Evaluation of the occupancy patterns effect and managerial decisions on the energy consumption of an educational building

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Manuscript received 12 April, 2022; revised 16 August, 2022; accepted 26 September, 2022. Paper no. JEMT-2204-1378.

Identifying and modeling the occupancy pattern and variable parameters affecting the energy consumption of a building is a key factor in optimizing the energy consumption in the buildings. In addition to the fixed parameters, variable parameters such as occupancy patterns affect the energy consumption of buildings. These factors are the most important issues that can help to reduce the difference between actual and simulated energy consumption. There is only a little evidence in the literature regarding the pattern of the occupant. Factors that are heavily dependent on the occupancy pattern include lighting, heating, cooling, and so on. In large commercial or office buildings, the implementation of some management programs helps to reduce energy consumption. This study aims to investigate the effect of occupancy patterns, facility managers, and managerial decisions on the cooling energy consumption in an educational building in Tehran to reduce uncertainty in the energy consumption forecasting. This study examines the influence of the presence of an occupant, aggregation of places, and the change in the temperature set point based on the Predicted Mean Vote (PMV) index on the cooling energy consumption in an educational building. It should be noted that suggesting some new managerial methods are considered as the innovations of the present study. Among the tested various methods for reducing the cooling energy consumption, changing the temperature set point of the cooling system by 4.26% had the greatest impact on the reduction of the cooling energy consumption in the building.

keywords: *Occupancy pattern, PMV index, Building simulation, Behavioral pattern, Energy saving in buildings.*

