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A study on the energy-saving potential of university campuses in Turkey

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Due to the large number of buildings, energy consumption in the university campuses of Turkey may tend to increase over time. In this context, their potential energy savings need to be explored. Therefore, the aim of this paper is to investigate energy savings in university campuses by applying different energy-efficient measures with simulation-based analysis. To do that, four buildings from the Balıkesir University campus were the focus of the present study. The energy billing data were used to calibrate and adjust the simulation models produced from the DesignBuilder software. The results showed that an energy reduction of over 60% in the examined buildings is possible with proper energy-efficient solutions, which is considered very effective. This means that the findings demonstrate a high potential for campus building retrofitting with passive, active and combined strategies. The energy-saving potentials calculated for each building can guide university authorities to determine feasible energy-saving techniques for buildings with large energy conservation potential and forecast future retrofitting planning development in campuses.

Notation

M_p	average of actual energy consumption
m_i	actual energy consumption
n	number of data
s_i	simulated energy consumption
U	overall heat transfer coefficient $(\text{W/m}^2)/\text{K}$

1. Introduction

According to the Intergovernmental Panel on Climate Change, buildings in the world were responsible for 32% of the total global energy use and 19% of greenhouse gas emissions in 2010 (Edenhofer *et al*., 2014). In modern societies, buildings greatly contribute to energy demand and they account for about 45% of the primary energy consumption in some countries (Gruber *et al*., 2017). For example, in Turkey, 34% of the total energy consumption was realised in the housing and service sector, 32% in the industrial sector and 28% in the transportation sector in 2014 (MENR, 2016).

Buildings may need different amounts of energy depending on their function and user behaviour (Robinson *et al*., 2016). For instance, educational buildings consume high energy for heating and electricity, and therefore, energy-saving measures need to be taken (Irulegi *et al*., 2017). On average, 13% of the total energy in the USA, 4% in Spain and 10% in the UK are consumed by schools (Pérez-Lombard *et al*., 2008). Therefore, energy savings and indoor environment quality are some of the key issues regarding educational buildings (Aisheh *et al*., 2010). Within this category, university campuses are special cases with their large student populations, activities and high number of diverse buildings, and can be considered small-scale models of cities where a high level of training and research opportunities are provided (Bonnet *et al*., 2002). Due to their scales and development potentials, they have significant socio-economic impact on cities. They also need more attention due to their private character compared with other buildings, and provide an opportunity to save energy (Allab *et al*., 2017). University campuses are complex and dynamic environments that serve a variety of needs to many people at the same time. For these reasons, they are among the important energy users in the building sector, and they have a continuous energy need with their 24 h libraries, hospitals and cafes (Luo *et al*., 2017). Some of the important and big universities in the world have realised their own negative effects on the environment and created awareness of excessive energy consumption and of energy efficiency by taking several measures to minimise this impact (Hong *et al*., 2011).

There has been a significant increase in the number of universities in Turkey. While there were only 27 in 1982, today, the total number of universities is 207 (Heims, 2020). When considering buildings in all universities, their energy consumption may correspond to a significant part of the country's total energy consumption in buildings, and at the same time, it can lead to an increase in its share in the public budget. In this context, it is possible that a significant amount of energy can be saved both with construction of new energy-efficient university buildings and by improving existing ones. This is particularly valid for university campuses consisting of buildings that have not been designed to today's energy performance standards and have never been refurbished (Robinson *et al*., 2015). For that reason, university campuses are suitable places to explore energy-saving potential and energy-reduction strategies. According to the preceding discussion, it can be concluded that energy saving and management in university campuses has become an issue (Robinson *et al*., 2015) and will be more significant in the future.

In the literature, a number of studies have been conducted in the field of investigation of energy efficiency and performance of university buildings. A simulation-based calculation in most of the studies was used for assessment of energy-efficient retrofit strategies and for better understanding energy-saving potential, which may vary significantly from building to building (Nagpal and Reinhart, 2018). Ge *et al*. (2018) investigated energy-efficiency-optimisation strategies in terms of building envelope thermal performance, sun shading and adaptive space heating and cooling behaviour in a university research building located in Hangzhou, China, by simulation. The findings provide technical support for energy-saving retrofitting of campus buildings in this region. Maistry and Annegarn (2016) defined energy-reduction opportunities by using energy consumption profiles in universities. The results showed that 9% electricity reduction could be possible by switching off a 350 kW chiller plant on weekdays during out-of-session and recess periods. Similarly, during in-session periods, 6% reduction could be possible.

Some of the recent papers focused on methodological approaches to retrofitting of campus buildings. For example, a framework was shown to help constitute a prioritisation plan by identifying which areas for improvement will be examined in more detail in which buildings (Nagpal and Reinhart, 2018). The proposed framework enables real-time evaluation of specific energy-efficient measures in each building in a campus within reasonable uncertainty limits. Another study by Nagpal *et al*. (2019) developed a continuous energy performance planning and tracking system for a university campus that renders possible exploration of potential upgrade scenarios and allows for the documentation of energy retrofits to individual buildings. Guan *et al*. (2016) proposed a method for examining the characteristics of energy and water usage trends in Norwegian university campus buildings. The long-term and real-time data on the electricity, heating and water usage of the campus were examined by using descriptive statistics. The results showed that energy and water usage in all buildings mainly varied between 50 and 100 (kWh/m^2)/year for heating, 100 and 150 (kWh/m^2)/year for electricity and 0 and 0.5 (m^3/m^2)/year for fresh water. They could be used for the energy planning of small cities and other urban energy systems. Irulegi *et al*. (2017) suggested a different method for defining and assessing strategies for achieving nearly zero-energy university buildings based on student comfort analysis under real conditions. A questionnaire and monitoring campaign were applied in a typical spring week in the Architecture Faculty in San Sebastian (Spain). The findings showed a potential energy saving of up to 62% in the heating period for the Faculty of Architecture. Another method for analysing whole-of-building retrofit measures was defined and tested on two case studies (from Italian universities) with students of the Integrated Design Refurbishment Laboratory of Building Engineering Faculty (Sesana *et al*., 2016). The study indicated that it is crucial to select a simulation tool for energy assessment in terms of the particular job and the output that one wants to reach with the tool in the beginning of the refurbishment design process. Building information modelling technology was used as a method for analysing options, including different building envelope designs, to reduce energy use intensity and energy-related costs in a faculty building at National Taiwan University (Guo and Wei, 2016). Soares *et al*. (2015) and Maistry and Annegarn (2016) likewise showed the concern of many countries and universities with actions to reduce energy consumption through technological innovations and user awareness. Some new studies (Chen *et al*., 2017) have developed web-based platforms and models that enable quick building and running of urban energy models that analyse the energy demand of individual buildings and evaluate alternative scenarios. These models make it easy to create a large number of individual building models by automatically obtaining information from existing data sets across the city (Coccolo *et al*., 2015). Nagpal and Reinhart (2018) stated that university administrators need a building-based prioritisation plan for campuses with a high degree of certainty in the expected energy or carbon dioxide emission reductions in return for their investments.

The efficiency of active systems can affect the amount of energy demand in buildings because the intensive use of air-conditioning units contributes significantly to energy consumption (Costa *et al*., 2019). A few studies have analysed the energy performance of active energy-saving technologies on existing university buildings, and some of them assessed energy-efficient options from the economic point of view. The most gainful active energy-refurbishment strategies found were installation of an air-source heat pump for space heating and of a full-roof photovoltaic (PV) system for a university building in Sannio, Italy (Ascione *et al*., 2017). In a previous study, 12 air-handling units (AHUs) in five diverse university buildings were investigated to evaluate the energy savings of three measures: reducing the static pressure of AHUs, scheduling AHUs off overnight and defining and fixing economiser controls. As a result, energy-saving rates between 17 and 35% were found (Bellia *et al*., 2018). The cost-optimal approach was also used by Shea *et al*. (2019) to compare retrofit options related to the building envelope and plant systems. The proposed scenario led to an energy saving of 41% and a reduction in the global cost of around 36%. Niemelä *et al*. (2016) focused on cost-effective solutions such as renovation of the original ventilation system, a ground-source heat pump system, new energy-efficient windows and a relatively large area of PV panels for typical educational buildings in the Lappeenranta University of Technology, Finland. Ferrari and Beccali (2017) investigated the impact of some measures, including several hypothetical improvements regarding the building envelope and plants, for an existing office building in the campus of the Politecnico di Milano University (Italy). The results showed that the primary energy demand and associated emissions could be reduced up to 40% from the current values by adopting market-available and well-proven technological solutions for retrofit. Despite an increase in the total floor area, three main university campuses at Osaka University, Japan, decreased 22% of their total energy consumption over a period by using several strategies such as double-glazing glass, improvement of the thermal insulation, light-emitting diode (LED) lighting, heat pump water heaters and high-efficiency heat source systems (Yoshida *et al*., 2017).

