Vol. 9, No. 3, 124-138, https://doi.org/10.22712/susb.20180013

INTERNATIONAL JOURNAL OF
SUSTAINABLE Building Technology and Urban Development

pISSN : 2093-761X

A study of the concurrent effect of the walls thermal resistance and air infiltration rate on the energy consumption of schools in the humid temperate climate of Iran

Reza Amiri Fard[1], Mahmoudreza Saghafi[2]*and Mansureh Tahbaz[3]

[1]PhD Candidate of Islamic architecture, School of Architecture and Urban Studies, Art University of Isfahan, Isfahan, Iran
[2]Assistant Professor, School of Architecture and Urban Studies, Art University of Isfahan, Isfahan, Iran
[3]Associate Professor, School of Architecture and Urban Studies, Shahid Beheshti University, Tehran, Iran

***Corresponding author:** mrsaghafi@gmail.com

Received: 31 May 2018
Accepted: 19 July 2018

A B S T R A C T

The infiltration rate and thermal resistance of the building envelope has a significant effect on the energy consumption of buildings among the construction factors. Both of these factors are affected by the building envelope design and its details. The purpose of this paper is to find out how the interaction of these two factors simultaneously affects the building energy consumption. The case study of this research is the schools constructed based on the specifications and standards of the School Renovation Organization in the humid temperate climate of Iran. Due to the possible cross-impact of these two variables, the effect of these two is examined concurrently. Based on the results of this study in this climate, the infiltration rate of the building has a much greater influence than the thermal resistance of the building walls on the total energy consumption. Therefore, by reducing the building's leakage to minimum, the total energy consumption of the building can be reduced by 20%, And the process of reducing energy consumption as a result of increasing the thermal resistance of the walls is depended on the amount of Infiltration rate of the building.

Keywords: thermal resistance; air infiltration rate; building energy consumption; humid temperate climate; school architecture

Introduction

In Iran, per capita consumption of domestic, public and commercial sections are 1.8 times higher than the global average, and in 2014 the consumption rate has increased by 2.9% compared to the previous year [1]. That is partly due to inappropriate execution practices and disregarding national building codes and regulations, accounting for about 40% of annual energy consumption in the country. In the new edition of the National Building Code, efforts have been made to improve these conditions and to pay more attention to the two factors of air infiltration and thermal resistance of the building envelope. In various studies, it has been indicated that these two factors have a significant effect on the total energy consumption of the buildings [2]. Understanding these two variables and

knowing the impact and sensitivity of their changes on the architecture design will greatly help to reduce further energy consumption. On the other hand, these two variables may have a mutual effect, which in different conditions, each one creates different variations. In this research, the sensitivity means the ratio of the change of total energy consumption to the change of that variable and indicates its significance.

In this study, the effect of the thermal resistance of the building envelope and the air infiltration rate on the energy consumption of the base model of schools has been studied. In this regard, after reviewing the studies carried out in this field and defining the base model, the quantitative results of the simulations based on the random input data are presented as a diagram of the changes. At the end of the analysis of the results, they are converted to applicable functional statements.

Literature of study

Studies have represented that in buildings up to three floors, 15 to 30 percent of the energy has been consumed by the heating system to compensate for heat fluctuations due to air infiltration, and this amount can rise up to 40 percent for un-airtight buildings [3].

Infiltration or air change is defined as the unwanted flow of air from the outside into the building, and the leakage rate is the ratio of the volume of this air flow to the volume of the interior space in the case of all the openings of the building are closed. In contrast to the natural ventilation in which the air is replaced through the openings. Three factors can affect the rate of air leakage in the building: 1. The vertical flow of air inside the building, which itself is affected by the difference between the internal and external temperature or the height of the building. 2. Wind impact that can cause areas of positive or negative pressure around the building envelope and air infiltration into the building. 3. Any ventilation equipment or fuel equipment with creating negative pressure inside which causes unwanted air influx into the building [4].

Air leakage is occurred through cracks and holes in the building envelope, or through joints and cracks between building components such as ceilings, openings and exterior walls. However, the amount of this infiltration is not the same in different parts of the building envelope [5].

The mentioned issues have been emphasized in many building standards and building sustainability assessment systems in order to control and further reduction of this factor. In Iran, educational buildings or schools usually do not use a closed HVAC system for heating and cooling and for providing fresh air. Therefore, fresh air supply in the cold seasons that the openings are closed, relies solely on the amount of air leakage. On the other hand, improving the envelope airtightness basically requires changing and enhancing construction details and materials which might increase construction costs.

The air leakage does not only affect the energy consumption of the building. Air leakage can cause unintended moisture transfer which causes mold problems in the building envelope. In addition, issues such as the transmission of air pollution, indoor air quality and unwanted noise exposure are also some of the other factors that remind the need to careful control of these subject matters. Several studies have been done on the factors that affect leakage

and air infiltration. These studies are generally performed empirically using a Blower Door Testing method. In such researches, the factors such as the building envelope area, building volume [6], window's specifications, total window frame lengths [7] or other building components such as building envelope specifications and the construction methods are studied [8]. Some studies also refer to the envelope specifications such as insulation type and the walls' assembly design [9]. A series of studies on air infiltration were about the influences of the executive factors such as construction methods, supervision, and engineering skills. They have indicated that these factors have a remarkable role in the end result of airtightness even more than technical factors [10, 11]. In relation to the effect of air infiltration on the amount of energy consumption in residential and office buildings, a comprehensive study was carried out by Nasrollahi [12]. Based on this study, the increase in air infiltration rate has a greater impact on the building heating energy compared to the building cooling energy, for example, increasing the rate of exchange of air from 0.5 times to 4 times increases the heating energy consumption by 14.4. It can be seen that because of many problems that exist in the current construction system in Iran, controlling the amount of airtightness can lead to significant reductions in building total energy consumption [12].