http://dx.doi.org/10.22109/JEMT.2022.337274.1378

1. INTRODUCTION

The energy consumption and the CO2 emission in the building sector account for 20.1% of the total energy consumption as well as 30% of the total emitted CO2 worldwide[1]. Moreover, according to the estimations, the energy consumption will be increased by 1.5% per year from 2012 to 2040 in this sector [2]. In this regard, a sizeable number of researches have been conducted on the reduction of the energy consumption in this sector to decrease the global energy consumption and the environmental impacts[3]. Recently, there has been a great emphasis on the following areas of research: the effect of dynamic behavior in the building, the presence of individuals, and the changes in comfort temperature with respect to the number of persons on energy consumption in the building sector. It should be noted that the energy consumption in buildings is affected by six driving factors including (1) climate, (2) building envelope, (3) building energy and services systems, (4) indoor design criteria, (5) building operation and maintenance, and (6) occupancy pattern[2]. Moreover, there are two ways to reduce the energy consumption in the buildings: improving technology and materials used in the building and occupational awareness. Improving occupancy patterns like employing the high energy efficiency equipment for cooling and heating of buildings, utilization of energy saving lamps, wearing appropriate clothes, etc. are the easier ways to save energy[2],[3],[4]. Several studies have analyzed the prominent role of occupancy pattern in the variations in energy consumption in different buildings[5],[6], [7]. Various factors such as lighting, electric consumption loads, heating-ventilation-air conditioning (HVAC), equipment utilization, and fresh air requirements could be affected by the occupancy pattern[8]. Research studies estimated that there is approximately a 300% difference between the actual and simulated energy consumption in the building sector[9]. Therefore, identifying occupancy pattern can help reduce such a difference. Accordingly, E. Delzendeh et al.[9] provided a comprehensive review of observational studies on adaptive occupancy pattern in buildings and proposed that active and passive occupant energy behaviors are not fully reflected within existing energy analysis instruments. Thus, they recommended that researchers and designers should improve the calculation of the energy consumption in buildings by considering occupant energy behaviors. V. M. Barthelmes et al. [10] simulated the energy consumption in a building and demonstrated potential different occupant behavior lifestyles in energy consumption in buildings. The results of their study indicated that the energy consumption varied between -24% and +26% in low consumption cases and high consumption cases in comparison with the base case. It is generally believed that air conditioning is recognized as the largest energy consuming sector in the buildings[11]. Moreover, a series of indexes that define the level of thermal comfort is used to calculate the impact of occupant behaviors and managerial decisions on cooling energy consumption reduction in buildings. Thermal comfort is a subjective manner based on a person's feelings; so, it may vary from an individual to another individual [11],[12]. M. H. Hasan et al. [12] claimed that determining the range of thermal comfort can have a significant impact on the energy consumption of the buildings. Several attempts have been made to design a unique and widely accepted thermal comfort model that can be approved by a great number of researchers in this field. ANSI/ASHRAE Standard 55 described the thermal comfort zone for people in the buildings. Accordingly, this standard highlights the combinations of indoor thermal environmental factors (temperature, thermal radiation, humidity, and air speed) and personal factors (related to activities and clothing) which can create tolerable thermal environmental conditions for most occupants in the space[13]. The thermal sensation of the occupants is predicted by applying the thermal comfort indicators. The PMV index is considered one of the prominent indicators to measure the level of thermal comfort. Hence, various factors such as physical activity and the amount of clothing have been taken into account in order to measure this index [11]. PMV index was also developed by P. O. Fanger (P.O. Fanger) as an empirical fit to the human sensation of thermal comfort. However, it was later adopted as an ISO standard. Moreover, numerous studies have investigated the thermal comfort zone using the PMV index[14]. Shao [15] implemented PMV index and green building to analyze the intelligent control system of indoor environment. human metabolic rate, human external work, and heat resistance of clothes, temperature, and air were used in PMV mathematical model. The suitable PMV value in different temperatures was defined. He found the PMV variation diagram under different control modes of building and energy saving amount. Espejel-Blanco et al. (Espejel-Blanco et al, 2021) used a design approach to control an HVAC, focused on an energy consumption reduction based on PMV method in the operation of the HVAC system of a building. Their proposed PMV-based temperature control system for the HVAC equipment achieved energy savings ranging from 33% to 44%. Conceição et al. (Conceição et al. 2018) carried out numerical research on the control of HVAC system based on the PMV index in university buildings located in the south of Portugal. They implemented numerical simulation to simulate the thermal behavior of buildings and the thermal comfort of occupants in transient thermal environment. Their results revealed that the application of PMV control allows to guarantee, in an efficient way of thermal comfort, both in winter and summer conditions, in most of the rooms of the building. Broday et al. [16] developed a Monte Carlo method to evaluate PMV and Predicted Percentage of Dissatisfied (PPD) indices uncertainties based on input variables and respective uncertainties. Also, it was employed to analyze different scenarios related to the metrological quality of indoor climate measurement equipment. Zhang et al. [17] developed a method based on PMV to evaluate the thermal characteristics of the submarine cabin and the changes in crew comfort on manned deep-sea mission. They found that the clothing and activity criteria greatly impacted on the PMV index. They implemented MATLAB to calculate the PMV index and PPD and showed PMV/PPD dynamic curve. An investigation of the effects of occupant control over their thermal environments and its effect on cooling energy consumption was carried out in seven air-conditioned buildings in South Korea. It would be possible to reduce cooling energy consumption by 9% without sacrificing thermal comfort if occupants were more aware of the thermal environment [18]. The vast majority of thermal comfort systems use predicted mean vote (PMV)-based management, which incorporates environmental variables as well as ambient temperature [19]. Zhanbo Xu et al. [20] developed a novel method for optimizing building operations by using the PMV index. As a result of describing thermal comfort using the PMV model, they found that the buildings could save energy and cost. Compared to using a static range of indoor air temperature, it can provide more availability of demand response. Moreover, they demonstrated numerically that their method can reduce communication and computational resources while providing a robust solution to uncertainty prediction errors. By using the PMV index, Wang et al. examined the efficiency of retrofitting existing hotels with energy-saving measures. A mathematical static analysis and field tests were conducted to evaluate the energy saving benefits. Energy saving retrofitting was evaluated based on simulated energy consumption, economics, and thermal comfort indicators [21]. The present study aims at filling the research gap energy consumption reduction of educational buildings implementing thermal comfort index, providing managerial solutions such as aggregating different places and changing the temperature setpoint for a real educational building. The solutions presented in this paper will be helpful in energy consumption reduction, especially in cases where the presence of people is small. It should be noted that assessing the changes in temperature set point based on the PMV index during different months as well as suggesting some new managerial methods are considered as the innovations of the present study. Due to the high share of air conditioning in the energy consumption of buildings and the undeniable effect of occupancy pattern behaviors on energy consumption in this sector, this study aims to examine various behavioral factors and managerial decisions affecting the energy consumption of air conditioning in an educational building. The main objective of this study is to set the correlation between cooling energy consumption and occupancy pattern in an educational building to create occupant awareness about the amount of energy that can be saved based on the PMV index. Inspiring occupants to pay more attention to energy saving issues is the ultimate goal of this research. As a case study, the Department of Energy Engineering at Sharif University of Technology in Tehran has been selected to be investigated in the present study. There are generally two types of parameters to reduce the energy consumption in a building: fixed parameters and variable parameters (Fig. 1). Fixed parameters include climate, construction and materials of the building, as well as the type of the buildings. Moreover, Variable parameters include occupant effect, operation and maintenance of the building equipment. In the present study, after identifying and modeling fixed parameters in the building, the researchers attempted to analyze the effect of variable parameters comprising of the number of occupants in different places of the department in a constant set-point temperature, the aggregation of different places of the department and the change of temperature set-point according to the PMV index. The parameters for personal effect, Influence on thermal comfort index (PMV) which will be explained further in Section 2-3. For example, clothing culture and level of clothing have a direct impact on the value of the PMV index. In addition, the amount of cooling energy consumption has been calculated for different values of these parameters. In the present study,

