Energy-Based University Timetabling Model as a Function of Class, Climate, and Building Conditions Subject to Educational Constraints

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This study investigates the effects of ACH, students' number, wall thickness, different semester starting dates, and energy consumption reduction. The optimal academic timetabling for reducing energy consumption considers curricula's rules for taking courses, departments' specific instructions, existing classes, professors' priorities, and other related factors. This research uses simulation and demand-side management models to determine the energy consumption of holding classes during a timeslot. They can quantify the factors' effects on energy use. ACH is between 1.5 and 12, wall thickness is up to 1.6 of its normal value, and students are 10 to 40. There are three starting dates for the semester: conventional time, one-week and two-week earlier. As long as there is no need to change cooling/heating systems, the factors' impacts on each timeslot from the energy reduction perspective when implementing optimal timetabling are investigated. The developed model revealed that the four factors do not change classes' priorities from the energy viewpoint but noticeably affect energy use reduction. The optimal scheduling by keeping the semester's starting date and classes' operational conditions decreases energy consumption between 11.5 and 24.5 %. The results show that the semester's early start has a substantial influence on energy consumption reduction. If the operational conditions are the same and classes begin two weeks earlier, energy consumption will be reduced between these two ranges: 36.7 - 52.2 % and 49.4 - 63.9%.

keywords: *Peer to Peer, Energy Transaction, ADMM algorithm, Decentralized approach, CAES.*

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1. INTRODUCTION

The building sector consumes around 30 % of the final energy, and its direct carbon dioxide emissions are 15 % among end-use sectors. Adding the indirect ones doubles this proportion, playing a critical role in climate change [1, 2]. Various measures mitigate the detrimental effects of giving off greenhouse gas emissions from this sector [3]. Its vast impacts have justified energy-saving methods in this sector [4]. There are many actions to deal with this issue and reduce the building's energy intensity, such as renovation, improved insulation, sophisticated HVAC, or passive design [3, 5]. Although technological advancements can bring the most diminish in energy use, this does not mean they are economical [6]. These activities have different expenses, and some are not applicable because of prohibitive costs [7]. One of the measures that do not pose any cost is demand-side management [5] since most energy use happens during the building's operational stage of its life cycle [8].

Public service buildings are important in decreasing energy consumption; in the long run, they will help reach the desired sustainable development goals [9, 10]. Commercial buildings, part of which are universities, have noticeable energy consumption, and there is a great potential for energy conservation, roughly up to a third of the total consumption [11]. These buildings' occupancy significantly affects energy use [12], like university class schedules. If they are adjusted, there could be beyond a 40 % fall in energy use [13, 14].

Many studies investigate university timetabling, not from the energy-saving perspective. But they introduce some points that have to be considered from the energy point of view. Generally, university timetabling allocates limited resources, such as classes, to some entities, like students, in which assumptions are satisfied [15]. A point in academic timetabling is a combination of faculty timetabling and course scheduling, requiring mathematical optimization that is difficult for optimality [16, 17]. Constraints to which this planning should adhere are time slots, not overlapping [18], available resources [19], a minimum perturbation problem [20], minimizing operational costs [21], and being fair for everyone [22]. Hence, these considerations should be part of any model.

Studies about educational buildings in the context of this study can be classified as understanding occupant behaviour and proposing strategies to conserve energy. The latter group can also be divided into two subsets: saving energy by managing the load and adjusting the systems. Both methods are challenging due to these buildings' complex and various functions [23]. Occupants are why there is a discrepancy between energy simulation models and actual data, and an agent-based model can entirely simulate occupant behaviour as the agents [12]. A questionnaire and interviews in a pilot study to analyze the relationship between the electrical energy demand and user activities showed that the occupancy pattern could help the building management system reach optimum energy consumption [6]. The critical electricity consumption driver collects data at different time steps from educational buildings' equipment and users [24]. Accurate models or interventions in occupancy behaviour demand specific energy data, requiring expensive apparatus. There is a non-intrusive occupant load monitoring to derive this information, utilizing the preferred data from the existing infrastructures [25]. Categorizing various university campuses and collecting their electricity data revealed higher educational buildings and some laboratories, owing to their operation, used the most energy [26].

Energy saving in university buildings is attainable through different approaches. State-of-the-art technologies for collecting energy consumption data, matching them with timetabling of the university, and then introducing a management framework for analyzing energy conservation potential is one way [27]. Another strategy is an agent-based system that compares outside weather conditions with the university's management system to optimize consumption [28] or establishes a methodology based on ISO guidelines for energy consumption reduction potentials [5]. HVAC scheduling reduces energy consumption, and three clusters are investigated: Basic meaning on and off, Conventional translating to decreasing the peak demand, and Advance, which is a combination of the other two [28]. An occupancy-based HVAC system operation schedule can cause a 14 % energy use reduction [29]. Simple measures like replacing extravagant fans or lighting fixtures dwindle electricity by nearly 14,000 kWh per month [30]. Demand-response control strategies are also suggested to cut heating energy consumption and heating energy cost by three and six per cent, respectively [31].

The other strategy to conserve energy in these buildings relies on load management via changing the timetable. These methods utilize mathematical optimization to obtain optimal scheduling. Centrally controlled variable air volume systems are commonly operated based on the fixed period occupancy assumption. Therefore, applying the actual occupancy patterns will save energy by around ten per cent [32]. Optimizing one department's schedule and comparing it with the conventional trial-and-error technique revealed that the solution's relative improvement is from 8% to 29% [33]. Not considering a group of educational buildings and some assumptions for simplifying the problem negatively affects that study's results. An energy-aware meeting schedule in academic buildings using mixed-integer linear programming, depending on the building's HVAC schedule, can halve energy consumption compared to arbitrary plans [34]. Course timetabling by genetic algorithms can lead to a five per cent energy-saving if hard constraints are removed [35]. Some factors, such as a multiobjective problem or different aspects of academic-related resources, need further investigation. A bi-level energy-efficient occupancy behaviour optimization technique, combined with a demand-driven control scheme, decreases the energy consumption of a university building by 1.23 per cent by only optimizing the timetable, and nearly 12%, with the demand-driven control strategy [35]. If these methods are integrated, a 19% reduction is achievable. The region of a building significantly influences energy consumption, occupant behaviour, and indoor environmental quality, and optimizing the behaviour will cut down energy between 11 to 15 per cent regarding the region [36]. A common BCVTB-based (Building Controls Virtual Test Bed) simulation method uses a genetic algorithm to optimize the university timetabling concerning building energy efficiency [37]. More courses were allocated in the afternoon, resulting in decreased lightning operations during the daytime and the heating load despite increasing the cooling load. The proposed scheduling could reduce energy use by 3.6 percent in the fall term.