The same issue applies to the thermal resistance of building envelopes. Normally, the necessity and the amount of thermal resistance required for the building envelope are different with respect to the climate and heating degree-day. Generally, the increase in thermal resistance of the building envelope always reduces the amount of heat loss and, consequently, reduces energy consumption. The whole detail designer's quest is about controlling these factors due to execution and cost limitations. Therefore, in this paper, we tried to examine the influence of each of these variables and their sensitivity to the total energy consumption of school buildings in the temperate and moderate climate of Iran.

in this paper our purpose of building envelope is the walls, the ceiling, the floor and the openings of the building, which generally includes transparent and opaque surfaces of the building. Naturally, the most important role of these elements are protecting residents or users against adverse environmental conditions and providing thermal comfort which requires energy in different climatic conditions. Thus, the envelope of the building can reduce the amount of heating energy consumption by reducing the heat exchange rate. Various studies have been conducted to find the relationship between changes in the characteristics of building envelope and the amount of energy used in buildings. For example, Dowd and Mourshed, in a study, examined the sensitivity of Masonry material changes in 36 building envelopes cases on energy consumption, taking into account simultaneous changes in the amount of transparent surfaces area. In this experiment they used dynamic simulation method in commercial buildings in the UK [13].

Chesne has studied the relationship between the increase in the thickness of thermal insulation and the thermal load of the building. Based on the results of this study, which was carried out in a parametric way for a French-urban construction sample, represented that the increase in the initial radius of a few centimeters of thermal insulation in the building shell had a significant impact in reducing the thermal requirements of the building and, by increasing this thickness, to a certain extent, the effect of increasing the thickness will decrease and will be even less

than one percent, which will be negligible against other factors [14].

In another study, Lolini examined the thermal properties of the material theoretically and in a parametric method in the building's structure and envelope, also he studied the influence of changes of the volume and other physical properties of building envelope in the six Italian regions. Based on the results of this research, the amount of thermal resistance variations in the building envelope is not necessarily consistent with the theoretical model of thermal resistance of the materials. A lot of research has also been done to find the optimum thermal resistance of the building envelope with consideration of economic or executive considerations [15-17], which reduces the amount of optimal thermal resistance based on the amount of energy cost and the type of insulation.

In another study, which was carried out in a parametric way for three cities in Turkey, it was indicated that the optimum thermal resistance of the building and its change pattern is different according to other construction factors such as the form of the building (surface to volume ratio), the percentage of transparent surfaces and building orientation [18]. In a recent study, the effect of different thicknesses of concrete walls in different orientations has been investigated considering economic considerations [19]. The collaborative chapter of these studies is the tracking of the changes in the static conditions of other components.

As mentioned above, these two factors are very important in terms of their high impact on energy consumption. On the other hand, their impact on the design and construction of the envelope assembly and related costs should be considered. These studies indicate that the changes in each of them can vary with respect to the other construction factors. Therefore, it is necessary to simultaneously examine these factors to study their possible interactions and the differences of the trends in different areas of the other factor.

The purpose of this study is to investigate the effect and the sensitivity of the two factors of thermal resistance and air infiltration on the total energy consumption of the building. In this research, the computer simulation method is used dynamically and hourly climatic data is applied. Different random conditions have given simultaneously to the base model in order to evaluate and analyze the effectiveness of both factors concurrently in the sample buildings.

Research Methodology

As mentioned previously, in this research, the effect and sensitivity of two building parameters, thermal resistance (walls) and air infiltration rate on the total building energy consumption is investigated. The case study for this research is the educational buildings (schools) built according to the standards and construction specifications of the School Renovation Organization in the moderate and humid climate of Iran (Rasht city). Considering the mutual effects of the variables mentioned in this study, their effects are examined simultaneously and continuously. The result of the study will be a spectrum of estimated energy consumption results that determines the effect of changes in each of these two variables on the energy consumption of the building. Therefore, the questions in this research will be as follows?

1. What is the pattern of total energy consumption changes based on the change in air leakage rate (unintentional air change) and thermal resistance of the building envelope?
2. What is the sensitivity of each of these variables to the total building energy consumption in the desired climate?

In order to assess the effect of the thermal resistance of the envelope and the influence of air infiltration on the building energy consumption, various types of school building typologies were considered based on the schools already built by the School Renovation Organization in last five years in Guilan province and their abundance. The basic model of the schools was modeled with regard to the frequency and generalizable commonalities.

Considering that due to the climate conditions of the region and the school curriculum in the nine-month school program and based on the energy bills of schools, about 67% of the total energy consumption and total cost of building energy is used for building heating. So in this study the main emphasis will be on the amount of energy used for heating, although in the model validation stage, the simulation results are used in both the cooling and heating stages in accordance with the building application.

In this research, the Design Builder V4 [20] software is used for modeling and simulation which has the EnergyPlus engine. There are many studies about the reliability of the Designbuilder and EnergyPlus. In a 2008 article by Skin et al., A comparison was made between heating and cooling loads estimated by EnergyPlus Software and actual consumption during one-day and three-week periods; a difference of 3% For heating loads, and 5% for cooling loads has been reported, which indicates the reliability of this software [21].

