EFFECTS OF GLAZING DESIGN AND INFILTRATION RATE ON ENERGY CONSUMPTION AND THERMAL COMFORT IN RESIDENTIAL BUILDINGS

by

Ali ALMARZOUQ [a] ***and Ahmad SAKHRIEH*** [b,c*]

[a] Jordan Standards and Metrology Organization, Amman, Jordan
[b] Department of Mechanical and Industrial Engineering,
American University of Ras Al Khaimah, Ras al-Khaimah, UAE
[c] Mechanical Engineering Department, The University of Jordan, Amman, Jordan

Original scientific paper
https://doi.org/10.2298/TSCI170910073A

The building envelope is the most affecting part in the energy interaction between the buildings and the surrounding. Proper design of the envelope components not only can save the required energy for the building but also can improve the thermal comfort of its occupants. In this research, energy modelling and simulation for a residential building in Amman, Jordan is performed to investigate the effects of glazing design and infiltration rate on energy consumption and thermal comfort. Different design alternatives have been investigated to find the best alternative design to reduce energy use and improve indoor environment. The results showed that replacing single glazing window with double glazing window argon-filled with low emissivity coating can save the consumed energy by 24.7% while degrade the thermal comfort by 1%. Reducing the infiltration rate by 50% can save 19.4% of the energy consumed and improves the thermal comfort by 10%.

Key words: *building envelope, thermal comfort, glazing system, infiltration rate, building simulation*

Introduction

Building envelope plays a key role in determining the required energy for cooling, heating, and lighting of buildings. Proper building envelope design can strongly save energy and enhance indoor environment and occupants' comfort. Energy modelling is a very powerful tool to simulate energy behavior in the buildings and the effect of the building design in the energy interaction with the surrounding. This allows designers to make alterations to the building design or operation while simultaneously monitoring the impact on system behavior and performance. Several researchers have investigated the effect of the building envelope to the energy demands using energy modelling of buildings [1, 2].

Energy modelling of building envelope in residential buildings form architectural and structural perspectives can increase the energy efficiency of these buildings and reduce the required energy for heating, cooling and lighting which will improve the sustainable performance of the buildings [3]. The building envelope is the most affecting part of the energy behavior within the building because it represents a thermal barrier to energy flow between the building and the surrounding. One of the most important components of the building envelope is the

* Corresponding author, e-mail: ahmad.sakhrieh@aurak.ac.ae

glazing system since it has a major contribution of the energy interaction inside buildings by allowing solar energy to penetrate to the building. Improving glazing system design can reduce the energy demands within buildings [4]. Also, a large amount of energy can be transferred through the glazing from/to the building. Another important parameter that affects the energy balance inside the building is infiltration rate which is responsible for air movement from/into the building [5].

Many researches have been performed to improve energy efficiency in residential buildings by modifying the building envelope design and by controlling the energy interactions within the surrounding. Also, integrated thermal modelling and life cycle cost approach have been used to evaluate these measures [6, 7].

Nikoofard, *et al.* [8] performed a simulation for a building model for a house in Canada with different design alternatives. The researchers found that using low E coated double glazing window with Argon filled instead of ordinary single glazing can save up to 53% of the heating loads and 24.4% of the cooling loads for the building model when simulating it at different locations in Canada. Moorjani and Asadi [9] performed a study to investigate the effect of using different types of glazing on optimized window dimensions and lay-out in an office room. They showed that using the optimal dimensions for the windows and highly insulated windows can significantly reduce the energy demands for the simulated model.

For the effect of the infiltration rate of the energy consumption in the buildings, Emmerich and Persily [10] have performed a study to estimate the energy use in commercial buildings due to infiltration and ventilation air-flows and to investigate the potential for energy savings that could be realized by envelope tightening efforts. It was estimated that infiltration is responsible for about 15% of the total heating energy and 4% of the total cooling energy for U.S. office buildings. Results also indicated that potential energy savings on the order of 26% for heating load and 15% for cooling load could be realized by tightening building envelopes varying percentage between 25% and 50%.