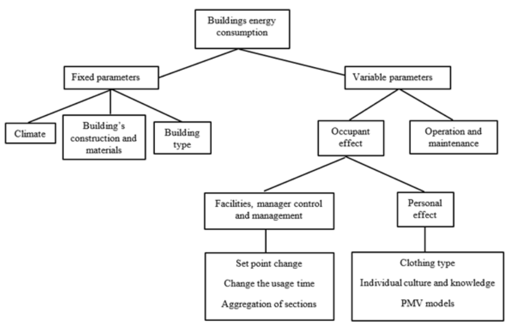

Fig. 1. Factors affecting the reduction of the energy consumption in buildings

to fill the research gap in identifying the actual and simulated cooling energy consumption in the educational building, a series of managerial strategies were applied based on the PMV index to calculate the reduction of cooling energy consumption in the educational building. This has been highlighted as the novelty of the present work. These solutions are easy to implement and do not require high investment costs. Moreover, only the effect of occupancy behavior on the energy consumption of buildings has been studied in previous articles and managerial decisions in crowded buildings such as the educational building have not been taken into consideration. In this regard, this research proposed an assessment of the changes in temperature set point based on the PMV index throughout different months as well as suggestions on some new managerial methods to reduce the cooling energy consumption. It is also worth mentioning that implementing these methods doesn't interfere with the comfort level of people and the work condition of the educational building.

2. MATERIAL AND METHODS

A. Overview of the framework

At the beginning of the project, a detailed HVAC model has been developed in Energy Plus software which considers building envelop, HVAC zones, and the HVAC components (Detailed audit). The model has then been verified using hourly gas consumption data of the Energy Engineering Department (High-res data and short-term energy monitoring). Since absorption chillers are used for cooling and the main consumption of absorption chillers is natural gas, only natural gas consumption has been studied. Energy Plus simulation and monthly gas bills were used to verify (MV) the effectiveness of control and retrofit actions on cooling gas consumption. Then, the researchers reviewed various applicable behavioral solutions that can reduce energy consumption and calculated the amount of the energy consumption reduction in each method. Energy Plus is used to calculate the cooling load of the Department of Energy Engineering (DOEE). The cooling load is a function of the ambient temperature and the thermal comfort zone. The thermal comfort zone in the building is determined using the PMV index. The PMV index is the most used index for the assessment of thermal conditions in indoor environments (Shan Gao, 2020). As the PMV index depends on various factors like clothing level, metabolic rate, etc., the comfort temperature changes as these parameters change. As a result, building set-point temperature and cooling load vary.