In this research the climate of Rasht city in the province of Guilan was studied and simulated. Rasht is located in 37.1-degree north latitude, 49.3-degree east longitude, 8.6 meters below sea level, and has a moderate and humid climate located at the south-west of the Caspian Sea. According to the latest division of the Koppen method, the Guilan plain area is located in Csb region; which means a temperate climate with hot and humid summers [22]. Detailed climatic information of Rasht was extracted by use of Meteonorm simulator software [23], and was adapted to the 25-year statistics of the country's Meteorological Organization. According to the climatic information, the lowest average minimum temperature is in January 2.4°C, and the highest average maximum temperature is in August 30.3°C [24].

Based on the analysis of the psychrometric chart in accordance with the ASHRAE Comfort Standard in this climate, In a total of 2727 school official hours in the nine months of the year. 12.8% of the time was in comfortable conditions, and in 15.4% of time, only by direct radiation and 14% of times, the interior comfort can be provided by preventing direct radiation [25].

Simulation

Simulation research can be done in two ways. Sometimes they simulate a model to a large number of times or simulate a large number of models in a small number of times and analyze the results. In this research, the first method was used; this means that for the implementation of the research, samples were made, taking into account

all the characteristics and properties of the actual samples. They are called base model. Then, simulations are performed on this base model according to the research objectives. In the first stage, the base model was selected using the abundance of existing buildings.

Table 1. Building Envelop specifications of base models based on the construction details of the School Renovation Organization

	Building Envelope Assembly	U-value
Roof	Gable roof (unconditioned attic space) Steel trusses Covered with galvanized metal sheets	-
Ceiling	Wooden Ceiling insulated by 10 mm rolled PVC foam blanket	2.71 W/m2 k
Floor	Crushed stone − cement mortar and concrete mosaic tiles	2.45 W/m2 k
Wall	brick core with outer cement mortar and stone tiles, gypsum plaster inside and a layer of ceramic tiles as a one-meter cornice	1.94 W/m2 k
Window	Double-pane Aluminium non-Thermal Bricks	2.626 W/m2 k

Based on the typology of school buildings that were repeatedly constructed and their frequency for the present study, base models were defined. In Table 1 the U-value of the different elements of the building envelope are shown. These elements are based on what the details show and how the building envelope assemblies are actually built. The selected base model is a two-storey 12-class school that are generally oriented east-west and classes and other spaces are organized on the sides of the central corridor. (Figure 1&2)

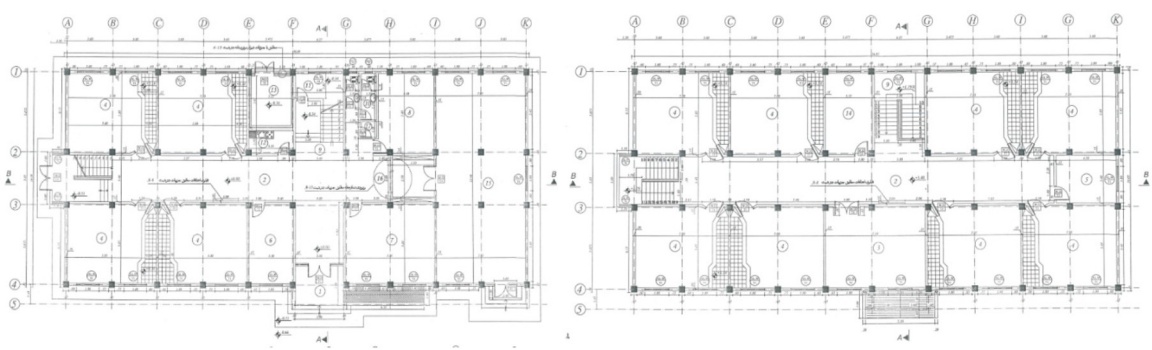

Figure 1. Ground and first floor plans of the base model (reference: documents of School Renovation Organization in Guilan province).

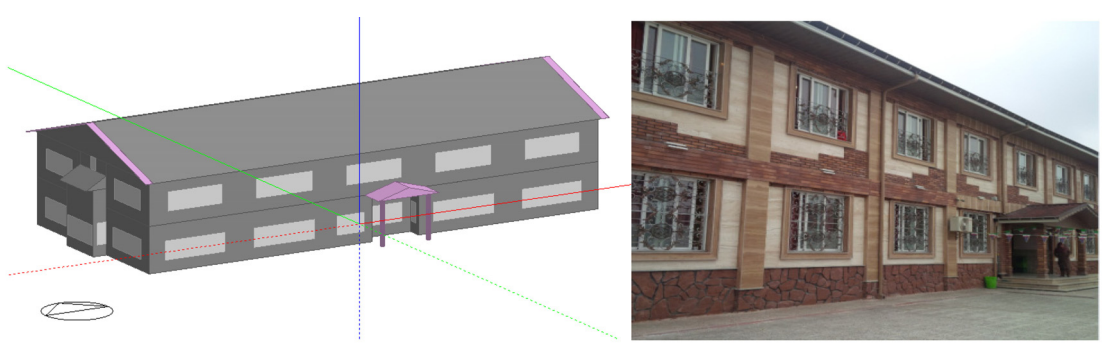

Figure 2. the simulated model based on Shahid Nejat Allahi School, one of the base model schools (Source: Writers).