Residential sector in Jordan is one of the main consumers of energy. According to Jordan's Ministry of Energy and Mineral Resources (MEMR) [11], The primary energy consumed by the residential buildings in Jordan in 2015 was 1.272 Mtoe (millionnnes of equivalent oil), which was equal to 22% of the total energy consumed in the country. The largest portion of the consumed energy was from electricity; residential buildings consumption of electric energy in 2015 was equal to 6938 GWh which represented 43% of the total electric energy consumed in Jordan.

Awwad and Sakhrieh [12] conducted a study to determine the feasibility of adopting energy efficiency measures and applications in the housing buildings in Jordan. They found that consumed energy in building in Jordan can be reduced by proper window design, using insulation materials and by implementing renewable energy system. Jaber and Ajib [13] performed an assessment of best orientation of the building, windows size, thermal insulation thickness from the energetic, economic and environmental point of view for typical residential building in Jordan. The results of this assessment showed that 27.59% of annual energy consumption can be saved by choosing best orientation, the optimum size of windows and shading device, and optimum insulation thickness.

In this research, energy modelling for building in early design stage has been performed to predict the energy demands over a specified time period for a residential building located in Amman, Jordan. This model has been used to simulate the system interactions in details and to enables accurate evaluation of different glazing system design and different infiltration rates within the building. The effect of each alternative on the energy demand and the occupants comfort has been evaluated.

Model description

This research aimed to model the energy interactions of building envelope design for residential buildings in order to predict the required energy for cooling, heating, and lighting. This provided an accurate evaluation of alternative designs of building envelope components and it came out with an improved design which reduced the required energy of the building and improved indoor environment for occupants' comfort.

The research approach is depending mainly on software simulation of energy interaction within a residential building located in Amman, Jordan. The base model of the study was a building divided into several thermal zones. The base model was a typical residential building in Jordan with a design performed according to the regulations for building envelope [14]. The energy behavior has been simulated by software to obtain the energy loads demanded by the building. Also, the quality of the indoor environment has been evaluated from occupants' point of view by evaluating of thermal comfort and percentage of dissatisfied people within the building.

After the evaluation of the energy status of the building with current regulations for building envelope. The improvement on building envelope design has been performed by modifying each parameter of interest in the way minimizing the energy demands for heating and cooling taking into account the thermal comfort of the occupants. The simulation outputs for this step have been compared with the base model simulation results obtained previously, and the effect of the energy demands has been revealed.

Model geometry

The building model is a residential house with an area of 168 m^2, a height of 4 m, and it is exposed to outside from all directions. Figure 1 shows a sketch of the house.

The house model consists of several rooms and corridors. Table 1 shows the details of the house and the rooms. To perform the modelling for the house, it is necessary to apply thermal-zoning for the house. Figure 2 shows thermal zones specifications of the house model.

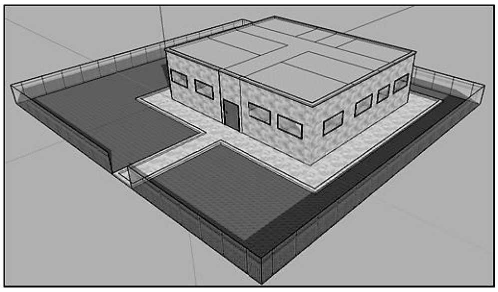

Figure 1. Sketch for the house model

Table 1. House and rooms dimensions

Item	Dimensions (length × width × height) [m]	Area [m^2]
House	12 × 14 × 4	168
Room 1	4 × 6 × 4	24
Room 2	4 × 6 × 4	24
Kitchen	3 × 6 × 4	18
Saloon	3 × 6 × 4	18
Corridors	Varies	42
Bedroom 1	3 × 5 × 4	15
Bedroom 2	3 × 5 × 4	15
Bathroom 1	3 × 2 × 4	6
Bathroom 2	3 × 2 × 4	6

Figure 2. Thermal zones for the house model

Model structure

The house model structure is selected based on the Jordan National Building Codes (JNBC) recommendations for the residential building structure provided by Ministry of Public Work and Housing [14, 15]. The recommendations for the walls, ceiling, and floor are stated in tab. 2.