The Department of Energy Engineering (DOEE) is located at Sharif University of technology in the west of Tehran at the longitude of 51.3 and the latitude of 35.7. DOEE is one of the most modern buildings of Sharif University of Technology and has modern facilities and laboratories, each of which has a high potential for energy saving. In this study, the researchers proposed solutions to reduce cooling energy consumption and calculate the energy consumption reduction by analyzing the cooling energy consumption in summer and investigating the effects of occupants and the role of managerial decisions. The simulation of the building has been done in the Energy Plus software according to Tehran's weather information. The input data to the model are divided into two categories: fixed data and variable data. Fixed data such as geometry, HVAC system, and equipment in the building are constant during time; on the other hand, variable data like Occupancy Schedule and number of occupants vary during the time. The pattern of the presence of occupants and occupant behavior in educational buildings is completely different from residential buildings. In educational buildings, the presence of occupants is more in the early morning to evening. usually, around noon, the presence of people in some rooms is less and in dining halls or corridors is more. While in residential buildings, occupant's presence usually tends to be more at night compared day long. In addition, occupant's presence in residential buildings on weekends is more than working days. while the occupant presence pattern in educational buildings is quite the opposite. These are issues that need to be considered in simulating the effect of occupant's behavior in this study. To follow modeling the cooling energy consumption, the data regarding the natural gas consumption were extracted from the gas consumption bills of the building during years 2005-2015, which demonstrated the monthly gas consumption of the Energy Engineering department. Then, the energy consumption of the model was validated in comparison with the actual consumption. This study examines the effect of changes in the occupancy pattern, some managerial decisions, and the change in temperature set-point in the cooling energy consumption of the Energy Engineering Faculty of Sharif University. The appropriate set-point temperature during different months is determined based on the PMV index. The following figure illustrates the general process of this study. Accordingly, the inputs and properties of the building as well as the behavior of the occupants are modeled considering local observation in DOEE. In addition, the cooling energy consumption of the building is calculated in different cases.

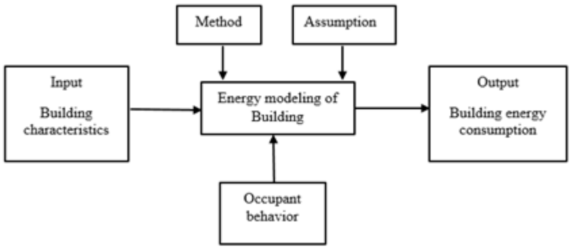

Fig. 2. Work overview

Table 1. Materials of building

Parameters	North	East	South	West	Total
Wall area [m^2]	1216	1248	1216	1248	4928
Window operating Area[m^2]	598.4	374.7	598.4	160	1731
Window–to-Wall Ratio[%]	49.21	30.02	49.21	12.82	35

B. Model description

B.1. Thermal and physical modeling in the Department of Energy Engineering

The building consists of 5 floors: underground, ground floor, and three floors above the ground floor. The majority of the building is covered with glass. Fig. 3 shows an overview of the department. Besides, Table. 1 shows the distribution of materials used in the shell of the building. A detailed DOEE HVAC model has been developed in the Energy Plus platform which considers the building envelop details, HVAC zones, and the HVAC components. The model has been then verified using hourly DOEE gas consumption data. The building HVAC system is based on natural gas-fired boilers and absorption chillers which both consume natural gas to provide hot and chilled water, respectively. The area of main body of building is calculated as 3762 square meters in 5 stories.

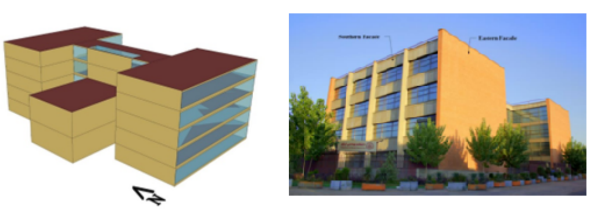

Fig. 3. The area of main body of building is calculated as 3762 square meters in 5 stories

The DOEE building has been divided into 11 districts in terms of the distribution of the HVAC system and information about each one has been introduced into the Energy Plus software. Table. 2 specifies information for each of the zones.