Analyses of passive heating and cooling techniques that serve campus buildings are another area of research interest. These kinds of measures, as well as active systems, are used to obtain desirable indoor thermal comfort conditions (Mytafides *et al*., 2017). Jing *et al*. (2019) stated that the thermal environment in university classrooms affects students' thermal comfort and energy consumption. They found that if the indoor temperature could be reduced from 21.85 to 19°C, 3.46% of the annual heating energy load could be saved. Findings from the study by Yang *et al*. (2017) showed that anthropogenic heat was reduced from 150 to 128 W/m^2 with the best energy-efficient retrofit measures (four passive solutions, four active solutions and two combined solutions) in campus buildings. Ostojić *et al*. (2016) analysed the envelope structures and elements of 23 faculty buildings at Zagreb University, Croatia, and architectural measures were evaluated to increase the energy efficiency of the buildings. An operating strategy may be accepted as a kind of passive strategy for reducing energy consumption. In previous studies, much research has been done to find a reasonable operating strategy for building energy equipment in order to meet the building energy demand in general and increase the efficiency of the system (Ding *et al*., 2019). Allab *et al*. (2017) presented an audit protocol covering simultaneously energy efficiency and indoor climate quality issues in a French university campus. The results confirmed that a successful energy management or operating strategy can increase comfort and decrease the energy consumption at the same time. Kolokotsa *et al*. (2016) assessed the energy savings potential of two faculty buildings at the Technical University of Crete by using a web-based energy-management system. It was found that a 20% energy-saving margin was possible. Such studies evaluated active and passive solutions together. Mancini *et al*. (2017) conducted a study on the energy refurbishment of the Orthopaedic and Traumatological Clinic Institute historical building located in the Città Universitaria campus of Sapienza University of Rome. The results focused on measures such as improvement of the building envelope for sustainable energy retrofitting of the historical building by preserving its architectural values.

It can be concluded that although most studies analyse, predict and quantify the energy consumption of individual university buildings and explore energy-reduction opportunities, the number of specific studies carried out to understand the general state of the energy performance of university campuses is still low. Furthermore, the literature about case studies evaluating energy-efficient retrofit in university campuses is still insufficient in Turkey. However, exploration of the energy-saving potential of university campuses other than individual education or research buildings is an important prerequisite to learning how to increase energy efficiency and how to plan good energy management for campus complexes (Evangelinos *et al*., 2009; Guan *et al*., 2016). Furthermore, the impact of energy-retrofit options can vary from building to building based on specific factors such as location, size, operation, building envelope and heating, ventilation and air-conditioning (HVAC) system properties (Cho *et al*., 2019). For individual buildings, what energy-efficient action is to be applied is important. For university campuses, no matter what type of retrofitting intervention is projected, the most critical factor to be considered is starting from which building. Thus, this study contributes to the literature by showing a strategic planning framework for campus-scale energy-saving potential. The first significant advantage of this approach is extending the current understanding of energy-saving retrofitting and which measure should be applied to which building in university campuses. This can also be considered in methods for the retrofitting process. The second advantage is that the paper shows a comparative analysis of three different and complementary strategies for reducing the energy demand of university campuses. The first option is to improve the building envelope (i.e. use of insulation and glazing) and the second one is to increase the efficiency of active systems (i.e. installation of highly energy-efficient lighting equipment and fan motors). The third one is the combination of the first two options. The last advantage of this approach is that the selected buildings used for the analysis are current buildings located in Balıkesir University (northern Turkey), which is representative of the existing university campus stock of the 1990s and 2000s. Therefore, the obtained results can be regarded as very helpful in evaluating the actual potential of energy-efficient measures. These are the main motivating factors that guided the originality and novelty of this work in this field. Against this background, this paper discusses the critical issue of energy-saving potential of a particular university campus in Turkey through a holistic retrofit approach by applying several energy-efficient measures. The results could be helpful for local authorities in determining policies and interventions for energy reductions in universities located in similar climatic conditions and showing the ways to move towards low-energy university campuses.

2. Research design and methods

This section presents the main method for the investigation of the energy-saving potential of the Balıkesir University campus. Figure 1 shows the following steps. Firstly, a target university campus is determined. Then, several data on university buildings are collected, such as their construction years, scales, HVAC systems, utilisation types and current energy consumption values. Thanks to these data, buildings are selected for deep analysis. The next stage is the validation of the simulation models of the selected buildings, followed by the calculation of potential savings with energy-efficient strategies. Lastly, the results are examined in detail to represent the energy-saving potential of buildings, and the conclusions drawn from the study are summarised.

2.1 Climate of the study area

The Balıkesir University campus is located 17 km far from the city centre, at latitude 39°32′06″ north and longitude 28°00′42″ east. Balıkesir has a hot-summer Mediterranean climate (Csa) according to the Köppen classification (Öztürk *et al*., 2017). Based on historical weather data of Balıkesir from 1938 to 2018, July is the hottest month, with an average dry-bulb temperature of 24.8°C, and the coldest month is January, with an average dry-bulb temperature of 4.8°C. Extreme temperatures have been measured in the range −21.8°C (13 January 1954) to 43.7°C (25 August 1958). The wettest month of the year is December, with

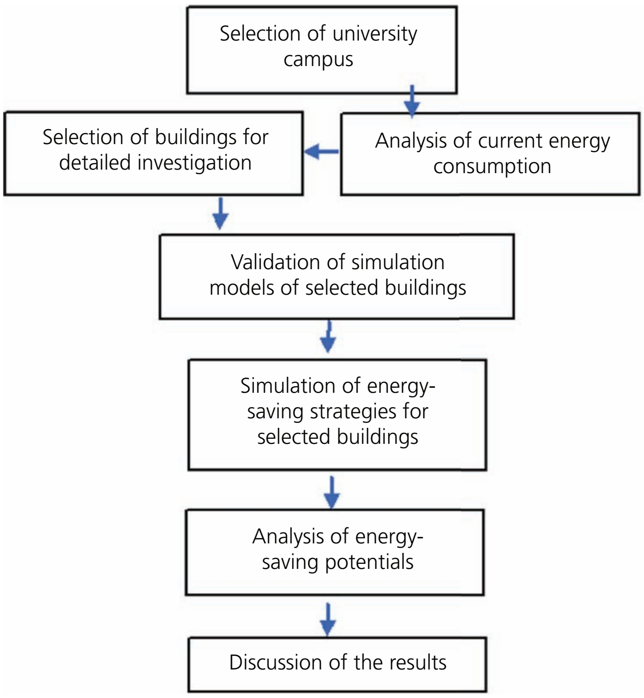


Figure 1. Steps of the main method

an average of 95.2 mm of rain (TSMS, 2020). The average wind speed in Balıkesir is 1.4 m/s. The maximum wind speed measured to date is 106.6 km/h (10 March 1958). The dominant wind direction of Balıkesir is north, and the secondary wind direction is north-north-east due to seasonal changes.

2.2 Case study: university campus and buildings

A university campus was selected as a case study in Balıkesir, Turkey. Balıkesir University was established on a land of 5000 acres (2023 ha) within the borders of Çağış and Paşaköy on the 17th km of the Bigadiç–Balıkesir highway in the south of the Marmara Region (Caner and Ilten, 2020). There are 20 buildings in the campus, which have several functions such as education, laboratory, sports, social, health and administrative (Figure 2).

While most of the buildings are single-function, some of them are multifunctional. For example, the university hospital is used for education and health. The basic information such as the construction year, area and functions of the buildings is summarised in Table 1. Most buildings were built in 2010 and earlier. The oldest building is the Vocational High School built in 1992. The Faculty of Medicine, Experimental Animals Centre and Faculty of Engineering buildings are the newest buildings, which were built in 2014. At the end of 2017, the total closed area of the 20 buildings reached 65 179.817 m^2.

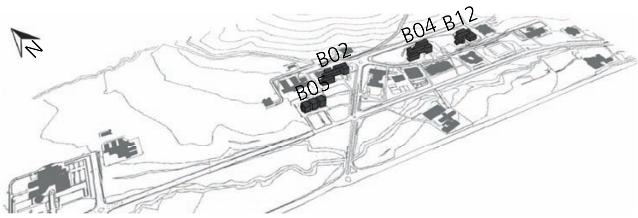


Figure 2. Site diagram of the Balıkesir University campus and three-dimensional view of the case studies

For the present study, the rectorship office provided the electrical and gas consumption data in 2017 for the buildings. The available energy consumption values are given in Table 2. The average energy consumption of the buildings in 2017 was found to be 107.80 kWh/m^2. It is clear that they have different contributions to the total energy consumption of the university campus. The investigation of all buildings is not feasible in this paper. Thus, the following factors were determined to select the buildings to be studied

- the availability of energy consumption data and architectural and mechanical projects
- whether the building is multipurpose, with activities including mainly lectures, administration, library, laboratory and cafeteria
- construction year.

Based on the preceding criteria, four buildings (Figure 3) were chosen to analyse energy-saving potentials.