This school is modeled in software based on the specifications and main design features such as: construction specifications, number of users, the schools' yearly schedule, and the heating and cooling set points based on the collected data of the selected case studies which are shown in Table 2.

Table 2. Base model specifications the base model (reference: documents of School Renovation Organization in Guilan province)

Window to Wall Ratio	Air exchange rate (infiltration)	Heating Setpoint	Cooling Setpoint	User Activity Rate (metabolism)	HVAC	Lighting	Occupancy	Schedule 08:00-14:45 Iranian school hours
30%	1.0 ac/h	21°C	26°C	0.8	5 air-conditioners package unit (20000Btu)	280 lux	0.55 (people/m2)	for educational full occupancy Jan. to Dec. except for Jul. & Aug
							0.2 (people/m2)	Only administration spaces. 3 days a week in Jul. And Aug.

The initial simulation of the base model was performed based on the existing situation. The main heating system was central heating system with radiators and natural gas fuel boiler and electric cooling system with electric air conditioners. The simulation output was adjusted annually to fuel consumption. By obtaining the actual consumption of the case studies in the form of electric power and gas consumption bills in the last 5 years, this information was used for calibration and validation of simulator software performance.

Simulation Validation

Naturally, any errors in the modeling and inaccurate input information can create unrealistic results and compromise the validity of simulation. In this study, empirical validation is used to validate simulation. In this way, after the modeling stage and the precise entry of the input data in accordance with the actual conditions of the base samples, simulation results are compared with respect to the actual energy consumption amount used for heating and cooling of selected buildings. The appropriate changes are done in model to match the results of simulation with the actual energy consumption diagrams.

For this purpose, the monthly bills of gas and electricity consumption are extracted from the case studies. Due to the fact that in Iranian schools, non-electric heating is mainly used for heating in cold seasons, so heating consumption amount can be considered based on the amount of gas consumed in the cold seasons and the difference between the average consumption in warm months for other uses like hot water or possibly cooking, calculating the actual consumption share of building heating and can be compared with the calculated outputs of the software.

Considering that the cooling of the school buildings in the warm seasons in this climate is electrical. The differential average electric power consumption in cold and hot seasons considered as the amount of power consumed for cooling and compared with the estimated software outcomes. In this way, the simulation models were

modified and validated by adjusting the input data according to actual energy consumption. In reality, various factors in each building may affect the energy consumption. As a result, these intervening factors make it difficult to adapt software results to reality. For this purpose, four real samples were taken to compare to base sample; in the field survey, the information of the four selected schools, such as the physical characteristics of the building, materials and user specifications (such as the number of students, daily and yearly schedule, etc.) as well as the details of the energy bills was obtained. By selecting case samples, in different physical conditions, such as orientation or surrounding urban context, their actual energy consumption was compared with the simulated model, and by adjusting and modifying the inputs. The modeling became valid for using the simulation results. In Figure 3 the simulated energy consumption of the base model and the average of actual energy consumption of the building samples in different months of the year are shown. It shows that The maximum difference between the monthly energy consumption are between 8% and 17%. It seems to be acceptable due to the differences in the way the mechanical systems were set up in the samples and the difference of the energy consumption of each sample case which is up to 25% in different years.

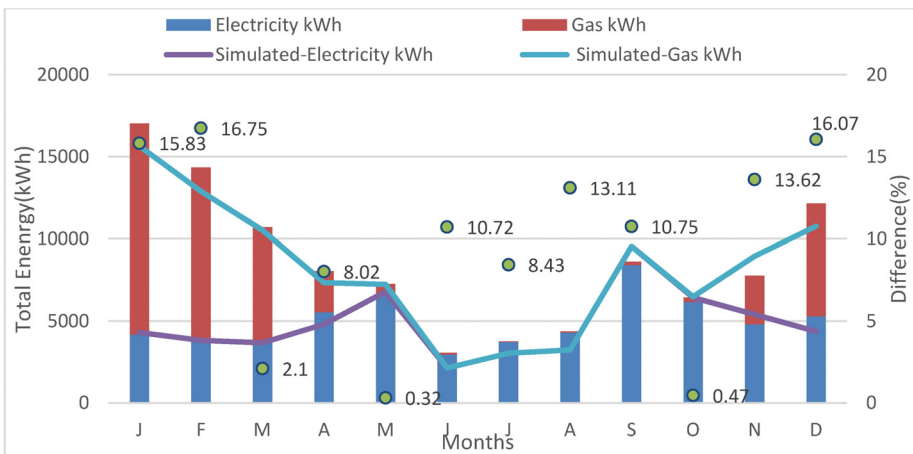

Figure 3. Difference between simulated and actual average energy consumption (Source: Writers).

Global Sensitivity Analysis method was used to analyze and measure the output changes. This means that instead of changing one parameter and examining its effect on the total consumption rate at each simulation, the two components are randomly changed and the corresponding output is recorded. Two-component sampling for two variables of thermal resistance of the envelope (walls) with varying ranges of R-1.0 (0.18) to R-25 (4.40) masonry type with polystyrene insulation with different thicknesses and variable infiltration rate with the variable range of 0.4 to 1.6 times per hour were done based on the Latin Hypercube sampling[1)] system. Hypercube sampling system

[1)] The Latin Hyper Cube is a square that has been converted into a network by dividing its sides. Everywhere in the ibn network have two vertical and horizontal components. Therefore, by selecting a number of these positions randomly, we will actually have a number of variables of two random variables. Now, more and more homogeneous positions are placed randomly on the condition. In this way, to select each position (variable of two authors), it must be controlled by previous choices that are not in a row or a column. This concept can be expanded by increasing the number of dimensions to three dimensions (cubes) and more.