Table 2. The JNBC recommendations for the building structure

Structure	Parameter	Recommendation [$Wm^{-2}K^{-1}$] (max)
External wall	U-Value	0.57
Internal wall		2.00
Ceiling		0.55
Floor		1.20

For the glazing system of the house model, it was a single glazing with an aluminum frame with a *U*-value of 5.7 W/m^2K. According to Ministry of Public Work and Housing [15], maximum window to wall ratio (WWR) for this type of glazing is 20.1%.

Model operational data

Characteristics of residential buildings in Jordan are a very important input data to the building model. These characteristics provide a description for the building operational and behavioral aspects which can be used to develop a realistic model with high accuracy.

Table 3. The operational data for the house model

Category	Parameter	Value	Unit
Internal weather data	Infiltration	1.5	[h^{-1}]
	Temperature set range	Winter 19-21	[°C]
		Summer 21-23	
	Heating set point	19	[°C]
	Cooling set point	23	[°C]
Occupant's data	Number of people	1	Person/Zone
	Activity	Seated/Light work	–
	Heat gain by person	120	[W]
	Clothing factor	0.6	clo
	Metabolic rate	1.2	met
Lighting system	Lighting density	5	[Wm^{-2}]
	Lighting Type	Fluorescent	–
	Control schedule	00:00 – 06:00	Off
		06:00 – 10:00	On
		10:00 – 18:00	Off
		18:00 – 00:00	On
Home appliances	Type	Computer with printer	–
	Power	230	W
	Scale	3	Pieces

Operational data describe the settings and specifications of the different operations within the building. Data were selected from a survey performed by MEMR [16] for the energy use for the residential building sector in Jordan in the year 2012. This survey aimed to acquire a real estimation of residential building characteristics in Jordan and the energy situation for residential sector in order to provide a description for the energy use and utilization in Jordanian's homes. Also, indoor environment parameters, equipment's setting, and other active systems specifications were stated in this survey. Table 3 represents building operational data used in the house model.

After the implementation of the model in TRNSYS environment and the selection of the required outputs, the simulation has been executed. Although TRNSYS simulates the model for 8760 hours (or steps), the processing time of the model simulation is quite small and it takes usually few second for this model. This is considered as an advantage of TRNSYS. Outputs can be observed in a plot format or in tabulated format and all can be selected by the program options [17]. It is worth to mention that there are some limitations when using TRNSYS to simulate buildings models such as the need to use very detailed specifications for the building, which might be difficult to specify. Also, the need to use a high accuracy weather data which might be not available for the exact location of the building [17]. Such limitations lead to increase the uncertainty of the inputs to the model, hence, increase the uncertainty of simulation results. Another limitation of TRNSYS is the poor integration with 3-D modelling software packages such as AutoCAD [18]. Despite of these limitations, TRNSYS has been widely used to simulate buildings performance and its interactions [19].

Model simulation

Model operational data

The building model has been simulated using TRNSYS software in order to reveal its performance and to evaluate the energy interaction within the building. The model is simulated by two sub-programs of TRNSYS, which are TRNSYS Studio and TRNBuild. Figure 3 shows the model using TRNSYS Studio program. Using TRNBuild program, the specifications of the building structure are determined and the operational data for the building and the occupants are inserted. Figure 4 shows the building model detailed by TRNBuild program.

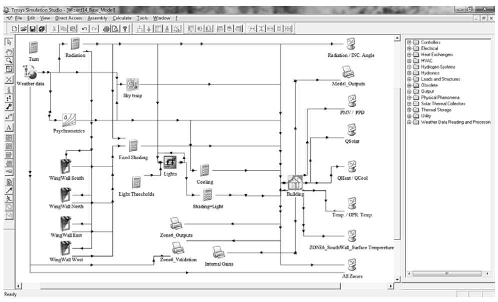

Figure 3. Model representation by TRNSYS studio

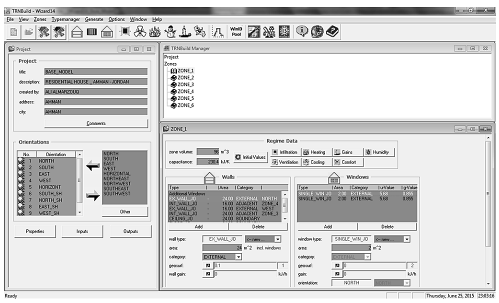

Figure 4. Model representation by TRNBuild

Simulation results

The TRNSYS was used to simulate the prepared model. The main outputs of interest are energy indicators and thermal comfort indicators. The simulation results are.