The first selected building is the Faculty of Engineering and Architecture (B02), built in 1993; it consists of rectangular blocks extending in the north-west–south-east direction. The building includes warehouses, laboratories, classrooms, a canteen, a conference room and academic and administrative staffrooms. It has different blocks with two, four, five and seven floors, and the total area of the building is 20 000 m^2. About 90% of this building is heated, and about 18% is cooled.

The second building is the Faculty of Arts and Sciences (B04), constructed in 1994; it consists of rectangular blocks extending in the north-west and south-east directions and covers various venues such as student social areas, laboratories, a canteen, classrooms and offices. This building has different blocks with two, five, six and eight floors, and its total area is 28 000 m^2. Approximately 91% of this building is heated, and about 12.5% is cooled.

The third building is the building of the rectorate (B05), built in 1996; it extends rectangularly in the north-west and south-east directions. This building, most of which consists of office spaces, also has a main library. The building has eight floors, and the total area of the building is 15 200 m^2. Approximately 85.50% of this area is heated and cooled.

The last building is the School of Physical Education and Sports, built in 2010; it consists of rectangular blocks extending in the north-west and south-east directions. It includes gyms, classrooms, a canteen and offices. This building has different blocks with one, two and four

Table 1. Summary of building information

Building code	Building type	Academic description	Construction year	Floor area: m^2	Total building area: m^2	Orientation
B01	Education	Vocational High School	1992	4074.18	14 993.30	N–E
B02	Education	**Faculty of Architecture and Engineering**	1993	5417.67	20 001.25	SW–SE
B03	Education	Faculty of Tourism	1993	4134.75	12 404.26	NW–SW
B04	Education	**Faculty of Arts and Sciences**	1994	6201.31	28 021.98	SW–SE
B05	Office + library + education	**Building of the rectorate**	1996	1770.10	15 202.34	SW–NE
B06	Accommodation	Guest house	1997	5234.12	14 316.55	SW
B07	Gymnasium	Sports hall	2000	3464.87	10 394.63	SW
B08	Education + hospital	Medico-social building	2001	2623.21	10 492.84	NW–SW
B09	Cooking	Dining hall	2007	5613.22	11 226.45	NE
B10	Research	Engineers' workplace	2008	564.74	1694.22	NW
B11	Health	University hospital	2010	2670.00	29 603.00	SW
B12	Education	**High School of Physical Education and Sports**	2010	5414.47	9020.50	SW
B13	Education	Faculty of Economics and Administrative Sciences	2010	2815.96	13 132.65	SW
B14	Sport	Swimming pool	2010	1651.01	4953.00	SE
B15	Research	Science and technology application and research centre	2010	1279.65	38 38.95	SW
B16	Accommodation	Dormitory	2011	3577.91	28 623.28	SW–NW
B17	Education + hospital	Faculty of Veterinary Medicine	2011	2815.96	13 132.65	SW
B18	Education	Faculty of Engineering building	2014	4200.00	17 860.00	SW
B19	Research	Experimental Animals Centre	2014	468.00	812.00	SW
B20	Education + research	Faculty of Medicine	2014	4998.75	19 328.67	W–NW

Bold indicates studied buildings
E, east; N, north; NE, north-east; NW, north-west; SE, south-east; SW, south-west; W, west

floors, and the total area of the building is 9000 m^2. About 88% of this area is heated, and about 17% is cooled. Two-dimensional plans of the selected buildings are shown in Figure 4.

Table 2. Energy consumption rates in 2017 (unit: kWh/m^2)

Building code	Electricity	Gas	Total
B01	40.45	49.05	89.50
B02	**49 (B02 + B05)**	**93.01**	**142.01**
B03	15.09	—	15.09
B04	**22.81**	**96.00**	**118.81**
B05	**—**	**97.00**	**97.00**
B06	4.08	48.20	52.28
B07	5.15	37.13	42.28
B08	62.28	92.14	154.42
B09	68.13	132.00	200.13
B10	—	—	—
B11	151.31	213.86	365.17
B12	**24.00**	**81.82**	**105.82**
B13	24.60	58.73	83.33
B14	3.00	35.64	38.64
B15	43.12	51.00	94.12
B16	—	—	—
B17	32.57	59.00	91.57
B18	—	—	—
B19	—	—	—
B20	13.40	21.28	34.68
		Average of buildings	**107.80**

Bold indicates studied buildings

2.3 Simulation and validation process

Building energy simulation is a valuable tool for refurbishment of buildings: it can help identify the most effective upgrades and provide information about energy savings (Di Giuseppe, 2019; Sesana *et al*., 2016; Sozer, 2010). Daly *et al*. (2018) reported that building performance simulation has become an important way of making the existing commercial building stock more energy efficient. It enables the user to estimate energy savings from improvements, consequently increasing energy efficiency and optimising financial or other benefits. In this study, a whole-building simulation program, DesignBuilder, was used to simulate and calculate the energy-saving potentials of strategies because it is an advanced energy simulation tool with user-friendly modelling techniques. The engine used by DesignBuilder for simulation is EnergyPlus. For each building, information about building massing, geometry, window-to-wall ratios and materials of components was collected through building audits and design drawings. The other variables included operational and occupancy profile and electrical and mechanical system characteristics, which are typically the most difficult to find reliable data on for existing buildings. When any of these parameters could not be determined through observation or from documentation, they were accepted as unknown in the simulation. Building floors were divided into 30 thermal zones for high accuracy. The advantage of a high number of thermal zones is that each part of the building can be used as a unique entity in terms of its equipment loading and occupancy if needed, hence

Figure 3. Views of the Faculty of Engineering and Architecture (B02), Faculty of Arts and Sciences (B04), rectorate building (B05) and School of Physical Education and Sports (B12)

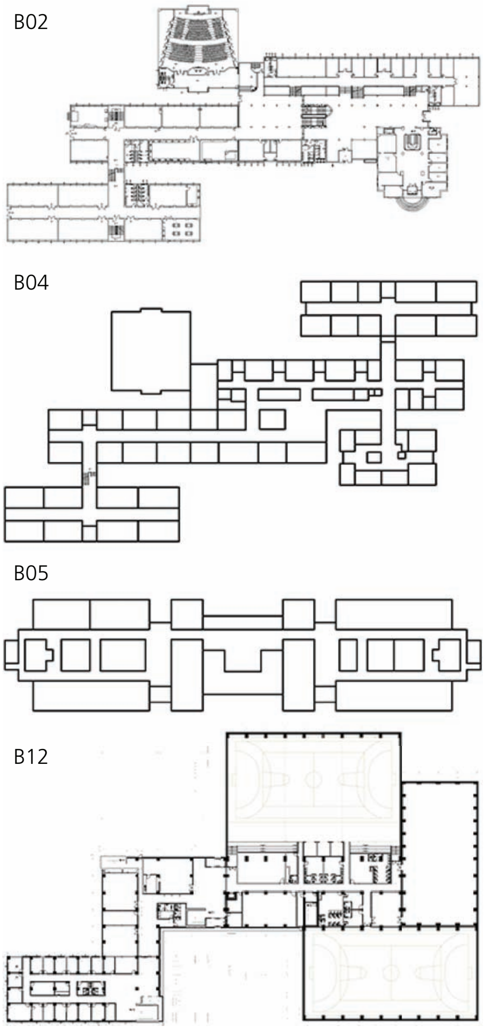


Figure 4. Schematic diagrams of all buildings

improving the accuracy of the simulation results (Jain *et al*., 2020). For space use, the occupancy scenarios were determined according to course schedule and a general pattern was drawn through headcount. The occupancy percentage and equipment density including staff and students (Table 3) were assumed constant per hour on a working day for all months except between June and September. The number of students and staff and equipment density were reduced by half between June and September because of the summer break. The buildings are in use on Monday to Friday from 8.00 a.m. to 5.00 p.m. The metabolic rates of occupants were assigned to each zone based on the activities. The general activities considered were 'light office work' and 'typing/reading'. The clothing factor was set to 0.5 for summer clothing and 1 for winter clothing. The majority of the power density in the buildings is focused on computers. Hence, a load of 140 W from each computer device was accepted, and every thermal zone was allotted a value according to its seating capacity. Surface-mounted fluorescent tube lamps (12 W) were used to provide adequate lighting for reading, writing and other activities in buildings. The number of lights on was roughly constant in the diurnal period.

There are natural gas heating systems and water chillers in all buildings. Set-point temperatures were determined based on TS 825 (TSE, 2013), which is a mandatory Turkish national standard. According to TS 825, the indoor set-point temperature in all spaces should be at least 20°C for schools. TS 825 does not suggest a specific value for cooling. The cooling set-point temperature was

Table 3. Variation of occupancy and equipment loading in 24 h

Time interval	Percentage: %
7 a.m.–10 a.m.	75
10 a.m.–12 p.m.	100
12 p.m.–1 p.m.	25
1 p.m.–3 p.m.	100
3 p.m.–5 p.m.	75
5 p.m.–7 p.m.	0

accepted as 24°C. While almost all parts of the buildings are heated, only offices and some laboratories are cooled. The cooling system is active in summer months (from June to August), and the heating system is in use between November and March. The buildings do not have any mechanical ventilation system. The heating and cooling systems in Turkish schools turn on 1 h before lessons start and turn off when the school closes. Thus, they were set to start at 7.00 am and turn off at 6.00 pm in simulations.