has better random coverage surface than simple random sampling. In Figure 4 it can be seen that with a smaller number of samples, a more uniformed coverage surface can be achieved. This method is very suitable for analyzes with few number of effective components in each step. The most important advantage of this method is the lower number of computations and simulations than other methods [10]. For example, for an eight-variable simulation, only 360 simulations are required in four steps, for which the number of variables in the variance method that is required to run a simulation is 608 [10]. Another advantage of this method is that, compared with other methods of integrated analysis, the results of the sensitivity coefficients can be represented as qualitative diagrams [10]. These diagrams can be used to evaluate design alternatives or to assess the changes to existing buildings.

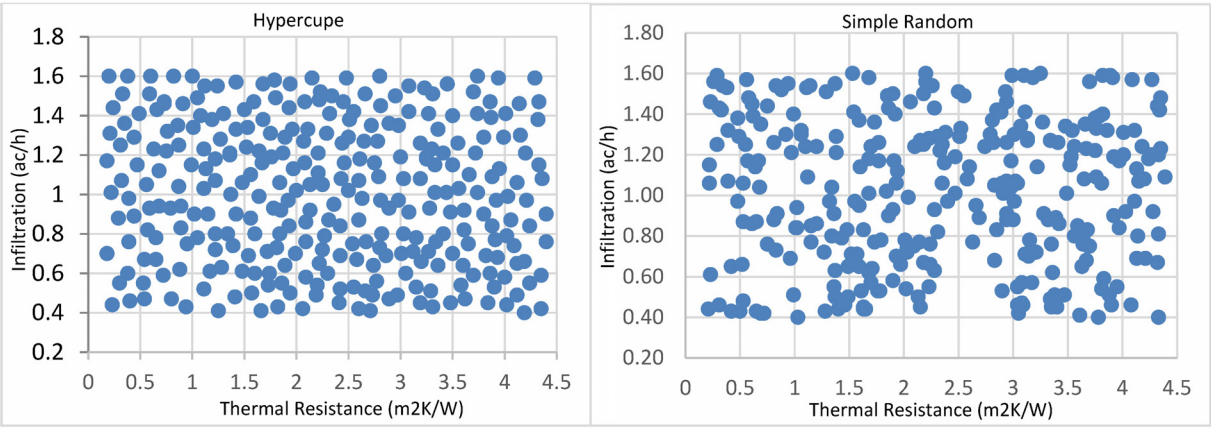

Figure 4. Difference of the two-component prototype system by the hypercube method on the left and the simple random method on the right in considered ranges. (Source: Writers).

These input samples were made in the defined ranges by the SimLab software [26] and was fed into the simulator as input and the outputs were considered as the total energy consumption. This means that the total consumption of the building is extracted in the form of a total simulated annual heating, cooling and illumination and is demonstrated in three-dimensional graphs.

Findings

In this section, the findings of this study and the results of the sensitivity analysis of the mentioned construction variables are presented. The sample number for the ranges listed and based on the hyper-cube system was determined by at least 280 samples in SimLab software which in this study, 300 two-component samples were input for the simulation of base model. The simulation results for analyzing the global sensitivity of two variables on energy consumption is shown in Figure 5.

As it can be seen in Figure 5, the amount of energy consumption and the process of its change for different ranges of variables are not the same. Therefore, to understand these changes and analyze their impact, each of the ranges of

the two variables is divided into four areas. The results are shown in scatter plot graphs for variable showing the changes. This means that in each range of a variable, the process of change of the consumption caused by the other variable is different. In general, the total energy reduction capacity by these two variables is 10.8 kW /m^2, which is about 20% of the average consumption of this building.

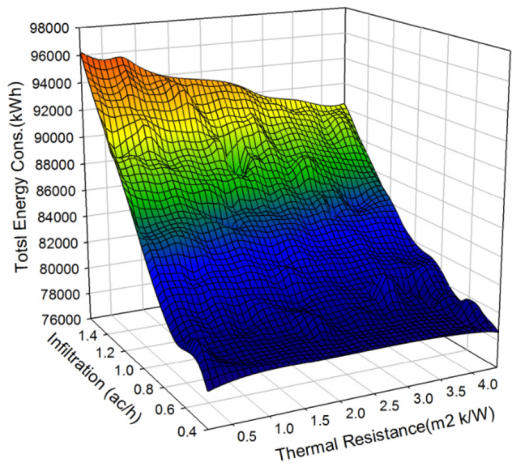

Figure 5. Simulation Results for Two-component Global Sensitivity Analysis (Source: Writers).

In this study, the range between 0.4 and 1.6 changes per hour of unwanted air change was examined and the process of energy consumption changes based on changes in the thermal insulation value in the four infiltration range of the building is shown in Figure 6.