Table 2. Information of DOEE zones

	Zone	Area (m^2)	Volume(m^3)
1	Amphitheater	252	1512
2	Corridors	192	3840
3	Engine Room	435	1740
4	Lab	435	1740
5	North 1-2	435	1740
6	North-GF	435	1740
7	North 3	435	1740
8	South 1-2	435	1740
9	South-GF	435	1740
10	South 3	435	1740
11	Library	252	1512

C. Indicators for determining the thermal comfort zone for people in the building

As mentioned in the introduction section, the PMV index has been used to calculate the amount of thermal comfort in different parts of the building. The ASHRAE thermal sensation scale is developed to help quantify people's thermal sensation. It should be noted that each of the PMV indexes ranges from -3 to +3 where +3, +2, +1, 0, -1, -2, -3 represent hot, warm, slightly warm, neutral, slightly cool, cool, and cold sensation, respectively. PMV index model uses the heat balance principles to relate the following six key factors for thermal comfort to the average response of people on the determined scale: metabolic rate, clothing insulation, air temperature, radiant temperature, airspeed, and humidity. The predicted percentage of the dissatisfied index (PPD) is also related to the PMV. Actually, PPD is defined as a function of the predicted mean vote (PMV). Based on the ASHRAE standard, the acceptable thermal environment for general comfort ranges within -0.5<PMV<0.5 provided that PPD<10. Based on the ASHRAE standard, appropriate PMV which doesn't disturb the comfort zone is between 0 and 0.5 for warm months. If the resulting PMV value generated by the model is equal to the recommended range, the conditions bring the comfort zone for the occupant. There are several computer codes available that predict PMV-PPD. Berkeley University in the United States has developed an online application named center for the built environment (CBE) for calculating PMV that estimates the value of PMV index online based on the parameters of temperature, wind speed, the clothing level, relative humidity, and the metabolic rate. In this work, the ambient data of Tehran from June to September, as well as the clothing level and metabolic rate in the educational environment in summer were used to calculate the PMV index.

3. RESULTS AND DISCUSSION

In this section, the results of energy saving plan in DOEE are described in three categories including the effect of the number of people, the effect of temperature set point, and aggregation of places.

A. Validation of the building model

The actual consumption of natural gas in the DOEE was extracted using data from the average consumption of years 2005-2015 during June to September. The output results of the model are validated by monthly gas bills. The output results of the model can be extracted hourly and daily. because the gas consumption bill was available monthly, the validation was performed on a monthly basis. Fig. 4 shows the actual and modeled natural gas consumption. As the figure shows, the maximum error was estimated at 8.4% which occurred in July. It should be

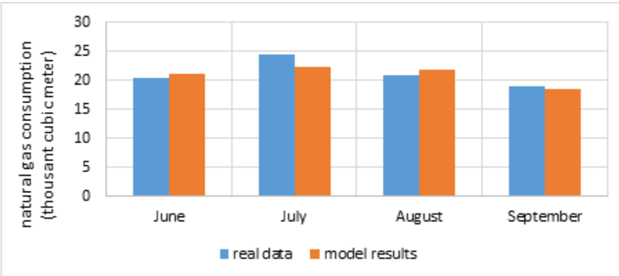

Fig. 4. Energy plus model validation

mentioned that the number of people and natural gas consumption in the base case is according to Fig. 5 and Fig. 6. The pattern of occupant presence is obtained based on the mean local observations at different days of the week. In some hours, the number of occupants in different areas of the building is the highest and in some hours is the lowest. In the hours before 7 am and after 6 pm, the presence of students is almost zero. A large part of