Table 4. Cooling and heating loads

Month	Cooling load [kWh]	Heating load [kWh]
January	0.0	2835.0
February	0.0	2107.0
March	66.2	1052.0
April	453.5	69.5
May	1591.0	4.4
June	3017.0	0.0
July	4109.0	0.0
August	3875.0	0.0
September	2707.0	0.0
October	1652.0	0.1
November	136.2	482.9
December	0.0	2155.0
Total	17610.0	8705.0

Cooling and heating loads

Table 4 shows monthly cooling and heating loads for the house model.

From tab. 4, it can be noticed that the cooling period through the year starts from April until October, while heating is needed from January to April and in November and December. This is attributed to the geographic location of Jordan in the northern hemisphere and in the intermediate climate region. Cooling is only required when the ambient temperature is higher than the set temperature for cooling. Similarly, heating is only required when the ambient temperature is lower than the set temperature for heating. The annual total energy required for space conditioning is the sum of annual heating and cooling loads which equals 26315 kWh. To find the space conditioning load per meter square of building area, this value is divided by the building area which is 168 m^2. So, the annual space conditioning load per area equals 156.6 kWh/m^2.

Thermal comfort indicators

Thermal comfort of the building occupants can be indicated by the predicted percentage of dissatisfied (PPD) people within the building defined by Fanger [20]. Since comfort parameters are defined in the inputs of the building model, the value of PPD can be obtained from the simulation process. Figure 5 shows PPD for the house model around the year.

From fig. 5, it can be concluded that during the cold weather conditions, a large percentage of occupants are dissatisfied. A possible reason for these results is that the heating is not sufficient enough to provide appropriate indoor comfort environment. Thermal comfort is better during the hot months of the year. Dissatisfaction in cold months motivates the investigation of the envelope design effects on the occupants comfort in order to be improved. The PPD is presented based on the yearly average value for each thermal zone. This is shown in fig. 6.

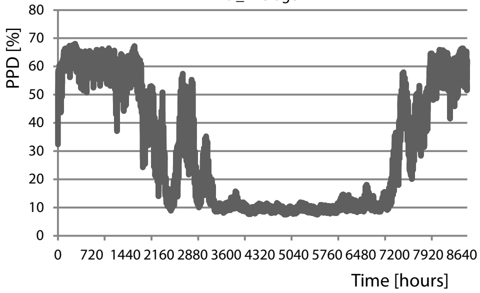

Figure 5. Hourly PPD for the house model

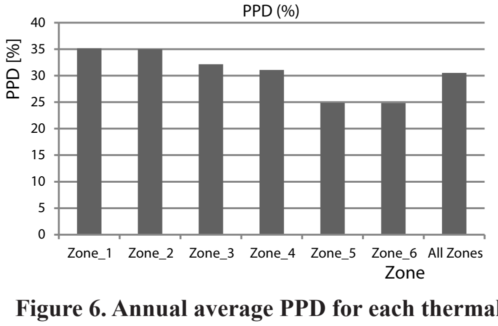

Figure 6. Annual average PPD for each thermal zone

It can be noticed that the similar zones have similar PPD because they have the same operational characteristics and they are exposed to an equal amount of solar energy. Zones with less exposure to solar radiation have a higher PPD values than other zones because the penetrated solar energy compensate the need of heating load during cold periods. It should be noticed that the annual average PPD for each thermal zone helps to evaluate each zone without considering the period of the year for this value. This is very useful when comparing and designing alternative results with the base model results and to evaluate the improvement (or the degradation) for this alternative.