The minimisation of the difference between simulation prediction and reality is very important. Therefore, several simulations and adjustments were conducted for validating the simulation models. This study reports only the final solutions. In order to validate the DesignBuilder models, the available electric and natural gas billing data of selected buildings were used for the whole year of 2017. According to the American Society of Heating Refrigerating and Air-conditioning Engineers ASHRAE Guideline 14-2002 (Ashrae, 2002), a simulation model can be considered validated when the mean bias error (MBE) and the coefficient of variation of the root mean square error (CV(RMSE)) reported in Equations 1 and 2, respectively, are within acceptable limits. These respectively equal ±5 and 15%.

$$\text{MBE}(\%) = \frac{\sum_{i=1}^{n}(m_i - s_i)}{\sum_{i=1}^{n}(m_i)} \times 100 \tag{1}$$

where m_i is the actual energy consumption and s_i is the simulated energy consumption.

$$\text{CV(RMSE)} = \frac{\sqrt{\sum_{i=1}^{n}(m_i - s_i)^2/n}}{\overline{M}_\text{P}} \times 100 \tag{2}$$

where M_p is the average of the actual energy consumption for a year and n is the number of data.

The calculated MBE (%) and CV(RMSE) (%) for each building model are shown in Table 4. They are within the limits, and this means good agreement between simulated and actual data. Thus, the building models can be accepted as calibrated.

Table 4. Validation results of buildings

Building	CV(RMSE):[a] %	MBE:[b] %
B02 based on natural gas consumption	5.53	2.98
B04 based on natural gas consumption	6.69	4.02
B04 based on electric consumption	3.93	3.08
B05 based on natural gas consumption	5.96	3.70
B12 based on natural gas consumption	6.88	4.94
B12 based on electric consumption	5.39	4.30

[a] ASHRAE Guideline 14-2002 recommendation: ±15%
[b] ASHRAE Guideline 14-2002 recommendation: ±5%

Once validations had been completed, the energy-efficient strategies were simulated. Generally, the building simulation program needs hourly weather data such as temperature, relative humidity, wind speed and solar radiation at a location in close proximity to the model building (Eames, 2016). However, there are no available hourly weather data for Balıkesir in the national and international databases. Therefore, all simulations were run using weather data (a new *.epw file) generated from Meteonorm software (Meteotest, 2020). In this study, real climatic parameters including outside dry-bulb temperature, relative humidity, wind speed and orientation were recorded at 0.5 h intervals by using a weather station located on the roof at the Faculty of Architecture and Engineering. Then, the measured values were entered into the weather data file taken from Meteonorm. The values for solar radiation and others were used from the current *.epw file.

2.4 Energy-efficient strategies

There are many possible alternatives for such measures to reduce the energy demand of buildings (Ceballos-Fuentealba *et al.*, 2019): (*a*) change the user behaviour, (*b*) control or manage building energy and (*c*) adopt an energy-efficient measure. This paper focuses on the third choice in that it supports the application of energy simulations in order to quantify the potential energy savings of a given measure compared with the current situation of the building. Both passive and active solutions were preferred in this study to have a holistic assessment framework regarding the effect of energy-efficient options on the reduction of the energy consumption of buildings. For the buildings in the present case study, the main strategies are all intended to improve the energy performance of each building through the addition of thermal insulation, replacement of the glazing type and lighting equipment, usage of shading, airtightness, use of energy-efficient fans and some combination of them. Among all the possible options, the measures were determined based on availability and technology feasibility in the Turkish building sector, as described as follows.

The building envelope has a significant role in energy transfer because it is the main barrier between the outdoors and the conditioned interior space (Sadineni *et al.*, 2011; Sozer, 2010). Therefore, the design of the building envelope has an important impact on building energy performance, particularly for large-footage buildings (Sozer, 2010), and the optimum design of the building envelope is a way of reducing the building energy consumption. The benefit of these kinds of measures is limiting the heat losses in winter and heat gains in summer due to thermal conduction through the building envelope such as walls, roofs, floors and windows. According to architectural and engineering projects of the selected buildings, there is no thermal insulation on walls and roofs except for the roof of B12 (a 3 cm thermal insulation exists). In this study, an extra insulation layer was added on exterior walls (7–10–15 cm) and roofs (10–15–20 cm) to limit heat transfer from opaque surfaces. Expanded polystyrene (EPS) and extruded polystyrene insulation

Table 5. *U*-values and construction materials of building components

Component	Construction materials	Total thickness: m	Existing *U*-value: (W/m^2)/K	Upgraded *U*-value: (W/m^2)/K
External walls	Gypsum plastering–brick–gypsum plaster	0.24	1.287	W1: 0.37 W2: 0.28 W3: 0.20
Internal walls	Gypsum plaster–brick–gypsum plaster	0.13	1.843	—
Roof	Tiles–waterproof layer–concrete–gypsum plaster	0.18	3.420 B12: 0.430[a]	R1: 0.35 R2: 0.24 R3: 0.18
Ground floor	Decorative finish–concrete–waterproof layer–sand blinding–hardcore	0.35	1.014	—
Floor	Decorative finish–concrete–gypsum plaster	0.21	2.267	—

[a] B12: 3 cm thermal insulation exists
R1, R2, R3, extra wall insulations; W1, W2, W3, extra wall insulations

materials are preferred over glass and rock wool in Turkey. Thus, the insulation material used in the simulation analysis is EPS for external wall and glass wool for roof. Table 5 shows the target values for the overall heat transfer coefficient (*U*-value) used in simulation models.

Another important measure for the building envelope is windows with energy-efficient glazing, which can affect the amount of solar radiation and heat transfer. Control of solar radiation can optimise the transmitted solar and heat flux through the glazing, and this leads to a reduction in the energy demand (Kirimtat *et al*., 2019). Thus, energy-efficient windows increase indoor comfort conditions and energy performance (Takashi *et al*., 2013). This study is focused on improving the *U*-value and solar heat gain coefficient (SHGC). The main idea is to control the transition of heat and solar energy through the windows. These two factors were determined for all glazing types, and a set of stricter target values is presented in Table 6. In the selection of glazing, besides energy performance, different perspectives can be taken into consideration (Foraboschi, 2014). For example, some models predicting accurately thermally induced stresses are available to help engineers, architects and manufacturers choose the most suitable glazing systems and types without over-demanding laboratory mock-up test results (Foraboschi, 2017). Usage of energy-efficient windows alone may not always be enough. Excessive solar radiation entering the interior space from glazing can not only continue to cause visual disturbance but also increase the cooling load in summer (Choi *et al*., 2017). Therefore, solar shading can be thought of as an extra solution to increase visual comfort and to control heat gain (Ashrae, 2013). In the scope of this study, 50 cm horizontally fitted sunshade awnings (S1) were preferred for the south-west facade because it is clear that in the northern hemisphere, the solar beams on south-facing windows can be effectively controlled by horizontal overhangs (Alhuwayil *et al*., 2019). Another suggestion for the shading device is the application of external venetian blinds (S2) for all windows. Daylight control with blinds can be provided easily, as it can be switched on and off as desired. In this study, external venetian blinds were defined as open in winter and as closed in summer in the simulation.

Table 6. *U*-values and SHGCs for glazing

Building	Glazing type	SHGC: %	*U*-value: (W/m^2)/K
B02	Double	69	2.7
B04	Double	69	2.7
B05	Double	69	2.7
B12	Double	46	2.5
Strategy	**Glazing type**	**SHGC: %**	***U*-value: (W/m^2)/K**
G1	Double	56	1.6
G2	Double	44	1.6
G3	Triple	51	1.2
G4	Triple	48	0.9
G5	Triple	39	0.9

G1, G2, G3, G4, G5, replacements of windows

The loss or gain of energy due to air infiltration from the building envelope is a significant part of the total energy consumed in buildings (Sikander, 2005). This may be as much as one-third of the energy used for heating and cooling in residential buildings (Emmerich and Persily, 1998) and as much as 40% of the total heat energy demand in industrial buildings (Brinks *et al*., 2015). In addition, air infiltration has significant effects on indoor air quality because it can lead to transfer of some particles through the inside of buildings (Airaksinen *et al*., 2004). Therefore, control of air infiltration is necessary to reduce energy use and improve air quality in buildings. The goal of this strategy is to limit the uncontrolled air movement through the building envelope. In the simulation program, the infiltration rate (I1) was reduced from 0.8 to 0.6 because of the improvements in the building envelope.