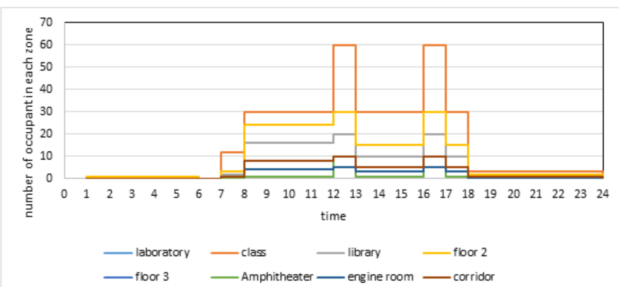

Fig. 5. Number of people in each zone

the DOEE space and energy consumption is dedicated to the corridors because of the high passing rate and impossibility of turning off the cooling systems. Corridors are also the students' resting place, and in many cases, students study in groups in the corridors. Also, the DOEE is designed in such a way that there are several office and security spaces in the corridors. According to the Energy Plus model, the total natural gas consumption in summer is 83.8 thousand cubic meters.

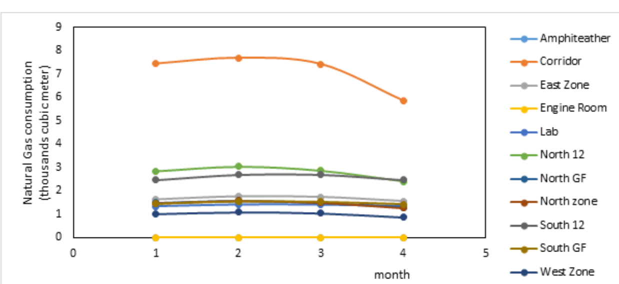

Fig. 6. Natural Gas consumption in each area (thousands cubic meter)

B. The effect of the number of people

To change the number of people, 6 scenarios are carried on. The variation of number of people is considered: +10%, +30%, +50%, +100% upper and -10%, -30% lower than the base scenario according to the local observation in different days. By changing the number of people in different zones, the gas consumption also changes due to changes in the load required for cooling. Accordingly, the presence of people in 6 different scenarios has been investigated in different zones. The following figure shows the energy consumption during different months in these 6 scenarios. As mentioned earlier, occupant presence as an important contributor has direct and indirect effect on energy consumption, such as lighting, cooling, heating, etc. According to Fig. 7,

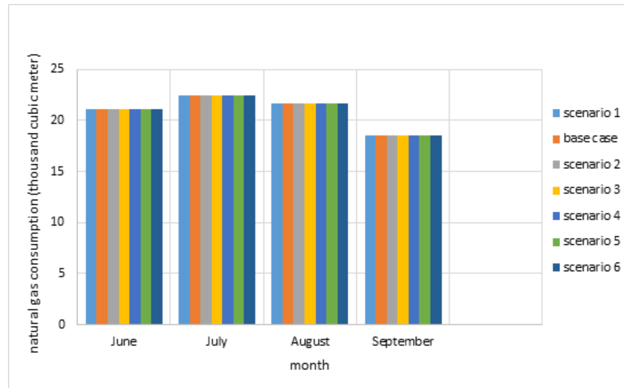

Fig. 7. Natural gas consumption in 6 scenarios

the total energy consumption during these four months in the fourth scenario (+100% increase in occupant presence) is only 0.018% higher than the base case. Moreover, the mere presence of occupants without considering set-point temperature change and management strategies can have missed effects on energy consumption.

C. The effect of the temperature set point

Increasing the temperature set point in the warm seasons decreases the amount of cooling energy. The thermal comfort zone has been considered to study the effect of temperature set point changes on the energy consumption of DOEE. Moreover, the CBE Thermal Comfort Tool is used to determine the comfort zone. According to (CBE), one can determine the range of permissible temperatures online by identifying other factors such as relative humidity, metabolic rate, and clothing level. Weather information from June to September was extracted from the Tehran Meteorological Office in the year 2015 and is used to calculate the PMV index. These data are summarized in Table. 3. The metabolic rate is considered 1, 1.1, and 1.2 according to