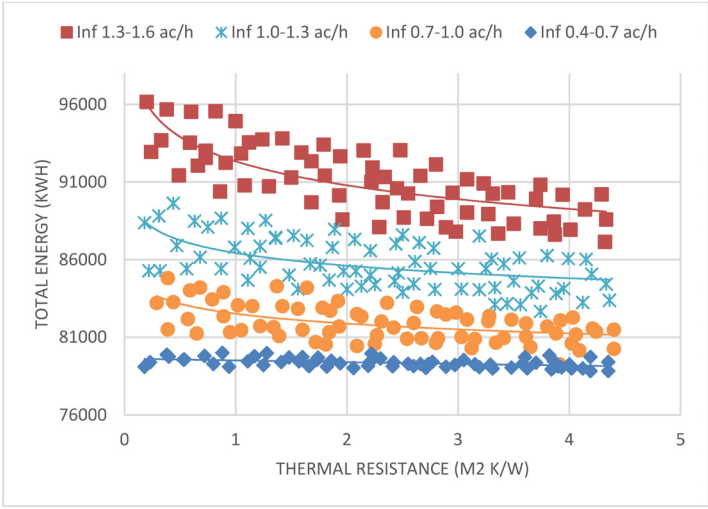

Figure 6. Chart of energy consumption changes with thermal resistance changes in different range of air infiltration in building (Source: Writers).

The range between 0.4 and 0.7 is the acceptable airtight range of public buildings. Of course, in this range, fresh air is required to provide by the mechanical air-conditioning system. The amount of energy consumption associated with it is not considered in this study. In this range, as can be seen, although the energy consumption is reduced by increasing the amount of insulation, but the process is almost constant, in other words, it can be said that in airtight buildings, the increase in the thermal resistance of the wall has not a significant effect on the reduction of energy consumption.

The range from 0.7 to 1 is considered as the range of normal infiltration. In this range, airtight levels are acceptable. According to the diagram, increasing the amount of thermal insulation decreases the energy consumption of the building and increases its reduction slope more than the previous one. Which reflects the increased impact of thermal insulation on reducing energy consumption in the building.

The range is between 1 and 1.3, with a relatively high infiltration range. Which is seen in conventional buildings. In this range, the air intake control is not readily possible. The range is between 1.3 and 1.6 times per hour of change which is considered to be a high infiltration range, which in addition to the energy waste problem, it can cause many problems in the envelope of the building, which at least it should be reduced. Each diagram shows that energy consumption decreases with increasing thermal resistance. Meanwhile, the higher the amount of air infiltration in the building, the higher the slope of the process of energy decrease. Therefore, it can be concluded that the increase in thermal resistance of walls is more sensitive and more important in buildings that have more infiltration. On the other hand, the slope of the change in consumption based on changes in the resistance is not the same and it is found that in resistance less than 2 m^2.k/W the slope of the process is higher, which means that the degree of sensitivity of this increase in thermal resistance is not uniform, In other words, the higher the thermal resistance, the lower the sensitivity.

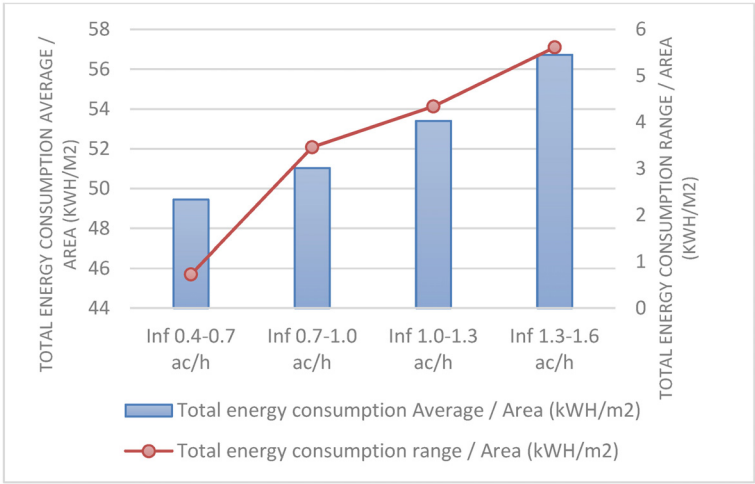

Figure 7. the average energy consumption per square meter and the difference between the maximum and minimum consumption due to the thermal resistance variation in each building infiltration range. (Source: Writers).

As seen in Figure 7, in more permeable buildings, the sensitivity the thermal resistance on energy consumption is higher. For example, it can be seen that in the range of high infiltration, the increase of thermal resistance from simulated minimum to maximum, reduces total energy consumption of the building by 5.6 kilowatt hours per square meter. (52% changeable), while for buildings with normal infiltration rate, this value is 3.4 kilowatt hours per square meter (31.4% changeable) and in the airtight building it is quite negligible 0.7 kilowatt hours per square meter (6.5% changeable)

In order to investigate the effect of air infiltration and its change on the building energy consumption with different thermal resistance of the walls, the range of thermal resistance was divided into four categories, and the scatter plot diagram of the simulation results and the trend line for each of the four conditions were presented (Figure 8). Based on what is seen in the energy consumption diagram of the changes, the overall total energy consumption is generally upward as the amount of air infiltration in the building increases. By increasing the infiltration value of air change from 0.4 to 1.6 times per hour with any wall thermal resistance, the total energy consumption of the building is increased by an average of 20.5 percent. In Figure 9, the trend lines of diagrams of the scatter plot graphs of all four conditions are shown. It can be seen with any amount of thermal resistance in the range of 0.4 to 0.7 air change per hour, the amount of energy consumption has not changed much. Therefore, the change of infiltration level in this range does not have a significant effect on the amount of consumption (1.25 kWh per square meter or about 11.5% of the changeable amount of consumption). After the 0.7 value change is ascending and the slope of the total consumption change is relatively constant.