A university's timetable on different campuses is an excellent example of load management. Not only does it not need any money to do energy-saving actions, but it also is among the easiest methods to implement. Educational buildings have vast capacities for conserving energy [38]. This type of load management can contribute to these potentials because of its features and users' vital role in energy consumption. Although not an acceptable number of studies assess energy timetabling thoroughly, this study would form its research on Fahi et al. [39]. Their comprehensive model based on shared resources between several departments considered the teaching constraints to optimize the energy consumption of an educational building. The model can calculate the thermal load only based on the ambient temperature. It determines the percentage reduction in the heating load of a building due to the change in room temperature, the start date of a semester, and shared classes compared to standard curricula by the Boolean method and ANAGRAM model. The results showed that the optimum curriculum is not affected by scenarios. The early two-week start of the semester and a class temperature of 23 degrees would reduce energy consumption by more than 50%.

Figure 1 depicts what parameters affect a building's energy load in general [40, 41]. Among them, occupants, air change rate, thermal resistance, and weather are significant in this study. People influence building energy use through occupancy, interactions, and behavioural efficiency [42]. Occupants add sensible and latent loads to the space, impacting cooling and heating demands [43]. A sufficient outdoor air supply is necessary for

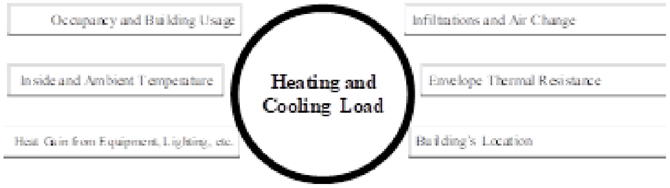


Fig. 1. Factors influencing heating and cooling load in general.

the inhabitants' well-being [45]. It also affects the building's energy demand. More fresh air leads to sensible and latent loads added to the space, meaning the airconditioning system would consume more energy to provide the heating or cooling demand [43]. Air Changes Per Hour (ACH) is the total volume of air passing through an enclosed space in one hour, equal to the space's volume [44]. One of the ways to reduce energy consumption is to lower ACH [45]. The number of people and ACH depend on the building usage. 40 to 60 % of the total heat transfer of a building occurs through envelopes [46, 47]. Therefore, the better thermal resistance of the material translates to less energy consumption [47]. The main objective of envelopes is to protect people from outside weather effects and bring a comfortable environment [48]. Weather, which relies on the building's location, is significant for determining envelopes' final design and thermal resistance [49, 50]. Other characteristics of a place are a building's positioning around other facilities or the solar radiation impact.

2. METHODOLOGY

The number of occupants, ACH, and thermal resistance are the features that would be added to the previous model to measure their effects on the results. In reality, the change in wall thickness cannot be implemented without structure calculations and other similar ones. Besides, although increasing the thickness would reduce the heating load, it affects the investment cost and the available area. Changing the weather is not among them because the location of the considered building is the same, which is Shiraz University's second engineering building complex. The approach to answering the main question is divided into simulation and demand-side management. The simulation model is used to involve the factors in the previous study. The demand-side management explains the necessary modifications that should be undertaken to the model.

A. Simulation Model

Different models to determine a building's energy load include time series, econometrics, simulation, and combined [51, 52]. Since this study aims to measure the factors' influences, the simulation method should be used. The financial aspects of choices are not involved in this research. Simulations also could be categorized into direct and indirect models [53]. The second method is similar to [36], heavily requiring installing equipment to obtain the building's data. Because there was not possible to implement these measures in the complex, the study used a direct method to determine the building's energy consumption.

A building has seven general categories of energy demand: cooling, heating, lighting, cooking, refrigeration, non-renewable electricity, and sanitation. HVAC is the most significant one on university campuses because of its noticeable energy consumption and around 40 % reduction potential [54, 55]. As a result, more studies concentrated on it. The other ones are negligible in comparison or cannot be adjusted through load management. Cooking, for example, does not exist in these buildings. Electricity by equipment always happens since it is essential for a class's functioning. The presence of electrical equipment affects the heating and cooling loads. Using these systems in the classrooms is not common in Iranian universities. Therefore, they are not investigated in this study. Since the classes are held in the daytime, lighting could be eliminated. However, the occupants would behave randomly, which could affect class prioritization. These behaviors are not assessed in this study. Lighting also follows this path, which is regularly on during class. Iranian universities generally do not have systems that simultaneously provide both heating and cooling demands [40]. Shiraz University's second engineering building complex, the previous research's location, has the same characteristic. The concentration is on the upcoming fall semester since students are anticipated to return to the class after a long period of absence. The heating demand, hence, is considered.

Building simulation models are based on fundamental heat balance principles. The model calculates the building's energy load. Temperate difference between the inside and outside causes heat transfer in a building, the basis for the considerable heat loss. Envelopes consist of various layers. Thin air heat flow on both sides of envelopes acts as thermal resistance. The overall thermal coefficient is as Equation (1).

$$U = \frac{1}{\frac{1}{f_i} + R_1 + R_2 + ... + \frac{1}{f_n}} \quad \textbf{(1)}$$

Where U is the overall coefficient, $\frac{1}{f}$ is convection thermal resistance, i is inside, O is outside, and R is the envelope's layers' thermal resistance. Then, Equation (2) determines the heat transfer from envelopes. Many features affect the thermal resistance, for example, materials, construction, or walls' thickness [56]. Analyzing the wall thickness is one of the common ways that influence the heating/cooling load.

$$Q = AU(t_1 - t_2) \quad \textbf{(2)}$$

Where Q is the heat transfer, A is the envelope's area, t_1 and t_2 are the hotter and colder sides' temperatures, respectively. Improving air change requires investment because existing equipment should be retrofitted or substituted. Infiltration happens when the pressure difference between the outside and inside results in air entry through the building's cracks [57]. It is assumed that any infiltration would mix with inside air and alter the energy load of the space. The infiltration quantity is included in ACH and could be determined by several methods like Equation (3) [58].

$$\inf iltration = (F_{Schedule}) \frac{A_L}{1000} \sqrt{C_s \Delta T + C_W (Wind\ speed)^2} \quad \textbf{(3)}$$

Where the user defines the value of $F_{Schedule}$, A_L is the effective air leakage area, C_s is the coefficient for stack-induced infiltration, C_w is the coefficient for wind-induced infiltration, and ΔT is the absolute temperature difference between indoor and outdoor air. Ventilation is intentionally controlled air entry to enhance indoor air quality [59]. There are also several methods to determine it. Equation (4) determines it and is a function of wind speed and thermal stack effect [60]. Equations (5) and (6) show how its two components should be calculated.