Table 3. Weather data

Month	Average ambient temperature (C)	Average air speed (m/s)	Average relative humidity (%)
June	30.7	14.5	23
July	31.47	10.5	23
August	28.75	12.5	29
September	24.35	15	34.75

the possible activities of individuals in the college environment

(CBE). Clothing level is estimated according to the air temperature, community culture in clothing, as well as the area under investigation [12]. It should be noted that the awareness of those attending college with appropriate summer clothing is taken into account. Moreover, as the number of people reaches zero during the weekends and holidays, the temperature set point is adjusted at a fixed temperature according to the ambient temperature. On the weekend, reaching the thermal comfort zone is not necessary because the presence of people is zero or very low. With the specificity of these factors, the temperature set point of each place is determined. Fig. 8 to Fig. 10 show the amount of energy consumed according to the specific temperature set point. The highest rate of energy reduction is related to June at the clothing level of 0.36 and metabolic rate of 1. In this case, gas consumption and reduction of cooling energy reach 20.255 thousand cubic meters and4.26% respectively. Fig. 11 also shows the

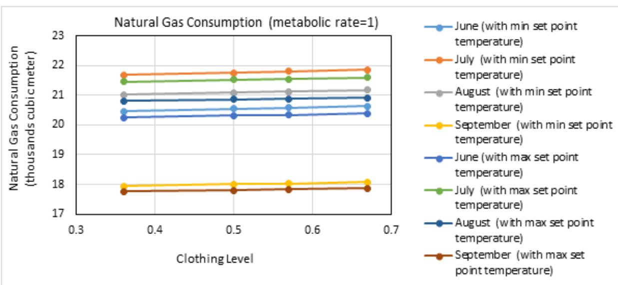

Fig. 8. Natural gas consumption in metabolic rate=1

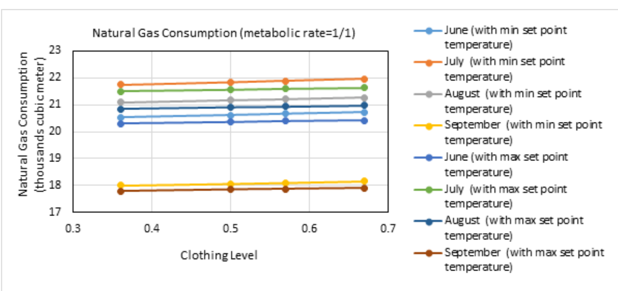

Fig. 9. Natural gas consumption in metabolic rate=1.1

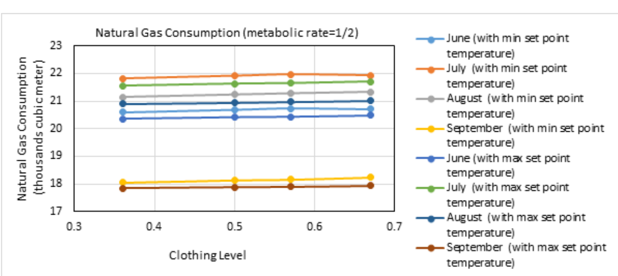

Fig. 10. Natural gas consumption in metabolic rate=1.2

highest reduction in energy consumption in different months, at metabolic rate 1 and different clothing levels. The clothing level is an index to determine the amount of clothing in different environments and depending on the type of building, the type of environment in which people are located, culture, and