Design improvement

Glazing system

Window design is a very important parameter of the building envelope since it controls the penetration of the solar radiation the building. Also, a large portion of heat is transferred through the window because of the high *U*-value [4]. For the base model, single glazing window with an aluminum frame is used. Three design alternatives are selected: double glazing (6 mm) with an aluminum frame, double glazing with PVC frame and low-emissivity coating-argon filled with PVC frame window. Characteristics of the design alternatives of the glazing system are shown in tab. 5.

Table 5. Glazing design alternatives

Glazing type	*U*-value	*G*-value	Frame	Frame *U*-value
Single	5.68	85.5%	Aluminum	2.0
Double (6 mm)	2.83	75.5%	Aluminum	2.0
Double – PVC frame	2.83	75.5%	PVC	1.9
Double – Low E (Argon filled)	1.26	39.7%	PVC	1.9

Besides the glass type and frame material, windows operating type is a very important parameter that affects the energy performance of the window.

There are different types of window operating mechanisms such as awning, casement, hung, hopper and sliding windows. The difference between these types is related to the amount of the air leakage through the window structure. As the air leakage is reduced, energy gain or loss is reduced. In the proposed model, the design improvement based on changing the glass and the frame type without changing the operating type of the window.

Results of simulation of these alternatives using TRNSYS with a comparison with base model results are shown in tab. 6. The compared results are heating load, cooling load, space conditioning per area, solar radiation penetrated through the building and average PPD. Results are also illustrated in fig. 7.

Table 6. Simulation results for different glazing design alternatives

Parameter	Heating load [kWh]	Cooling load [kWh]	Space conditioning [kWhm^{-2}]	% of base
Single (base)	8705	17610	156.6	–
Double – Aluminum frame	6243	17010	138.4	–11.6%
Double – PVC frame	6238	17010	138.4	–11.7%
Double – Low E Argon filled	6805	13010	117.9	–24.7%

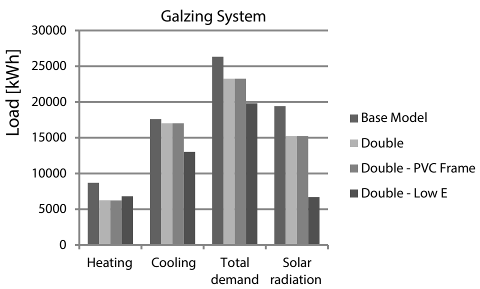

Figure 7. Simulation results for different glazing design alternatives

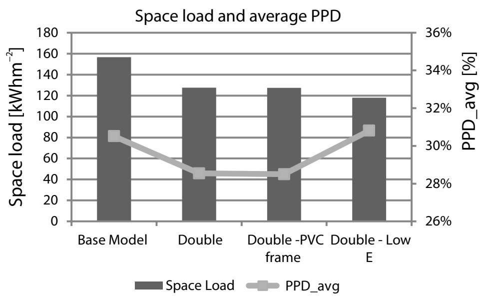

Figure 8. Yearly space conditioning load and the average PPD for different glazing design alternatives

Figure 8 shows the yearly space conditioning load and the average PPD for different glazing designs. Using double glazing window with Aluminum or PVC frame reduces PPD by 7.4%. While using Low E coated window increases PPD by 1%.This is attributed to the blocking of the solar radiation gain in cold weather. Consequently, the heat balance of the occupants is disturbed and an increase in the heating load is required. Since thermal comfort depends on radiant temperature, the reduction of solar radiation by the coating while low air temperature exists causes this dissatisfaction. The reason why the thermal comfort for double glazing system without coating is improved is that it reduces the heat loss without affecting the solar radiation while for the coated window it reduces both heat loss and solar radiation.

Infiltration rate

Infiltration is the accidental penetration of air to the building interior. Avoiding air leakage into the building controls the effect of infiltration on the energy performance. For the proposed design, the default value of the infiltration rate is 1.5 per hour defined by the Ministry of Public Work and Housing [14]. To improve the envelope design, two infiltration rates are simulated with the results shown in tab. 7. An illustration of these results is shown in fig. 9.