$$Ventilation = \sqrt{Q_S^2 + Q_W^2} \quad \textbf{(4)}$$

$$Q_s = C_D A_{opening} F_{schedule} \sqrt{2g\Delta H_{NPL}(\frac{|T_{zone} - T_{odb}|}{T_{zone}})} \quad (5)$$

$$Q_w = C_w A_{opening} F_{schedule} V \quad (6)$$

Where Q_s and Q_w are the volumetric airflow rate due to stack effect and driven by wind, respectively. And C_D is the discharge coefficient for opening, $A_{opening}$ is the open area, $F_{schedule}$ is the user-defined open area fraction, $H_N PL$ is the height from the midpoint of the lower opening to the neutral pressure level, T_{zone} is zone air dry-bulb temperature, and T_{odb} is local outdoor air dry-bulb temperature. Also,$C_w$is opening effectiveness, and V is the local wind speed. Metabolism generates heat in the human body. This heat dissipates into the building, causing impacting the energy load. The heat gain could be calculated by Equation (7) or is available in standard handbooks [61, 62]. The original formulation was in the Imperial unit, but the following is in SI.

$$\begin{gathered} S = 6.461927 + 0.946892M + 0.0000255737M^2 + \\ 7.139322T - 0.627909TM + 0.0000589172TM^2 - \\ 0.19855T^2 + 0.000940018T^2M - 0.00000149532T^2M^2 \end{gathered} \quad (7)$$

Where S is the sensible heat, M is the metabolic rate, and T is the air temperature. Software such as EnergyPlus, DesignBuilder, or Rhino employs these bases, some of which have a user-friendly graphical interface. Their proposed model is holistic and prevents verification problems. The following section explains the utilization of this part in the demand-side model.

B. Demand-Side Management Model

The previous model's objective function should be modified to include the factors' influences. Hence, the function's coefficients and the prioritizations could change. However, the modifications are carried out so that it does not alter the prioritizations because the constraint should be revised. Changing them means each university or department should develop its own model based on its rules. It is against the primary goal of this research since it seeks to investigate the three factors. In that case, there would be many additional factors apart from the main ones. It is worth mentioning that other studies used soft constraints despite Fathi et al.'s hard ones. Hard indicates the constraints must be satisfied, and soft is that if it is not met, paying fines is still acceptable. Its novelty is that every individual's limitations are answered, and there is no trade-off between variables owing to not having penalties. It gives a great advantage to the previous model and another reason for just the objective function's adjustment. The following constraints in educational planning should be met:

- Time interference between classes, like resting period
- Courses not being held due to professor scarcity
- Holding the same courses at matching times. This is necessarily not for every department. But, regarding this assumption, the only factor for taking classes by students is educational quality and other related considerations, not the time of classes
- Preventing the students' required courses at the same timeslot
- Limitation of each department's allocated classes in each timeslot
- Limitation of a professor's presence in each timeslot in a class
- Holding course (i) by the professor (j) of the department (d) at the time (k)

The proposed mathematical programming is similar to the previous study except for the objective function. Its coefficients were a function of outside and inside temperatures during class periods. Since the ambient temperature could be random at the same timeslot during various days, the coefficients of energy costs of a timeslot are determined by proper equations. These coefficients consider students' number, buildings' characteristics, outdoor and indoor climate, and occupants' behaviour. This study does not include the last part. In the study's time frame, the student arrangement did not have an influence on the prioritization.The coefficients of holding classes in each timeslot for all days ($\bar{C}_k$) are assumed equal. To quantify the factors' impacts on energy consumption,($\bar{C}_k$) in different scenarios contain students, ACH, wall thickness, and other related factors. Therefore, each scenario's useful cooling and heating energy is calculated for a year. Equations (8) and (9) present how($\bar{C}_k$) is calculated.

$$C_{i-j} = \textstyle\sum_{Day=St}^{en} \left(\sum_{K=1}^{n} (Load_{Day*\frac{j-i}{n}*24+i+\frac{j-i}{n}*K}) \right) \quad (8)$$

$$\bar{C} = \frac{C}{\|C\|_{\infty}} \quad (9)$$

Where $Load_t$ of timeslots is a function of factors determined by the simulation model. C_{i-j} is the energy cost of cooling/heating services for holding a class in the period between i and j. n is the number of temperatures measured during i to j. $st$is the first and en is the last day of a semester. C is a coefficient vector of the energy cost of providing cooling/heating load. $\|C\|_{\infty}$is infinity norm and $\bar{C}$ is the normalized vector of energy cost. Regarding the randomness of temperature in a specific period of the day and not considering temperature forecast for these periods, the energy cost coefficients are the same if other factors are constant. Achieving this requires gathering the cooling/heating load of timeslots and then normalizing the energy cost coefficients. This model is presented in Table (1).
Where $x_{idjd^{kd}}$ is the binary decision variables. λ is a subset of the conventional intervals. i_d and j_d are a course and a faculty member of the department. K is the number of time slots in a week. $N_k d$ is the number of classes assigned to a department in a time slot.

3. RESULTS AND DISCUSSION

In this section, the case study is described. The results are then presented.

A. Second Engineering Building Complex

First, the weather features of Shiraz are described and then the building itself is outlined. The university's second engineering complex is situated in Shiraz. This city is located in southwestern Iran. Its climate is categorized as hot and semi-arid, with hot summers and cool winters [63]. Some days the temperature is below freezing. Figure (2) shows the annual temperature of Shiraz. It also depicts Iranian universities' fall and winter

Table 1. The revised mathematical programming model based on [40,64]

