:http://dx.doi.org/10.1016/J.ENBUILD.2006.03.00

[20] ASHRAE Standard 62-1 Ventilation for Acceptable Indoor Air Quality, ASHRAE inc, 2019