Table 7. Simulation results for different infiltration rates

Infiltration rate [h^{-1}]	Heating load [kWh]	Cooling load [kWh]	Space conditioning [kWhm^{-2}]	Base [%]
1.5 (base)	8705	17610	156.6	–
1	5627	17150	135.6	–13.4%
0.75	4190	17030	126.3	–19.4%

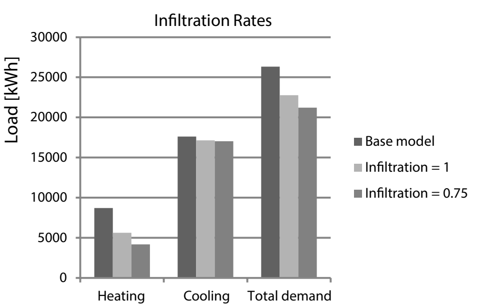

Figure 9. Simulation results for different infiltration rates

It is clear that infiltration rate has a large impact on the energy demands of the building. Reducing the infiltration rate causes a large reduction in the required heating demands in the building. This resulted from the fact that infiltration air has the same temperature of outside air. This *cold* air reduces the air temperature inside and leads to increase.

The Same conclusion can be made for the cooling load, preventing *hot* air from flowing to the building interior helps to reduce the cooling demands. By reducing the infiltration rate to 50%

of the original rate, 51.9% and 3.3% of the heating and cooling loads are reduced, respectively. Also, 19.4% of the total space conditioning requirements is reduced.

The infiltration rate affects the thermal comfort. As the infiltration rate decreases, the thermal comfort increases. Relative air speed and air temperature strongly affect the thermal comfort of the occupants. By controlling these parameters, PPD can be improved up to 10% when the infiltration rate is 0.75 per hour. Figure 10 shows space conditioning load with the average PPD for different infiltration rates.

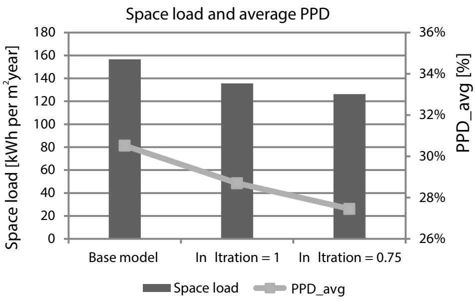

Figure 10. Yearly space conditioning load and the average PPD for different infiltration rates

Conclusions

This paper presents the effects of glazing design and infiltration rate on energy consumption and thermal comfort in residential buildings. A case study of a residential building in Amman, Jordan is presented as a case study. The building model was developed according to the regulations in Jordan. The building model has been simulated to calculate the energy demand of the building and the thermal comfort indicators.

An improvement of the glazing system and infiltration rate design is proposed. Each parameter was studied individually to find its effect on energy consumption of the building envelope and the occupant's thermal comfort. After that, selection of the alternatives at which minimum energy consumption and maximum thermal comfort are achieved has been performed.

For improvement of envelope design in this paper, improving glazing system by replacing single glazing window with double glazing window Argon-filled with low emissivity coating has the dominant effect on the energy saving by 24.7%. At the same time, thermal comfort is degraded by 1%. Reducing the infiltration rate by 50% can save 19.4% of the energy consumed and improves thermal comfort by 10%.

These results showed that by improving the building envelope design, a significant amount of energy can be saved along with improving the thermal comfort of the occupants. Even the reduction of the consumed energy is vital; sometimes it has undesired effects on the thermal comfort. Improving glazing system of the proposed model caused a reduction in the consumed energy and a degradation of the thermal comfort. For the proposed design, the overall results are a reduction of energy consumed and an improvement of thermal comfort.

For the residential buildings in Jordan, it is recommended to use high insulated glazing windows to reduce heat transfer through it. Also, air leakage must be minimized as much as possible.