$Min\ Z_d = \sum_{k}\sum_{j_d}\sum_{i_d} \bar{C}_k\ (ACH\ ,\ OCC\ ,\ Building\ ,\ Weather\ Conditions\ ,\ T_{setpoint}\ ,\ Neighborhood)\ x_{idjd^{kd}}$			
First set of constraints General set of constraints	$x_{i_d j_d k_d} = 0$	$\forall \lambda \in \lambda, \lambda \subseteq K$	Time interference between classes
Second set of constraints General set of constraints	$x_{i_d j'_d k'_d} = 0$	$\forall j'_d \in j'_d, j'_d\ , \subseteq K$	Course not being held due to professor scarcity
Third set of constraints Specific set of constraints	$x_{\alpha j_d}{}^{kd} = x_{\alpha j'_d}{}^{kd}$	$\forall j_d\ \&\ j'_d\ , \in j_d$ $\forall \alpha \in I_d\ ,\ \forall k \in K$	Holding the same courses at matching times
Fourth set of constraints General set of constraints	$x_{i_d j_d kd} + x_{i_d j'_d kd}\ \leq\ \tau_{jj'}$	$\tau \in \{1,2\}\ ,\ \forall i_d$ $i'_d \in I_\alpha\ ,\ \forall j_d \& j'_d \in j_\alpha$	Preventing the students required courses at the same time slot
Fifth set of constraints General set of constraints	$\sum_{i_d=1}^{I_d} \sum_{j_d}^{J_d} x_{i_d j_d kd}\ ,\ \leq N_{kd}$	$\forall k \in K$	limitation of each department's allocated classes in each timeslot
Sixth set of constraints Specific set of constraints	$\sum_{j_d}^{J_d} x_{i_d j_d kd} \leq 1$	$\forall k \in K\ \ ,\ \forall i_d \in I_d$	Limitation of a professor's presence in each timeslot in a class
Upper and lower boundary	$x_{i_d j_d kd}$: $Boolean$		Holding course by the professor of the department at the time

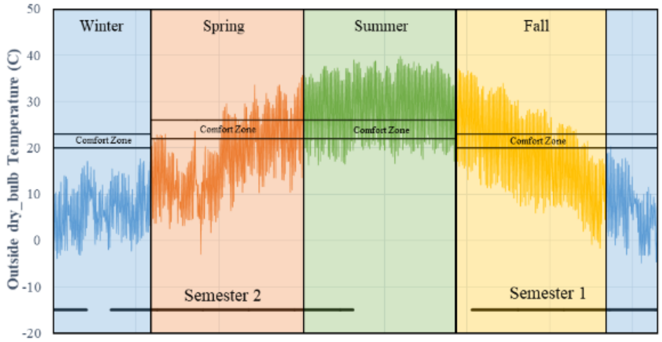
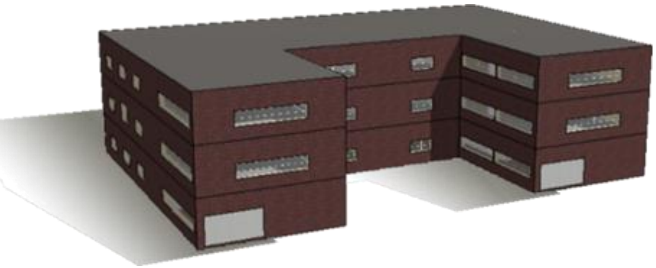


Fig. 2. Shiraz's annual temperature

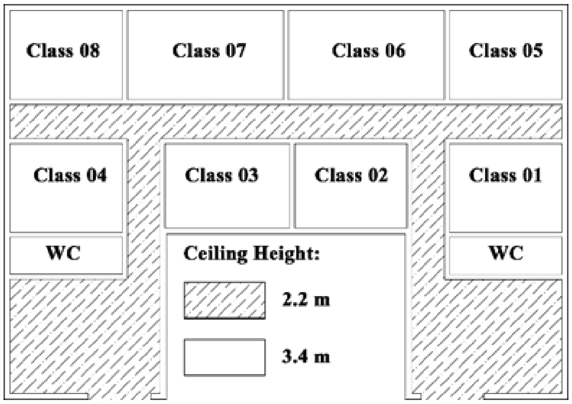
semesters duration based on the Iranian calendar. The Fathi et al. study demonstrated starting the semester in summer will significantly reduce energy consumption, which can also be seen in the chart. Through this strategy, the outside air temperature range approaches the comfort zone, reducing the need for a cooling system. There are also restrictions on starting classes in the summer. The most important limitation is the lack or inefficient operation of a cooling system in educational environments. Due to the different climates in different countries, zero to 93 days can be considered for this transfer of study program. The other reason for limiting the start of classes in the summer is the beliefs and habits of the people about summer, which have accepted this season as a holiday. The studied building's primary usage is for holding classes. These buildings, utilized for teaching purposes, have higher energy consumption than all campus buildings [64]. The building contains eight classrooms, two bathrooms and a corridor on its three floors. The hall ceiling height is 2.2 meters; in other parts, it increases to 3.4 meters. The building is graphically modelled to consider the interactions between floors and simulate the total energy load. The building and its floor plan with each part's dimensions are displayed in Figure (3).

B. Results of Considering the Three Factors in the Model

The impacts of changing ACH, number of students, and wall resistance on the beginning date of semesters of the heating load are assessed. The results are also compared with the simple thermal model, not requiring the building's specific characteristics and outdoor climate. Because the majority of Iran is located in a hot and dry climate, one of the best strategies is to start universities and schools earlier until the less demanded period for cooling. This method, therefore, is analyzed. ACH changes from 1.5 to 12. The walls' thickness equals the same quantity of existing value to 1.6 times of it. The students are between 10 and 40 people. Figure (4) presents the effect of ACH, the students' number, and wall thickness in the three different starting dates on the heating energy cost of each timeslot. These dates are usual and one-week and two-week earlier Figure (5) shows the calculated coefficient of normalized heating expenses in each timeslot with the help of the previous model. The normalized coefficient cost of each scenario is shown in Figure (6). Figure (4) delineates that changing three factors does not affect the class times from the energy standpoint. Comparing these results with Figure (5) reveals that the precise models do not improve educational timetabling in contrast to the low-computational load models. Therefore, Fathi et al.'s model can be used unless the amount of energy reduction is not the main focus of scheduling. Although the priority of classes does not change with increasing ACH, normalized cost coefficients rise except for the first timeslot. Comparing it to Figure (6) indicates that the higher ACH, the higher the energy expenses in all timeslots. Thus, Reducing air leakages and better controlling HVAC decrease energy consumption. Similarly to this, increasing wall thickness