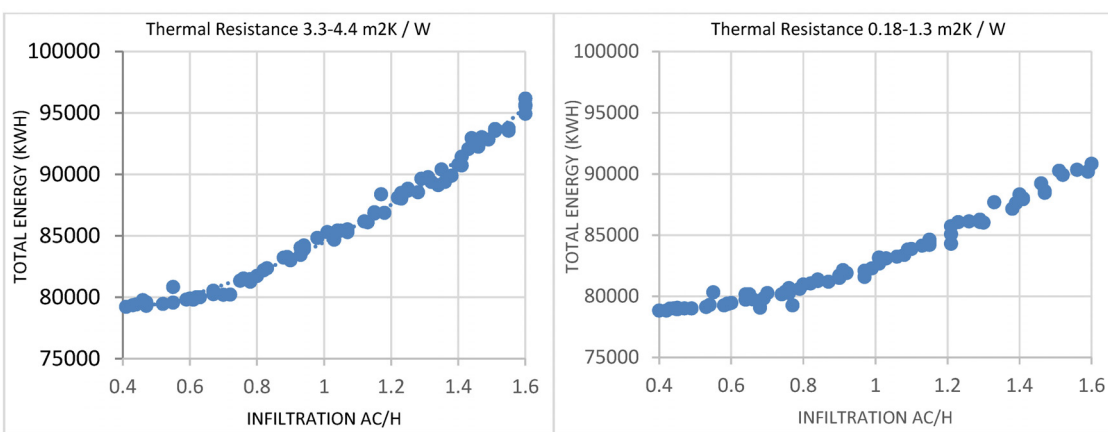

Figure 8. Chart of energy consumption changes with variations in air infiltration rate in the range of (Thermal Resistance 0.18-1.3 m2K / W) on the right and in the range of (Thermal Resistance 3.3-4.4 m2K / W) on the left. (Source: Writers).

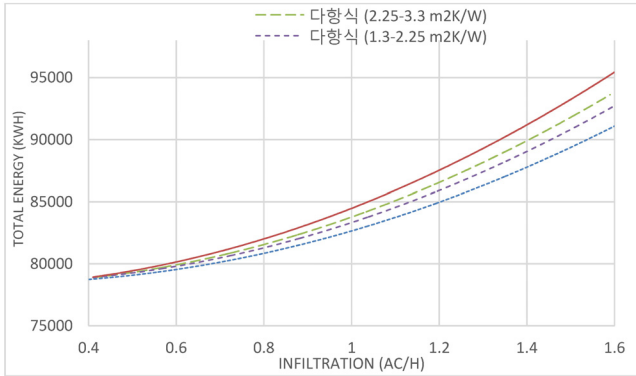

Figure 9. Changes of energy consumption with air infiltration rate changes in four ranges of thermal resistance of walls. (Source: Writers).

Therefore, according to the diagram, after the range of airtight buildings, the sensitivity of the building's infiltration on the total energy consumption of the building is very high. So that, by these two variables, 2.5 kilowatt hours per square meter is reduced for reducing the amount of infiltration 0.3 times per hour (about 35 percent of the changeable amount of consumption). Although this behavior is similar for all four thermal resistance ranges of the walls. Figure 9 shows that there is a slight difference between the slope of the total energy consumption trend lines, or in other words, its sensitivity in different thermal resistance ranges. As the thermal resistance of the building walls is higher, the sensitivity of the building's infiltration will be slightly higher.

Conclusion

The purpose of this study was to investigate and compare the effect of two building variables: the thermal resistance of the walls and the infiltration of the building simultaneously on the total energy consumption of buildings in moderate and humid climate in Iran. For this purpose, simulation of the base model was carried out based on the construction specifications of the existing buildings in the Designbuilder software. After the validation of the simulation results with energy bills of existing buildings as the case studies, the model was simulated and analyzed in terms of multiple conditions defined by input dual variables and the total energy consumption value was determined in the defined limits. In this study, the infiltration rate was between 0.4 to 1.6 air exchange per hour and thermal resistance between 0.18 to 4.4 m^2.k/W were studied and the following results were obtained:

Due to the fact that various studies on the effect of thermal resistance on energy consumption have been carried out, other variables are assumed constant. This study showed that under different conditions, thermal resistance can effect differently and there are other more effective factors that should be investigated simultaneously with thermal resistance. The change processes of energy consumption based on the change of infiltration rate with different thermal resistance are the same, but these change processes are not the same based on thermal resistance changes in buildings with different infiltration rate.

In a moderate and humid climate, the amount of infiltration rare has a great impact on energy consumption, so that with any thermal resistance, energy consumption can be reduced to at least 20% by decreasing infiltration rate. whereas, without changing the infiltration rate, and only by increasing the thermal resistance of the walls in the best conditions, the maximum amount of energy consumption decrease will be 10%.

Reducing even 0.3 air exchange per hour in buildings with normal and relatively high infiltration is more effective than increasing the thermal resistance of their wall from 0.2 to 4.4 m^2.k/W.

The thermal resistance sensitivity of the airtight buildings on the energy consumption is very low. Considering that in other studies it has been shown that increasing the surface-to-volume ratio of the Masonry buildings increases the infiltration rate of the building (Vinha et al., 2015). In this climate, by increasing the number of floors and reducing the surface area, On the one hand, it reduces infiltration and thus reduces energy consumption in cold seasons. On the other hand, it increases the possibility of natural ventilation by openings in hot seasons.

The results of this research can be used to design the envelope and body of the new buildings, audit and improve the energy consumption of the existing buildings.