Nomenclature

U-value – overall heat transfer coefficient
G-value – solar energy transmittance of windows
JNBC – Jordan National Building Council
WWR – window to wall ratio
MEMR – Ministry of Energy and Mineral Resources
PPD – Predicted percentage of dissatisfied people

References

[1] Liu, Y., *et al*, Thermal Comfort and Building Energy Consumption Implications – A Review, *Applied Energy*, *115* (2014), Feb., pp. 164-173

[2] Xiwang, L., Jin, W., Review of Building Energy Modelling for Control and Operation, *Renewable and Sustainable Energy Reviews*, *37* (2014), Sept., pp. 517-537
[3] Mwasha, A., *et al*., Modelling the Performance of Residential Building Envelope: The Role of Sustainable Energy Performance Indicators, *Energy and Buildings*, *43* (2011), 9, pp. 2108-2177
[4] Hassan, A., *et al*., Key Design Features of Multi Glazed Windows: A Review, *Thermal Science*, *21* (2017), 6, pp. 2673-2687
[5] Sadineni, S. B., *et al.*, Passive Building Energy Savings: A Review of Building Envelope Components, *Renewable and Sustainable Energy Reviews*, *15* (2011), 8, pp. 3617-3631
[6] Feng, Y., Thermal Design Standards for Energy Efficiency of Residential Buildings in Hot Summer/Cold Winter Zones, *Energy and Buildings*, *36* (2004), 12, pp. 1309-1312
[7] Morrissey, J., Horne, R. E., Life Cycle Cost Implications of Energy Efficiency Measures in New Residential Buildings, *Energy and Buildings*, *43* (2011), 4, pp. 915-924
[8] Nikoofard, S., *et al*., Effect of Window Modifications on Household Energy Requirement for Heating and Cooling in Canada, *Proceedings*, eSim 2012: The Canadian Conference on Building Simulation, Halifax, Canada, 2012
[9] Moorjani, V., Asadi, S., Assessing the Effects of Glazing Type on Optimum Dimension of Windows in Office Buildings, *Proceedings*, 50th ASC Annual International Conference, The Associated Schools of Construction, Washington DC, 2014
[10] Emmerich, S., Persily, A., Energy Impacts of Infiltration and Ventilation in U. S. Office Buildings Using Multizone Air-Flow Simulation, *ProceedingS*, 98th Conference of IAQ and Energy, New Orleans, La., USA, 1998, pp. 198-203
[11] ***, Ministry of Energy and Mineral Resources MEMR, Energy Facts and Figures 2016, Amman, Jordan, 2016
[12] Awwad, R., Sakhrieh, A., Investment Potentials of Conversion Energy Efficient Buildings in the Housing Sector in Jordan, *Proceedings*, International Conference on Renewable Energy and its Future in the Arab World 2013, Amman, Jordan, 2013
[13] Jaber, S., Ajib, S., Optimum, Technical and Energy Efficiency Design of Residential Building in Mediterranean Region, *Energy and Buildings*, *43* (2011), 8, pp. 1829-1834
[14] ***, Ministry of Public Work and Housing, Jordan National Building Codes JNBC, Amman, Jordan, 2009
[15] ***, Ministry of Public Work and Housing 2, Thermal Insulation Code for Buildings, Amman, Jordan, 2009
[16] ***, Ministry of Energy and Mineral Resources MEMR, Energy Consumption in Residential Buildings in Jordan for 2012 Survey, Amman, Jordan, 2013
[17] ***, TRNSYS Software Help, Solar Energy Laboratory, University of Wisconsin-Madison, usa, 2000
[18] Coakley, D., *et al*., A Review of Methods to Match Building Energy Simulation Models to Measured Data, *Renewable and Sustainable Energy Reviews*, *37* (2014), Sept., pp. 123-141
[19] Monien, D., *et al*., Comparison of Building Modelling Assumptions and Methods for Urban Scale Heat Demand Forecasting, *Future Cities and Environment, 3* (2017), Dec., pp. 1-13
[20] Fanger, P., *Thermal Comfort*: *Analysis and Applications in Environmental Engineering*, McGraw-Hill, Neew York, USA, 1970

Paper submitted: September 10, 2017
Paper revised: January 31, 2018
Paper accepted: February 6, 2018