a: The building



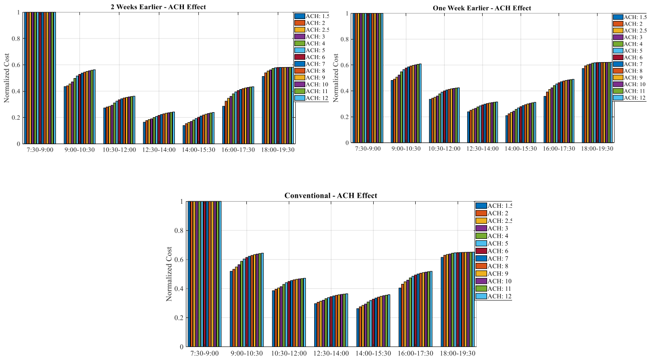
b: Floor plan

Fig. 3. Shiraz University's second engineering building and its floor plan

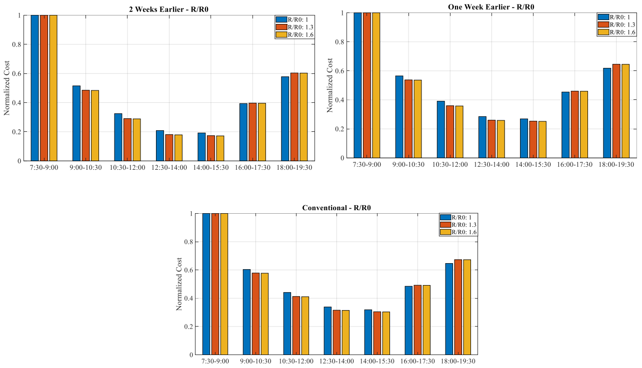
does not impact the priority. It, however, reduces normalized cost coefficients. This rise causes a decline in energy use, raising investment costs. The number of students has the same effect as the other two and reduces the coefficients. Its increase leads to a reduction in heating energy costs and merges two demandant student groups into one, meaning a cost reduction. But it is also associated with a plummet in learning quality and lower demand for students. These challenges could be solved through smaller classes. The earlier beginning of all scenarios results in a decrease in energy consumption. This happens because the semester would be in the more moderate weather condition of the year. The climate data demonstrates that an early start of more than two weeks needs cooling systems in Shiraz. The other effect is the earlier start of the next semester, cutting the cooling load.

Analyzing the four factors' effects on coefficients of the cost of holding a class per timeslot shows that adjusting ACH and the semester's earlier start considerably influence the heating energy load. This is presented in Figure (7).

Changing ACH, early beginning, and optimal timetabling are the best strategies to reduce the heating load in cold seasons. The last two have the lowest implementation costs. Figure (8) shows the projected range of heating load reduction if applying the optimal scheduling and keeping operational conditions. In these circumstances, the reduction is between 11.5 to 24.5 %. As this figure indicates, the share of heat load reduction when the optimal scheduling is implemented without changing other conditions in the early start is more than others. The maximum reduction in this situation is 24 %. The results show that the semester's earlier beginning can reduce heating load between 36.7 to 52.2 %, typically around 40 %. Also, if it is accompanied by optimal timetabling, the reduction is 49.4 – 63.4



a: various ACHs, room temperature of 23°C, 25 students, and normal wall thickness



b: various wall thicknesses, room temperature of 23°C, 25 students, and ACH around 5

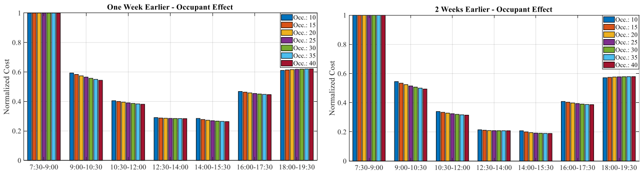
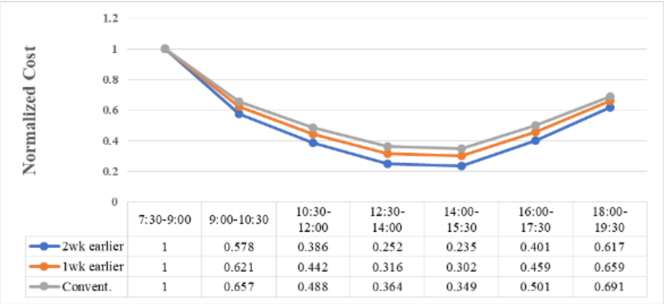


Fig. 4. Energy cost coefficient of holding classes in each timeslot for different ACHs, students' numbers, and wall thicknesses in the three beginning dates of the semester



	7:30-9:00	9:00-10:30	10:30-12:00	12:30-14:00	14:00-15:30	16:00-17:30	18:00-19:30
2wk earlier	1	0.578	0.386	0.252	0.235	0.401	0.617
1wk earlier	1	0.621	0.442	0.316	0.302	0.459	0.659
Convent.	1	0.657	0.488	0.364	0.349	0.501	0.691

Fig. 5. Coefficient of normalized heating costs

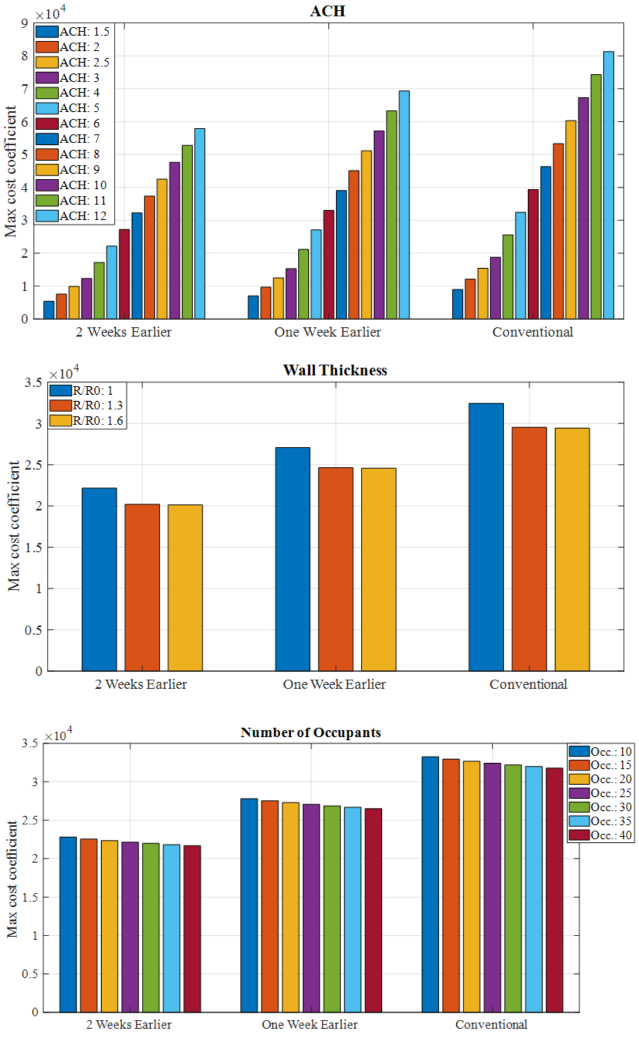
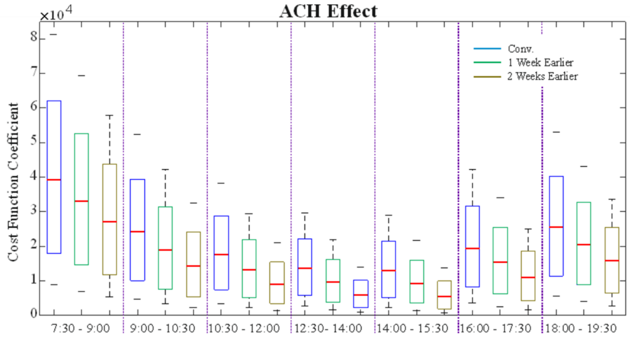
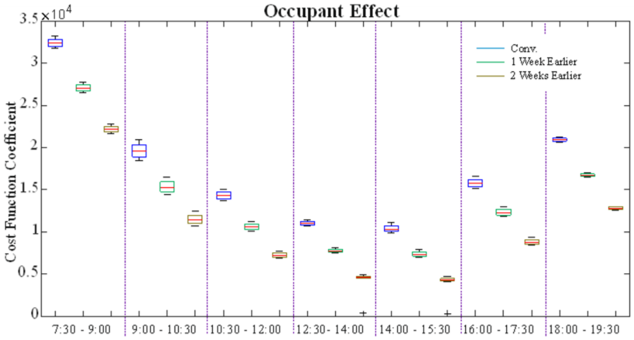