Artificial lighting and HVAC are the major active systems consuming energy in buildings. They are responsible for nearly half (Vali *et al*., 2009) and 14% of the primary energy usage in the office buildings (Fontoynont *et al*., 2016), respectively. Lighting is responsible from almost one-fifth of the total energy consumption in commercial buildings (Kozminski *et al*., 2006). Thus, usage of energy-efficient HVAC and lighting equipment could improve the energy performance of buildings. For example, low-energy lamps and ballasts with a programmable controller and motion sensors integrated with daylight control in buildings can reduce the energy consumption of the lighting (Haq *et al*., 2014). It was observed that in selected buildings, there was no active control for the lighting system and the number of lights switched on is roughly constant in the diurnal period. In this study, this measure focuses on the installation of more efficient artificial lighting equipment consisting of LED lights (L1) to estimate their energy-saving potential. All lamps were replaced with LED lights (6 W) in the buildings.

HVAC in buildings is also a big and complex system. It consists of several subsystems and components such as cooling/heating loops, fans and pumps. Any failures or faults can lead to a negative effect on the building energy performance (Qian *et al*., 2019). Improving a part of HVAC system has been one of the effective ways of reducing its energy consumption. Reducing energy consumption associated with fans is possible by using high-efficiency fan motors (Qian *et al*., 2019). Thus, the goal of this measure is to predict the associated energy-saving potential by applying high-efficiency fan motors (F1). The current fan has 67% peak total efficiency. During the simulation, the fan efficiency was set to 80%.

Two combinations were defined after energy consumption analysis of single strategies. While combination 1 (C1: W1 + G1 + R1 + L1 + I1 + F1 + S1) consists of strategies leading to the lowest energy saving, combination 2 (C2: W3 + G4 + R3 + L1 + I1 + F1 + S2) includes strategies leading to the highest energy saving. In total, 19 scenarios were simulated to calculate the energy-saving potentials of the selected buildings. For the analysis shown in this paper, only heating, cooling and electricity loads were considered.

3. Results and discussion

In this section, the results calculated by using the validated energy models are analysed and compared with the existing conditions of buildings. The possible saving rates of the energy-efficient measures for buildings are discussed in the following sections.

3.1 Impact of improving the building envelope

Firstly, the impact of six strategies consisting of thermal insulation for external walls and roofs was determined on each building. The energy-saving potential of the improvement proposals determined for the exterior walls is given for each building in Figure 5.

In general, an energy saving between 14 and 31% is possible with the addition of thermal insulation on external walls. This corroborates the studies of Cho *et al*. (2019) and Chung and Rhee (2014). Ali and Hashlamun (2019) found that all retrofitting strategies for the envelope could reduce the total energy by between 8 and 54% in uninsulated school buildings in Jordan. The highest heating-energy-saving potential was obtained in the Faculty of Arts and Sciences (B04) with 26.12%. This is probably due to the fact that B04 has the largest external wall area with a total area of 15 984.83 m^2. The building with the second highest energy-saving potential is the Faculty of Engineering and Architecture (B02) with 23.72%. The total external wall area of this building is 11 000 m^2 and comes after that of B04. The building of the rectorate (B05) ranks third with 21.61% in the heating-energy-saving potential order. The total external wall area of this building is 7439.85 m^2. The effects of wall insulation appeared to be the lowest heating-energy-saving potential for High School of Physical Education and Sports (B12) with 15.90%. This is thought to be due to the fact that B12 has the smallest total external wall area. When the impact of insulation thickness is evaluated, it is clear that energy consumption for heating decreases on average by 7% as the insulation thickness increases.

When extra insulation was applied on walls, the cooling energy saving ranged from 15 to 31%. Obviously, the savings from

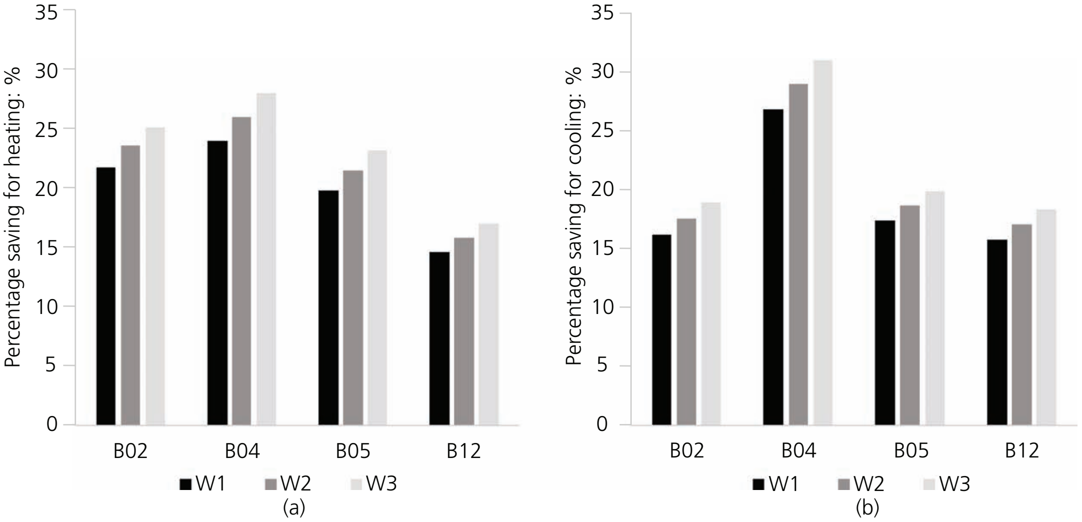


Figure 5. Application of wall insulation: energy-saving percentages for (a) heating and (b) cooling

cooling use are the highest if it is applied to the Faculty of Arts and Sciences (B04). It can be related to the size of the cooled area. In the building of the rectorate (B02) and the Faculty of Engineering and Architecture (B05) and High School of Physical Education and Sports (B12) buildings, similar energy-saving rates were achieved for cooling. The amount of cooling demand varies according to the thickness of the insulation. Another important point is that energy-saving potentials for heating and cooling increase almost linearly based on the insulation thickness.

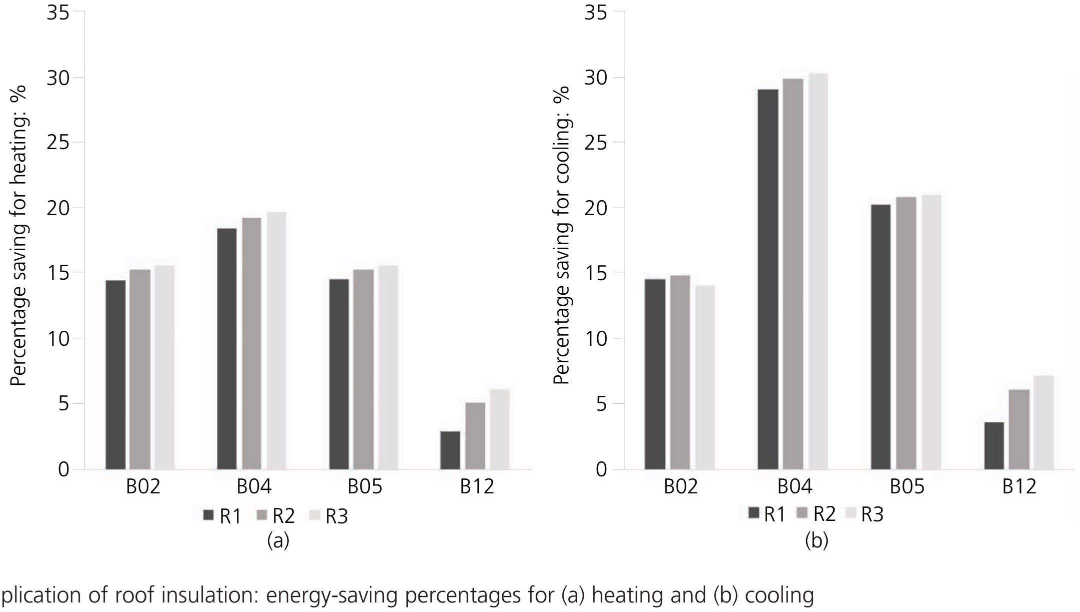
The energy-saving potentials as a result of the extra roof insulation are presented in Figure 6. It is very clear that the energy-saving rate changes from 3 to 30% and the reduction in energy consumption is directly proportional with the thickness of roof insulation in general.

The highest energy-saving potential for heating due to the additional roof insulation was obtained in the Faculty of Arts and Sciences (B04) with 19.8%. The possible reason for this is that B04 has the largest roof area with 6415.36 m^2. It is observed that the heating-energy-saving potentials for the Faculty of Engineering and Architecture (B02) and the rectorate building (B05) are at a similar level with an average of 15%. B12 has the lowest heating-energy-saving potential. This is due to the fact that while an EPS thermal insulation (3 cm) exists on the roof of B12, there is no thermal insulation on the roofs of the other buildings. When the energy-saving potentials for cooling are compared, the building with the highest energy-saving potential is realised for the Faculty of Arts and Sciences (B04) with an average of 29.8% because of it having the largest roof area. The cooling energy-saving potential of the building of the rectorate is 20.79%, and it is 14.86% for the Faculty of Engineering and Architecture (B02). Although the roof area of the rectorate building (B05) is approximately half of that of B02, more cooling energy was saved in the building of the rectorate as a result of the addition of thermal insulation on the roof. The reason for this is that the cooled area of the building of the rectorate is larger than that of B02. The building with the lowest potential for cooling energy saving is B12 (5.67%). This is probably due to the already existing thermal insulation on the roof of that building. When all results are evaluated, it can be stated that roof insulation is highly important for the reduction of heating and cooling needs.