References

[1] F. Amini, N. Ghahramani, L. Saberfattahi, P. Soleimanpour, and M.Tavanpour, *Iran and World Energy Facts and Figures*. 2014, Tehran, Iran: Deputy for Power & Energy Affairs.

[2] L.C. Ng, A.K. Persily, and S.J. Emmerich, *IAQ and energy impacts of ventilation strategies and building envelope airtightness in a big box retail building*, Building and Environment, 92 (2015), pp. 627-634.

[3] J. Jokisalo, J. Kurnitski, M. Korpi, T. Kalamees, and J. Vinha, *Building leakage, infiltration, and energy performance analyses for Finnish detached houses*, Building and Environment, 44(2) (2009), pp. 377-387.

[4] P. Brinks, O. Kornadt, and R. Oly, *Air infiltration assessment for industrial buildings*, Energy and Buildings, 86 (2015), pp. 663-676.

[5] T. Kalamees, Ü. Alev, and M. Pärnalaas, *Air leakage levels in timber frame building envelope joints*, Building and Environment, 116 (2017), pp. 121-129.

[6] F.R.d.A. Alfano, M. Dell'Isola, G. Ficco, and F. Tassini, *Experimental analysis of air tightness in Mediterranean buildings using the fan pressurization method*, Building and Environment, 53(Supplement C) (2012), pp. 16-25.

[7] J. Fernández-Agüera, S. Domínguez-Amarillo, J.J. Sendra, and R. Suárez, *An approach to modelling envelope airtightness in multi-family social housing in Mediterranean Europe based on the situation in Spain*, Energy and Buildings, 128(Supplement C) (2016), pp. 236-253.

[8] C.N. Bramiana, A.G. Entrop, and J.I.M. Halman, *Relationships between Building Characteristics and Airtightness of Dutch Dwellings*, Energy Procedia, 96(Supplement C) (2016), pp. 580-591.

[9] J. Vinha, E. Manelius, M. Korpi, K.Salminen, J. Kurnitski, M. Kiviste, and A. Laukkarinen, *Airtightness of residential buildings in Finland*, Building and Environment, 93(Part 2) (2015), pp. 128-140.

[10] M. Colijn, A.G. Entrop, and M.E. Toxopeus, *Evaluating the effectiveness of improved workmanship quality on the airtightness of Dutch detached houses*, Energy Procedia, 132(Supplement C) (2017), pp. 843-848.

[11] D. Sinnott, and M. Dyer, *Air-tightness field data for dwellings in Ireland*, Building and Environment, 51(Supplement C) (2012), pp. 269-275.

[12] F. Nasrollahi, *Economic and Ecologic Method of Energy Efficiency in Office Buildings*, World Sustainable Building Conference, Helsinki, Finland, (2011).

[13] R.M. Dowd, and M. Mourshed, *Low carbon Buildings: Sensitivity of Thermal Properties of Opaque Envelope Construction and Glazing*, Energy Procedia, 75(Supplement C) (2015), pp. 1284-1289.

[14] L. Chesné, T. Duforestel, J.J. Roux, and G. Rusaouën, *Energy saving and environmental resources potentials: Toward new methods of building design Building and Environment*, 58(Supplement C) (2012), pp. 199-207.

[15] M. Bojić, M. Despotović, J. Malešević, and D. Soković, *Evaluation of the impact of internal partitions on energy conservation for residential buildings in Serbia*, Building and Environment, 42(4) (2007), pp. 1644-1653.

[16] K. Kuusk, T. Kalamees, and M. Maivel, *Cost effectiveness of energy performance improvements in Estonian brick apartment buildings*, Energy and Buildings, 77 (2014), pp. 313-322.

[17] X. Shi, *Design optimization of insulation usage and space conditioning load using energy simulation and genetic algorithm*, Energy, 36(3) (2011), pp. 1659-1667.

[18] G.K. Oral, and Z. Yilmaz, *Building form for cold climatic zones related to building envelope from heating energy conservation point of view*. Energy and Buildings, 35(4) (2003), pp. 383-388.

[19] T. Tzoulis, and K. J. Kontoleon, *Thermal Behaviour of Concrete Walls Around all Cardinal Orientations and Optimal Thickness of Insulation from an Economic Point of View*. Procedia Environmental Sciences, 38(Supplement C) , (2017), pp. 381-388.

[20] A. Tindale and S. Potter, *Design Builder (Version v4)*, (2015), London,UK: DesignBuilder, Software Ltd.

[21] N. Eskin and H. Turkmen, *Analysis of Annual Heating and Cooling Energy Requirments for Office Buildings in Different Climates in Turkey*, Energy and Buildings, 40 (2008), pp. 763-773.

[22] F. Rubel and M. Kottek, *Observed and projected climate shifts 1901-2100 depicted by world maps of the Köppen-Geiger climate classification*, Meteorol, 19(1) (2010), pp. 135-141.

[23] S. Kunz, *Meteonorm (Version 6)*, (2015), Bern, Switzerland.

[24] IRIMO, I.R.OF IRAN Meteorological Organization, [Online], 2015. Available at: http://www.irimo.ir [Accessed 17/11/2017]

[25] R. Liggett and M. Milne, *ClimateConsultant (Version 6)*, 2017.

[26] SIMLAB. Simulation environment for uncertainty and sensitivity analysis (version 2.2), Developed by the Joint Research Center of the European Commission, 2011. Available at: https://ec.europa.eu/jrc/en/samo/simlab [Accessed 21/10/2017]