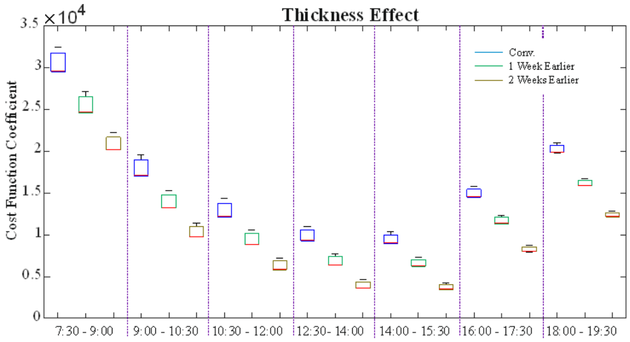
Fig. 6. Normalized coefficient cost of each scenario



a: Changing ACH



b: Changing the number of students



c: Changing wall thickness

Fig. 7. Intervals of coefficients of the cost of holding a class per timeslot

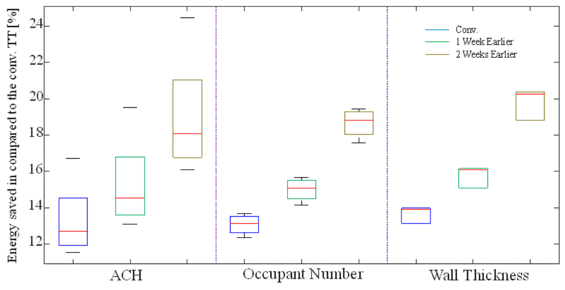


Fig. 8. Effects of the semester's early start on the heating load reduction

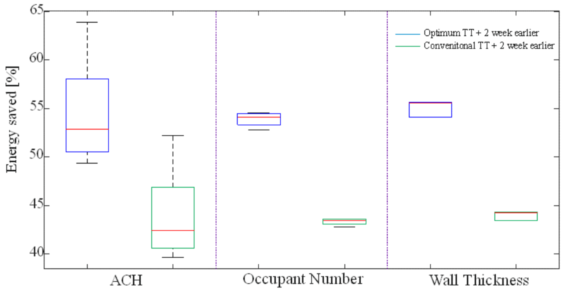


Fig. 9. Effects of the semester's early start on the heating load reduction

%, typically around 50 %. Figure (9) indicates the range of heating load reduction with the early start in different scenarios. Among the strategies, the beginning of the semester is the most important because of the case study's mild weather and optimal timetabling. Applying them does not significantly impact investment and operational expenses besides their influences. If the heating load reduction prediction is not that important, using the building's thermal model, which does not require the building's characteristics and operational situations, can be a better option.

4. CONCLUSION

Load management is among the conventional measures to reduce energy consumption and the peak. Academic timetabling is one of these methods. It not only has a suitable time for courses and allows students to take the maximum number of courses but also lowers energy costs. Its noticeable challenge is possessing a great number of decision variables and constraints. To carry out its objective function, which is minimizing energy expenses, this model requires the thermal model of the building and its surroundings, indoor climate control, weather condition, number and behaviour of students, and other related considerations. Although a rise in students without considering their random behaviors would decrease the heating demand, using this method is not always possible. Altering ACH would affect indoor air quality and, therefore, the quality of education. But optimally modifying ACH could reduce energy consumption while keeping the quality of education. Another common strategy is beginning the fall semester early. As long as the cooling load is small, this method is proper because the spring semester could end early, cutting the cooling load. The objective function of this study can consider the heating/cooling energy demand, quantifying solar radiation influences, ambient temperature, operating conditions, students number, and adjacent buildings. Its constraints are like the previous research [40]. The prioritization of the class times from the energy consumption view is based on ambient temperature during the semester. And this prioritization could change every day. However, the class timing cannot change. Therefore, ACH, wall thickness, and the number of students can be analyzed. In this study, ACH is between 1.5 and 12, wall thickness is up to 1.6 of its normal value, and students are 10 to 40. They represent the uncertainty of students' presence, outside and inside climate, and different buildings. The Second Engineering Building Complex of Shiraz University has three different starting dates. The results demonstrate that these three factors do not affect the priority of timeslots for holding classes from the energy use viewpoint. These priorities are aligned with the previous study. The optimal scheduling with keeping conditions of use of the class and the semester's start can cut the heating load by 11.5 to 24.5 %. With a two-week earlier beginning, this strategy will decrease the load between 49.4 – 63.9 %.