The energy-saving potentials of the replacement of the window glazing with a more energy-efficient one are shown in Figure 7.

In all buildings except for B12, the heating energy-saving potentials were less than the cooling energy-saving potentials. This fact underlines the potential of proper glazing to achieve very important reductions in the cooling energy demand. As a result of replacing the window glazing with more efficient glazing, the building with the highest energy-saving potential for heating is B12 with 11%. This fact is probably due to the ratio of the window-to-wall area (33.91%) of B12 being higher than those of the other studied buildings. The heating energy-saving potential of the other buildings is approximately 5%. B02 and B05 have almost the same energy-saving potential for heating because the window-to-wall areas of these buildings are close to each other. It is found that the highest reduction in the heating load was achieved when glazing strategy G4 was applied. This confirms that a glazing with a low *U*-value can reduce heating energy significantly (Yang *et al.*, 2017).

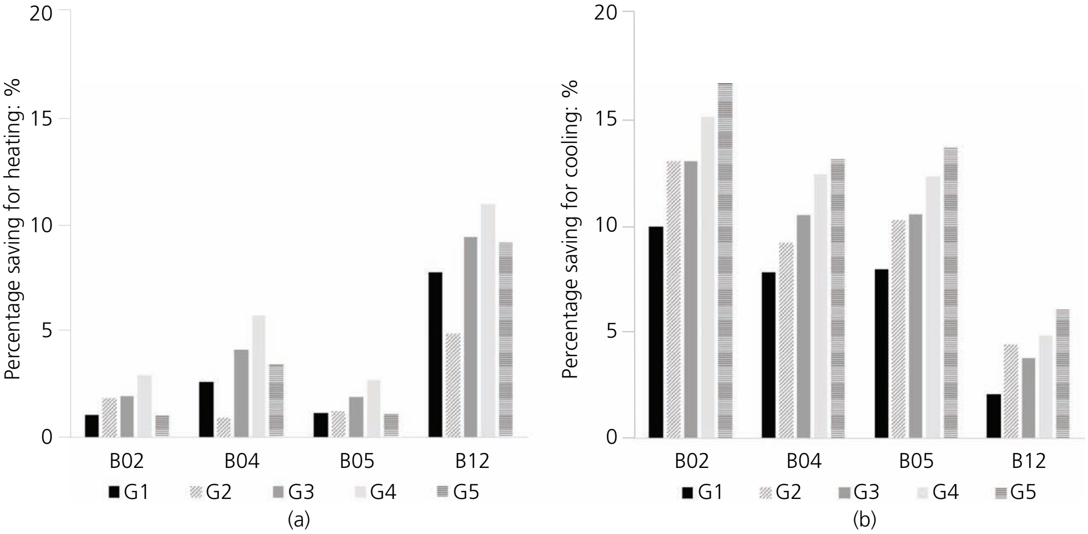
While B02 has the highest energy-saving potential for cooling with 16%, the B12 building has the lowest cooling energy-saving potential (2%). This is probably due to the fact that B12 has a colourful glazing resisting transformation of solar radiation through indoors. This makes the effect of window glazing



(a)

(b)

Figure 6. Application of roof insulation: energy-saving percentages for (a) heating and (b) cooling



(a) (b)

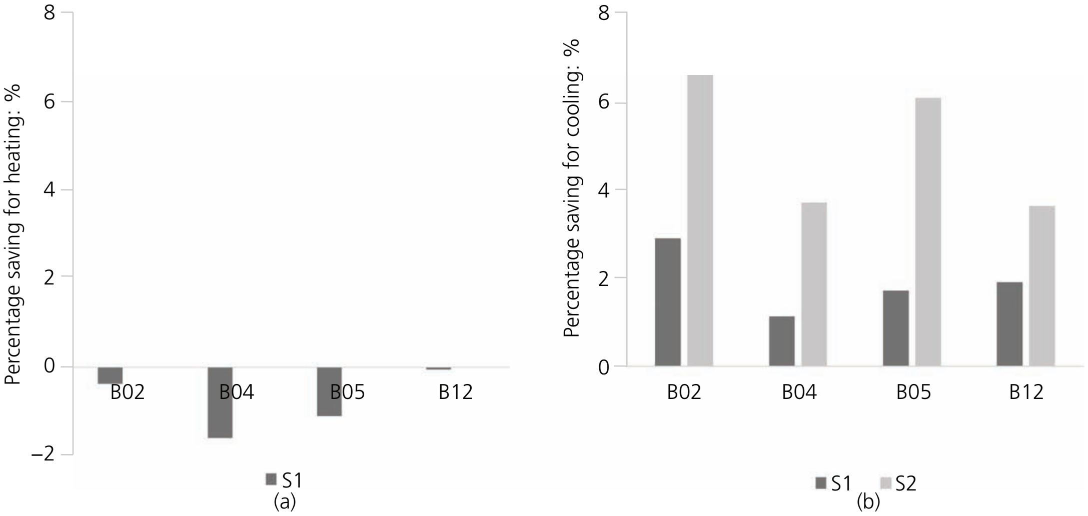
Figure 7. Replacement of the window glazing: energy-saving percentages for (a) heating and (b) cooling

changes on cooling consumption unable to be seen fully. B04 and B05 have similar energy-saving potentials for cooling, and their average is 10%. The best strategy providing high saving from cooling load is G5, which has the lowest SHGC value. From the analysis of the results, it can be deduced that the effect of glazing on energy performance can change for heating and cooling. This fact underlines that detailed investigation is necessary for making the right decision before selecting a glazing strategy.

3.2 Impact of the shading strategy

It is seen in Figure 8 that the S1 measure has almost no positive impact on the heating energy saving of the buildings. S1 reduced most probably the heat gain in winter, and it caused a small increase in heating energy demand. In this research, because of the S1 measure, the heating energy consumption increased in buildings B02, B04 and B05. S1 is the only way to reduce the heating energy consumption for B12, and this has been analysed as the lowest heating energy-saving rate. Notably, these savings seem to be modest than those claimed in the literature. The impact of the shading device on heating energy consumption in buildings should be investigated carefully in the design phase because the shading strategy can increase the need for heating while reducing the need for cooling.

In contrast, S1 and S2 lead to a reduction of between 1 and 7% in the cooling demand. The saving rate agrees with those from previous studies (Alhuwayil *et al*., 2019). The energy saving achieved in this study is also comparable with and lower than



(a) (b)

Figure 8. Application of a shading device: energy-saving percentages for (a) heating and (b) cooling

previously reported savings of 14% for school buildings in Los Angeles, CA, USA, that were achieved when using overhangs and fins (Alshamrani and Abdul Mujeebu, 2016). It should be noted that the energy-saving rate can change depending on the shading strategy, building features and the climate and the weather of the location. It is also very clear that external venetian blinds (S2) are more effective than horizontally fitted sunshades (S1) in reducing cooling energy consumption. Another advantage of external venetian blinds is that they can be opened and closed whenever it is necessary.

It can be deduced that if shading strategy S1 is applied to the Faculty of Arts and Sciences (B04), the building of the rectorate (B05) and High School of Physical Education and Sports (B12), it is not possible to reduce the cooling load even by 2%. However, when S2 is implemented on these buildings, their cooling demand can be reduced by more than 3%. The best results of up to 7% energy saving can be achieved when the shading strategy is applied to the Faculty of Engineering and Architecture (B02). The present study verifies the results of the study by Cho *et al*. (2019) that even a measure that reduces one energy type can result in an increase in the demand for another energy type.

3.3 Impact of the energy-efficient lamps

Energy-saving percentages arising from replacing lamps with more efficient ones are given in Figure 9. It is observed that the energy consumption for artificial lighting undergoes a remarkable reduction when more efficient lighting equipment is installed. The energy-saving potentials of the examined buildings are approximately similar. This may be because the existing lighting devices are of the same type and vary the power intensities per unit area to the same degree in buildings. The simulation results show that energy-efficient lamps contribute to a high decrease in the electricity demand. The yearly energy consumption for artificial lighting can be reduced by over 60% in all buildings. This is found to be the most effective way to reduce the highest artificial lighting energy consumption in this paper. The results agree with those in the literature where the expected lighting energy savings that can be achieved are 59, 65.1, 43.6 and 38.4% for circulation spaces, classrooms, open offices and computer rooms during occupied hours, respectively (Anand *et al*., 2019).