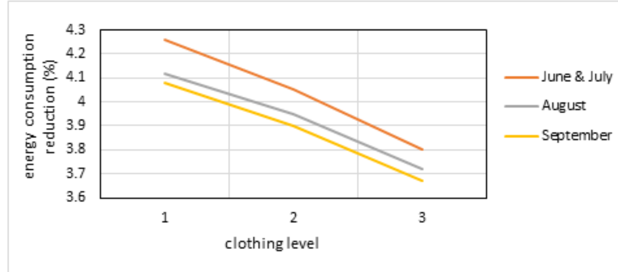

Fig. 11. Maximum the energy consumption reduction (%) in each month

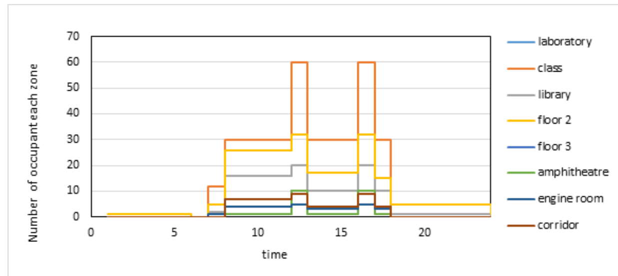

Fig. 12. Number of people in each place after aggregation

personal style. According to (CBE), this index varies between 0 and 4 in different modes. In determining the PMV index of this study, according to the predominant clothing of people in the universities in Tehran, this index varies between 1 and 3. As can be seen from Fig. 11, the reduction in the energy consumption in different conditions is between 3.67% and 4.26%.

D. Aggregation of places

Some of the sectors in the DOEE can be aggregated to save more cooling energy. It should be kept in mind that there is no feasibility of integrating different sectors of the faculty for all departments and this should be considered in practice to avoid any interference with the functions of the other sectors. As a practical suggestion, there is the possibility of integrating the administrative sector of floor 3 into the administrative sector of floor 2. Also, since the class is not set up after 6pm, the absence of students in class saves some energy. Therefore, transferring students from the class to the corridors after 6 pm can be considered as another option. According to these practical solutions and these conditions, the total cooling energy consumption reaches 83.2 thousand cubic meters which shows 0.64% cooling energy consumption reduction. Fig. 12 shows the number of occupants in different places of DOEE after merging some areas. To save energy, some places in the building have been taken off and merged with other places. Fig. 13 shows the energy consumption of the subdivisions under these conditions.

4. CONCLUSION

This paper presented the effect of occupancy pattern and some managerial decisions on the cooling energy consumption of an educational building. The PMV index was used to determine the thermal comfort range of the occupants present in the building. Aggregation of faculty places and changing the temperature set-point on working days and off days based on PMV index has been proposed as the managerial decisions. These decisions

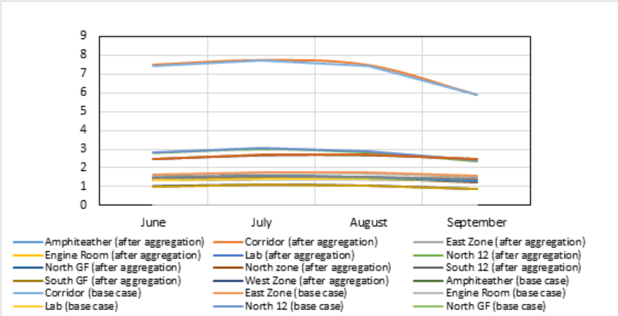

Fig. 13. Natural Gas consumption in each area after aggregation (thousands cubic meter)

should have been made according to the occupant presence in the building and the level of thermal comfort.

Finally, the amount of cooling energy saving was calculated by applying the proposed methods. The results demonstrated that understanding occupancy pattern can help to predict some parameters in the energy consumption modeling and energy demand estimation. The results show that difference in occupancy pattern like the various number of people in different places of the DOEE without changing the temperature set point has no significant change in the cooling energy. In fact, according to the results, if the number of people is twice the normal number in different places of the DOEE, the amount of cooling energy during these 4 months will increase by 15 cubic meters or 0.018%, and in situations where the number of people is 30% less than the base case, the amount of cooling energy consumption is reduced by 4.5 cubic meters. One of the managerial decisions that do not disrupt the performance of the building (aggregation of some places of the DOEE in summer) causes a 0.064% reduction in cooling energy consumption. Among the various methods tested in order to reduce the cooling energy consumption, changing the temperature set point of a cooling system based on the PMV index by 4.26% had the greatest impact on the reduction of the cooling energy consumption in the department of the energy engineering building. In fact, switching the set-point temperature according to the presence of people is one of the most effective approaches to reducing energy consumption. The set point temperature of different zones can be increased at night or when there are only a few people in different areas. This effect is particularly highlighted in zones where the number of people in certain hours of the night is very low.

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