REFERENCES

1. L. Cozzi, T. Gould, S. Bouckart, D. Crow, T.-Y. Kim, C. McGlade, P. Olejarnik, B. Wanner, and D. Wetzel, "World energy outlook 2020," *International Energy Agency: Paris, France*, pp. 1–461, 2020.
2. S. S. Ghouri, "World energy outlook-2050: Policy options," 2007.
3. A. Albatayneh, D. Alterman, A. Page, and B. Moghtaderi, "The impact of the thermal comfort models on the prediction of building energy consumption," *Sustainability*, vol. 10, no. 10, p. 3609, 2018.
4. L. Pérez-Lombard, J. Ortiz, and C. Pout, "A review on buildings energy consumption information," *Energy and buildings*, vol. 40, no. 3, pp. 394–398, 2008.
5. E. A. O. Batlle, J. C. E. Palacio, E. E. S. Lora, A. M. M. Reyes, M. M. Moreno, and M. B. Morejón, "A methodology to estimate baseline energy use and quantify savings in electrical energy consumption in higher education institution buildings: Case study, federal university of itajubá (unifei)," *Journal of Cleaner Production*, vol. 244, p. 118551, 2020.
6. M. S. Gul and S. Patidar, "Understanding the energy consumption and occupancy of a multi-purpose academic building," *Energy and Buildings*, vol. 87, pp. 155–165, 2015.
7. A. Enshassi, A. Ayash, and S. Mohamed, "Key barriers to the implementation of energy-management strategies in building construction projects," *International Journal of Building Pathology and Adaptation*, vol. 36, no. 1, pp. 15–40, 2018.
8. R. Bisset, "Buildings can play a key role in combating climate change," *Bulletin on Energy Efficiency*, vol. 7, no. 4, 2007.
9. B. Ó. Gallachóir, M. Keane, E. Morrissey, and J. O'Donnell, "Using indicators to profile energy consumption and to inform energy policy in a university—a case study in ireland," *Energy and Buildings*, vol. 39, no. 8, pp. 913–922, 2007.
10. E. Azar and C. C. Menassa, "A comprehensive analysis of the impact of occupancy parameters in energy simulation of office buildings," *Energy and buildings*, vol. 55, pp. 841–853, 2012.
11. M. H. Chung and E. K. Rhee, "Potential opportunities for energy conservation in existing buildings on university campus: A field survey in korea," *Energy and Buildings*, vol. 78, pp. 176–182, 2014.
12. E. Azar and C. C. Menassa, "Agent-based modeling of occupants and their impact on energy use in commercial buildings," *Journal of Computing in Civil Engineering*, vol. 26, no. 4, pp. 506–518, 2012.
13. A. Emery and C. Kippenhan, "A long term study of residential home heating consumption and the effect of occupant behavior on homes in the pacific northwest constructed according to improved thermal standards," *Energy*, vol. 31, no. 5, pp. 677–693, 2006.
14. A. Meier, "Operating buildings during temporary electricity shortages," *Energy and Buildings*, vol. 38, no. 11, pp. 1296–1301, 2006.