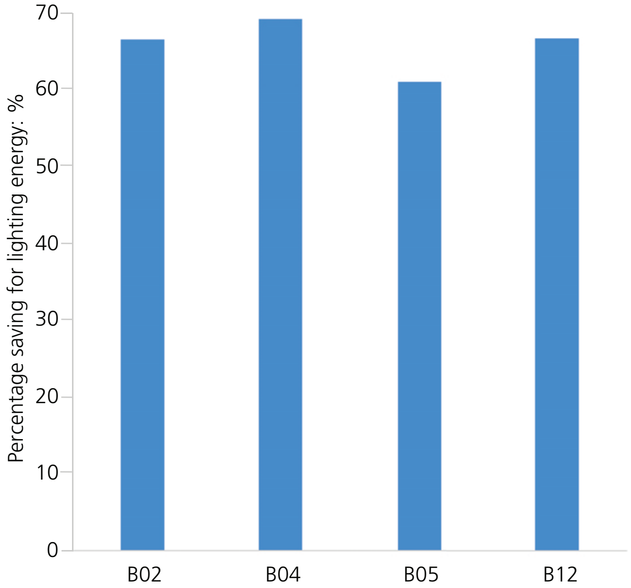


Figure 9. Replacement of lamps: energy-saving percentages for lighting

3.4 Impact of the energy-efficient fans

A fan coil unit is a device that consists of a coil and a fan motor for heating or cooling a room. Figure 10 shows the heating and cooling energy-saving potentials on the basis of the buildings resulting from the replacement of existing fans with more energy-efficient ones. When energy-saving rates are compared, those for cooling are higher than those for heating because fan coil usage for heating is low and radiators are used for heating in some parts of the buildings.

According to Figure 10, the highest energy saving for heating was obtained in the building of the rectorate (B05) with 18%. It is mostly related to the number of fan coil units because its rate is high. B02 is the other building with a high heating-energy-saving rate (12%). The lowest saving from heating energy (mean of 6%) was obtained in B12, and it is similar to that of building B04.

Use of an energy-efficient fan coil seems to be the best scenario contributing to the reduction in the cooling energy demand. Buildings B05 and B02 have the highest energy-saving potential for cooling with 60%. B12 has the lowest cooling energy-saving potential (49%). Again, this is mostly related to the usage rate of the fan coil system. These results indicate that the subsystems of the main HVAC should be constituted from energy-efficient components.

3.5 Impact of airtightness of buildings

The infiltration rate was assumed to be decreased due to the improvement in the building envelope with the application of energy-efficient strategies. The energy-saving potential of low air infiltration, for both heating and cooling, is shown in Figure 11. It is clear that there are no big differences in the energy-saving rates of buildings. While building B05 has the highest energy-saving potential for heating and cooling, building B02 has the lowest energy-saving potential. According to the results, increasing the airtightness can save energy by approximately between 16 and 21% for heating and between 10 and 15% for cooling. The results are similar to those by the studies of Chen *et al*. (2012) and Sun and Yang (2014). It can also be concluded that changes in the airtightness of buildings have more impact on heating energy saving than cooling energy saving.

3.6 Comparison of single measures for each building

To visualise better the effectiveness of each measure based on buildings, the energy-saving potentials of all the cases are

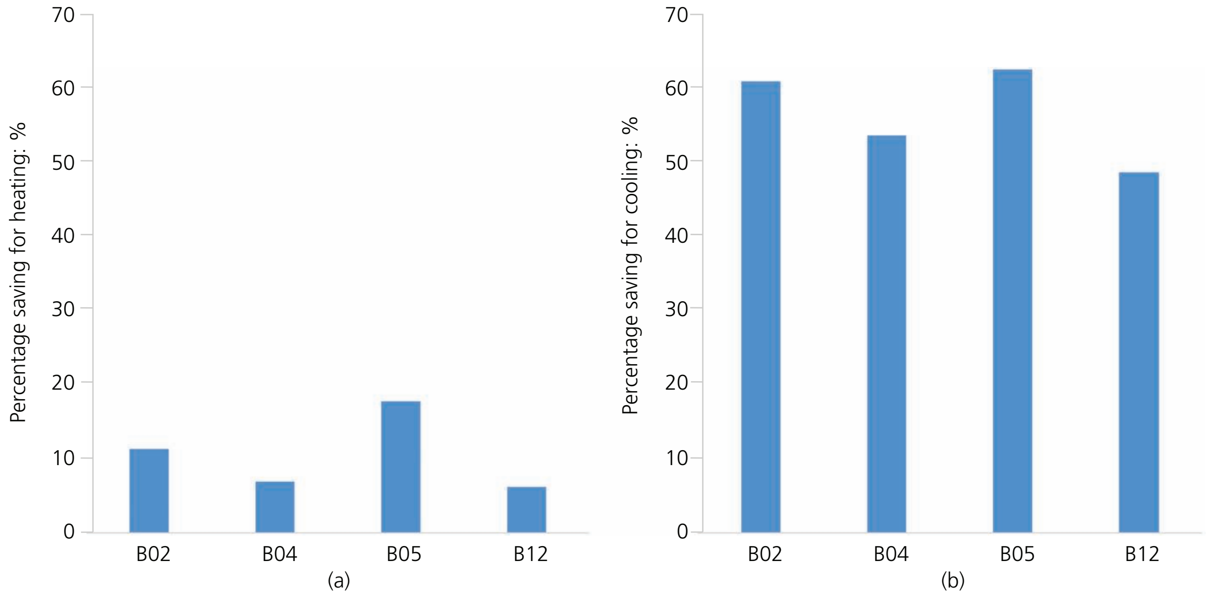


Figure 10. Replacement of fans: energy-saving percentages for (a) heating and (b) cooling

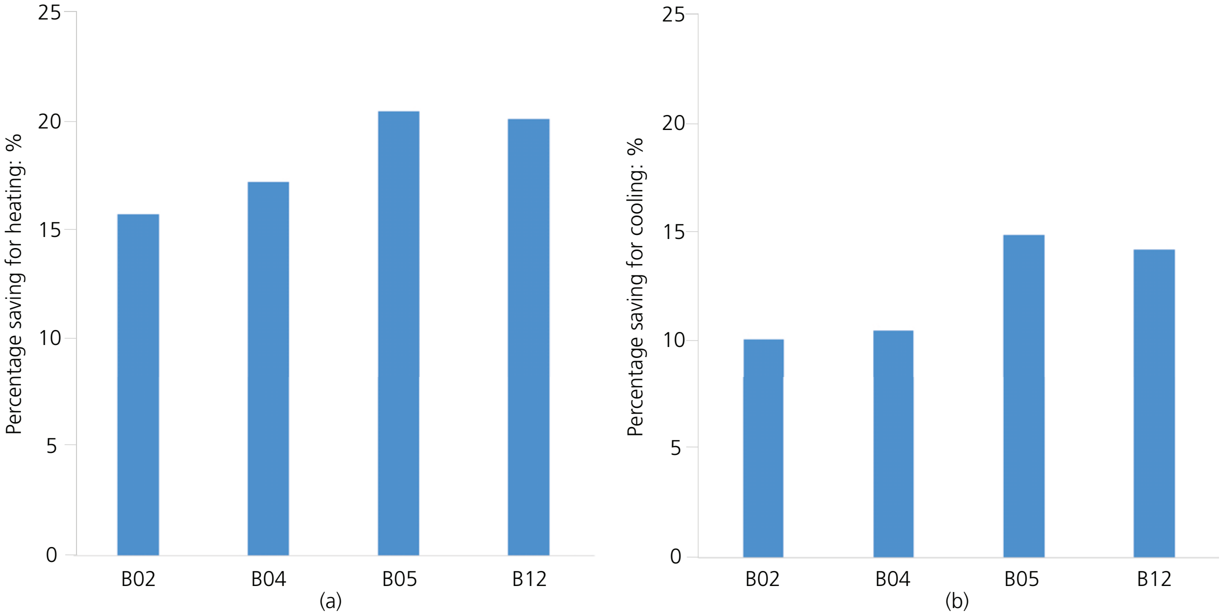


Figure 11. Increasing the airtightness of buildings: energy-saving percentages for (a) heating and (b) cooling

graphically compared in Figure 12. The results show that a significant energy reduction with a single option of up to 28% for heating and 31% for cooling is possible except for the F1 measure. Minimum heating energy-saving potentials are similar, but maximum energy-saving potentials change depending on buildings. While B04 is the building with the highest energy-saving potential for heating, B12 has the lowest heating energy-saving potential. B02 is the second building where a high energy saving for heating is obtained. The heating energy-saving potential of B02 is at least 0.9% and could reach up to 25.49% in proper scenarios. In terms of cooling, the largest energy-saving potential (31%) was ensured by B04. For the rest of the buildings, an energy-saving potential of up to almost 20% is possible. These means that the heating or cooling energy demand of one building can be reduced on average by 20% by applying only one measure.

External wall and roof insulation, airtightness and energy-efficient fan usage have the highest saving potential among the studied energy-efficient strategies. It can also be observed that thermal insulation for external walls leads to the highest energy reduction compared with

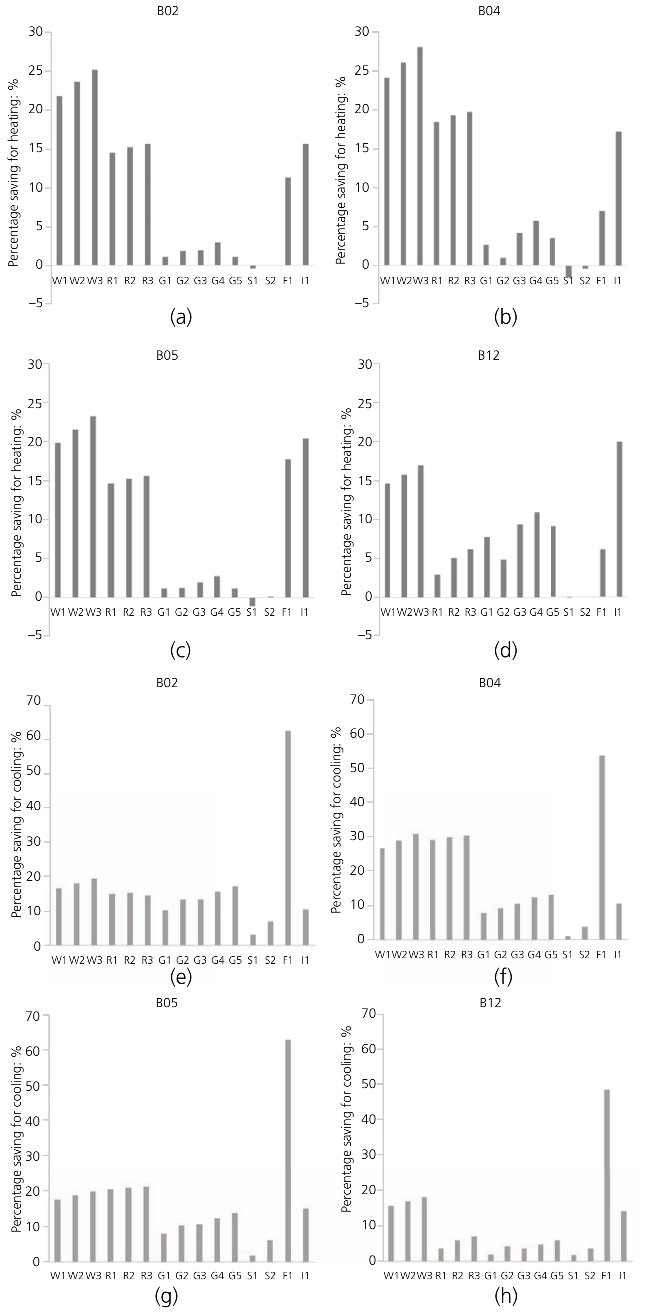


Figure 12. Comparisons of individual measures' energy-saving percentages for (a–d) heating and (e–h) cooling

other measures (except for F1) for all buildings. Then, increasing the airtightness has a significant energy-reduction potential for heating in all buildings. Energy-efficient glazing for B02 and B05 leads to a saving of lower than 5% for heating energy.

Over 20% cooling energy saving can be achieved with wall and roof insulation and energy-efficient fan usage. In addition, fan efficiency has the maximum impact on cooling demand in all buildings. It is found that shading-device usage results in savings for cooling and has a negative impact on heating. This negative effect is less than 2%. The shading formation may lead to different cooling/heating loads in the whole building (Ge *et al*., 2018). In this study, shading has a low potential to decrease cooling energy consumption and glazing is more effective than shading. A mean of 10% energy for cooling can be saved with proper glazing in buildings B02, B04 and B05. In B12, approximately 5% energy saving for cooling is manageable. Glazing strategies are more attractive for cooling energy saving than for heating saving.

3.7 Impact of combinations

After evaluation of the effects of single measures on energy saving, combinations were simulated to see their potential. From the analysis of the findings, it can be deduced (Figure 13) that energy-saving percentages present considerably similar trends. It was found that it is possible to achieve heating energy savings of between 38 and 51% with combination C1. Combination C2 can ensure a heating energy reduction of between 49 and 52%. There is no big difference between combinations C1 and C2. Another interesting point is that some single measures have half the heating energy-saving rates of combinations C1 and C2. While B4 is the building with the highest energy-saving potential, B12 has the lowest saving potential.

It can be inferred that combinations C1 and C2 have more impact on cooling energy saving than on heating energy saving. The cooling saving rate varies between 59 and 75%. While B04 has the highest energy-saving potential for cooling, others have a similar rate. The difference for cooling between C1 and C2 is only 25% at maximum for all buildings. It can be concluded that a combination of single measures can be used to achieve high benefits. Retrofitting an existing building can oftentimes be more cost-effective than constructing a new energy-efficient building. Therefore, these results help guide important interventions in terms of energy saving for decision makers.

4. Conclusions

University campuses are energy guzzlers, and there is an increasing number of educational buildings in Turkey. Therefore, their energy consumption may correspond to a significant amount of the total energy consumption in the building sector of the country. They need special plans to reduce their energy demand. In response to this issue, the current study was aimed at estimating the energy-saving potential of the Balıkesir University campus by implementing energy upgrade scenarios to the educational buildings. The six main retrofitting strategies investigated to examine energy-saving potentials were: thermal insulation of walls and roofs, window replacement, addition of shading, and fan and lamp replacements. From the analysis of the simulation results, some conclusions can be highlighted.

- There is a large potential for energy saving in the buildings of the Balıkesir University campus. The energy demand of the buildings for heating, cooling and lighting could be reduced by over 60%. This means that energy efficiency measures in

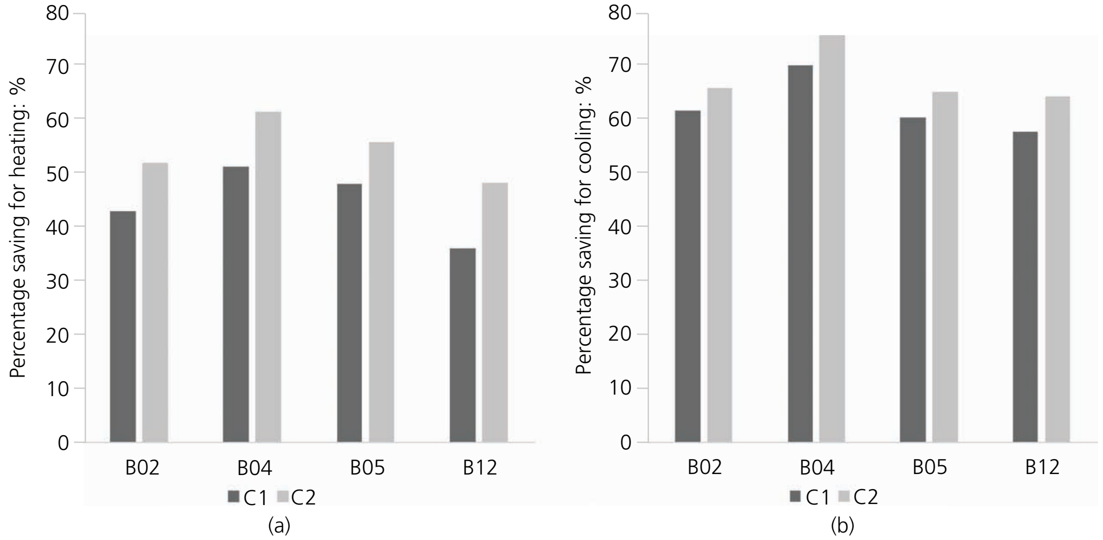


Figure 13. Application of combinations: energy-saving percentages for (a) heating and (b) cooling

this study show a high potential for the campus building retrofitting.

- If the single strategies are considered, wall and roof insulations seem to be the best passive retrofit actions in all buildings, while the worst scenario is shading. This fact indicates that not all energy-retrofit actions are suitable and efficient. The replacement of fans and lamps with more energy-efficient ones is an active scenario with huge energy-saving potentials.
- The energy-saving rate of strategies used for opaque and transparent components can change based on their surface areas. In other words, if the transparent surface area of a building is larger than its opaque surface area, retrofitting strategies should primarily be focused on windows because wall insulation may have no feasible impact on the annual energy saving because of its relatively small area.
- The understanding of which retrofitting strategies should be applied individually or together for which building is a very significant issue because it is very clear that every measure cannot lead to a high energy saving for all buildings. Thus, measures leading to low energy saving should be determined and then eliminated in the planning phase. In other words, the decision maker should constitute a retrofitting plan consisting of measures providing a relatively high energy saving with little investment cost for proper building. Another crucial point is that each case has its own special characteristics; thus, these should be analysed well in detail.

In conclusion, this paper contributes to the literature on campus-scale energy-saving potential by introducing the use of several passive and active measures that have different impacts on energy consumption. This can improve the quality of decision making through analysis of energy strategies for university campuses from multiple perspectives and provides a methodological framework that is suitable for the planning phase of energy retrofitting in terms of prioritisation of buildings and measures. It would possibly reduce the implementation of low-effectiveness measures to the buildings. The results could also serve as a helpful reference for practical projects.

The findings herein are case study specific; thus, more work is necessary to define the validity and applicability of the findings to other climate patterns and building statuses.

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