15. R. Lewis, “A survey of metaheuristic-based techniques for university timetabling problems,” *OR spectrum*, vol. 30, no. 1, pp. 167–190, 2008.
16. V. A. Bardadym, “Computer-aided school and university timetabling: The new wave,” in *international conference on the practice and theory of automated timetabling*, pp. 22–45, Springer, 1995.
17. M. Ayob and G. Jaradat, “Hybrid ant colony systems for course timetabling problems,” in *2009 2nd Conference on Data Mining and Optimization*, pp. 120–126, IEEE, 2009.
18. P. De Causmaecker, P. Demeester, and G. V. Berghe, “A decomposed metaheuristic approach for a real-world university timetabling problem,” *European Journal of Operational Research*, vol. 195, no. 1, pp. 307–318, 2009.
19. M. Lindahl, A. J. Mason, T. Stidsen, and M. Sørensen, “A strategic view of university timetabling,” *European Journal of Operational Research*, vol. 266, no. 1, pp. 35–45, 2018.
20. M. Lindahl, T. Stidsen, and M. Sørensen, “Quality recovering of university timetables,” *European Journal of Operational Research*, vol. 276, no. 2, pp. 422–435, 2019.
21. S. Daskalaki, T. Birbas, and E. Housos, “An integer programming formulation for a case study in university timetabling,” *European journal of operational research*, vol. 153, no. 1, pp. 117–135, 2004.
22. M. Mühlenthaler and M. Mühlenthaler, *Fairness in academic course timetabling*. Springer, 2015.
23. M. Khoshbakht, Z. Gou, and K. Dupre, “Energy use characteristics and benchmarking for higher education buildings,” *Energy and Buildings*, vol. 164, pp. 61–76, 2018.
24. M. Bourdeau, X. Guo, and E. Nefzaoui, “Buildings energy consumption generation gap: A post-occupancy assessment in a case study of three higher education buildings,” *Energy and Buildings*, vol. 159, pp. 600–611, 2018.
25. H. N. Rafsanjani, C. R. Ahn, and J. Chen, “Linking building energy consumption with occupants’ energy-consuming behaviors in commercial buildings: Non-intrusive occupant load monitoring (niolm),” *Energy and buildings*, vol. 172, pp. 317–327, 2018.
26. X. Gui, Z. Gou, and F. Zhang, “The relationship between energy use and space use of higher educational buildings in subtropical australia,” *Energy and Buildings*, vol. 211, p. 109799, 2020.
27. A. Al-Daraiseh, N. Shah, and E. El-Qawasmeh, “An intelligent energy management system for educational buildings,” *International Journal of Distributed Sensor Networks*, vol. 9, no. 9, p. 209803, 2013.
28. M. F. Haniff, H. Selamat, R. Yusof, S. Buyamin, and F. S. Ismail, “Review of hvac scheduling techniques for buildings towards energy-efficient and cost-effective operations,” *Renewable and Sustainable Energy Reviews*, vol. 27, pp. 94–103, 2013.
29. A. Capozzoli, M. S. Piscitelli, A. Gorrino, I. Ballarini, and V. Corrado, “Data analytics for occupancy pattern learning to reduce the energy consumption of hvac systems in office buildings,” *Sustainable cities and society*, vol. 35, pp. 191–208, 2017.
30. S. Acharya, A. Shil, C. Debbarma, J. Reang, R. Chakraborty, and A. Ghosh, “Analysis of energy consumption, emission and saving opportunities in an educational institute in northeast india,” *International Journal of Energy and Water Resources*, vol. 4, pp. 375–388, 2020.
31. B. Vand, K. Martin, J. Jokisalo, R. Kosonen, and A. Hast, “Demand response potential of district heating and ventilation in an educational office building,” *Science and Technology for the Built Environment*, vol. 26, no. 3, pp. 304–319, 2020.
32. Z. Yang and B. Becerik-Gerber, “The coupled effects of personalized occupancy profile based hvac schedules and room reassignment on building energy use,” *Energy and Buildings*, vol. 78, pp. 113–122, 2014.
33. K. Sethanan, S. Theerakulpisut, and C. Benjapiyaporn, “Improving energy efficiency by classroom scheduling: a case study in a thai university,” *Advanced Materials Research*, vol. 931, pp. 1089–1095, 2014.
34. B. Lim, M. Van Den Briel, S. Thiébaux, S. Backhaus, and R. Bent, “Hvac-aware occupancy scheduling,” in *Proceedings of the AAAI conference on artificial intelligence*, vol. 29, 2015.
35. T. Jafarinejad, A. Erfani, A. Fathi, and M. B. Shafii, “Bi-level energy-efficient occupancy profile optimization integrated with demand-driven control strategy: University building energy saving,” *Sustainable Cities and Society*, vol. 48, p. 101539, 2019.
36. J. Kim, T. Hong, J. Jeong, M. Lee, M. Lee, K. Jeong, C. Koo, and J. Jeong, “Establishment of an optimal occupant behavior considering the energy consumption and indoor environmental quality by region,” *Applied Energy*, vol. 204, pp. 1431–1443, 2017.
37. Y. Sun, X. Luo, and X. Liu, “Optimization of a university timetable considering building energy efficiency: An approach based on the building controls virtual test bed platform using a genetic algorithm,” *Journal of Building Engineering*, vol. 35, p. 102095, 2021.
38. J. Yeo, Y. Wang, A. K. An, and L. Zhang, “Estimation of energy efficiency for educational buildings in hong kong,” *Journal of Cleaner Production*, vol. 235, pp. 453–460, 2019.
39. A. Fathi, M. Salehi, M. Mohammadi, Y. Rahimof, and P. Hajialigol, “Cooling/heating load management in educational buildings through course scheduling,” *Journal of Building Engineering*, vol. 41, p. 102405, 2021.
40. J. Kim, T. Hong, J. Jeong, C. Koo, and M. Kong, “An integrated psychological response score of the occupants based on their activities and the indoor environmental quality condition changes,” *Building and Environment*, vol. 123, pp. 66–77, 2017.
41. H. Yoshino, T. Hong, and N. Nord, “Iea ebc annex 53: Total energy use in buildings—analysis and evaluation methods,” *Energy and Buildings*, vol. 152, pp. 124–136, 2017.
42. S. Chen, G. Zhang, X. Xia, Y. Chen, S. Setunge, and L. Shi, “The impacts of occupant behavior on building energy consumption: A review,” *Sustainable Energy Technologies and Assessments*, vol. 45, p. 101212, 2021.
43. V. Garg, J. Mathur, and A. Bhatia, *Building energy simulation: A workbook using designbuilder™*. CRC Press, 2020.
44. P. S. Charlesworth, “Air exchange rate and airtightness measurement techniques-an applications guide.,” 1988.
45. N. H. Abu-Hamdeh, R. A. Alsulami, and R. I. Hatamleh, “A case study in the field of building sustainability energy: Performance enhancement of solar air heater equipped with pcm: A trade-off between energy consumption and absorbed energy,” *Journal of Building Engineering*, vol. 48, p. 103903, 2022.
46. F. Ascione, N. Bianco, G. M. Mauro, and D. F. Napolitano, “Building envelope design: Multi-objective optimization to minimize energy consumption, global cost and thermal discomfort. application to different italian climatic zones,” *Energy*, vol. 174, pp. 359–374, 2019.
47. X. Meng, Y. Huang, Y. Cao, Y. Gao, C. Hou, L. Zhang, and Q. Shen, “Optimization of the wall thermal insulation characteristics based on the intermittent heating operation,” *Case studies in construction materials*, vol. 9, p. e00188, 2018.
48. J. Kočí, V. Kočí, J. Maděra, and R. Černỳ, “Effect of applied weather data sets in simulation of building energy demands: Comparison of design years with recent weather data,” *Renewable and Sustainable Energy Reviews*, vol. 100, pp. 22–32, 2019.
49. B. Chen, Q. Liu, H. Chen, L. Wang, T. Deng, L. Zhang, and X. Wu, “Multiobjective optimization of building energy consumption based on bim-db and lssvm-nsga-ii,” *Journal of Cleaner Production*, vol. 294, p. 126153, 2021.
50. W. A. Friess and K. Rakhshan, “A review of passive envelope measures for improved building energy efficiency in the uae,” *Renewable and Sustainable Energy Reviews*, vol. 72, pp. 485–496, 2017.
51. V. Harish and A. Kumar, “A review on modeling and simulation of building energy systems,” *Renewable and sustainable energy reviews*, vol. 56, pp. 1272–1292, 2016.
52. C. Deb, F. Zhang, J. Yang, S. E. Lee, and K. W. Shah, “A review on time series forecasting techniques for building energy consumption,” *Renewable and Sustainable Energy Reviews*, vol. 74, pp. 902–924, 2017.
53. M. Krarti, *Energy audit of building systems: an engineering approach*. CRC press, 2020.
54. A. Escobedo, S. Briceño, H. Juárez, D. Castillo, M. Imaz, and C. Sheinbaum, “Energy consumption and ghg emission scenarios of a university campus in mexico,” *Energy for sustainable development*, vol. 18, pp. 49–

57, 2014.
55. T. A. Nguyen and M. Aiello, “Energy intelligent buildings based on user activity: A survey,” *Energy and buildings*, vol. 56, pp. 244–257, 2013.
56. C. Peng and Z. Wu, “In situ measuring and evaluating the thermal resistance of building construction,” *Energy and Buildings*, vol. 40, no. 11, pp. 2076–2082, 2008.
57. K. Gowri, D. W. Winiarski, and R. E. Jarnagin, “Infiltration modeling guidelines for commercial building energy analysis,” tech. rep., Pacific Northwest National Lab.(PNNL), Richland, WA (United States), 2009.
58. M. H. Sherman, “Infiltration-pressurization correlation: Simplified physical modeling,” 1980.
59. M. J. Sorgato, A. P. Melo, and R. Lamberts, “The effect of window opening ventilation control on residential building energy consumption,” *Energy and Buildings*, vol. 133, pp. 1–13, 2016.
60. A. Handbook-Fundamentals, “American society of heating,” *Refrigerating and Air-Conditioning Engineers*, 2009.
61. C. C. C. A. C. Company, *Handbook of air conditioning system design*, vol. 1. McGraw-Hill Companies, 1965.
62. S. Edition, “Ashrae handbook,” *Stephen Comstock: Atlanta, GA, USA*, 1993.
63. G. Roshan, M. Moghbel, and S. Attia, “Evaluating the wind cooling potential on outdoor thermal comfort in selected iranian climate types,” *Journal of Thermal Biology*, vol. 92, p. 102660, 2020.
64. X. Gui, Z. Gou, and Y. Lu, “Reducing university energy use beyond energy retrofitting: The academic calendar impacts,” *Energy and Buildings*, vol. 231, p. 110647, 2021.