ASSESSMENT OF SINGLE ZONE BUILDING ENVELOPE USING TRANSIENT SYSTEM SIMULATION TOOL (TRNSYS)

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Abstract:

The aim of present study is to investigate the thermal performance of a residential building equipped with a ventilation cooling system during the summer season using the TRNSYS simulation tool. New scenario to reduce the thermal resistance of the building envelope using thermal insulation and double glazed windows was proposed. The archived weather data of Benghazi city where the simulated building is located was entered to the simulation tool. The daily ambient air-temperature variations are recorded based on hourly changes. The simulation is carried out to hourly calculate the indoor air-temperature in the building model zones. It was found that the proposed building envelope contributes to saving energy by reducing the variations of indoor air-temperature close to 1.5°C and 2.5°C based on average and peak-to-peak difference, respectively.

Keywords: Building, Simulation, Transient.

الملخص:

الهدف من هذه الدراسة هو فحص الأداء الحراري لمبنى سكني مجهز بنظام تبريد وتهوية خلال فصل الصيف باستخدام أداة محاكاة TRNSYS. تم اقتراح سيناريو جديد لتقليل المقاومة الحرارية لغلاف المبنى باستخدام العزل الحراري والنوافذ الزجاجية المزدوجة. تم إدخال بيانات الطقس المؤرشفة لمدينة بنغازي حيث يقع المبنى المحاكي في أداة المحاكاة. يتم تسجيل التغيرات اليومية في درجة حرارة الهواء المحيط بناءً على التغيرات في الساعة. يتم إجراء المحاكاة لحساب درجة حرارة الهواء الداخلي في مناطق نموذج البناء كل ساعة. وجد أن غلاف المبنى المقترح يساهم في توفير الطاقة عن طريق تقليل الاختلافات في درجة حرارة الهواء الداخلي بالقرب من 1.5 درجة مئوية و 2.5 درجة مئوية على أساس الفرق المتوسط والذروة إلى الذروة ، على التوالي.

كلمات مفتاحية: بناء ، محاكاة ، متغير زمني عابر.

1. Introduction

Conventional cooling systems require a considerable amount of primary energy resulting in an increase of building operation cost. As a result, the greenhouse gas (GHG) emissions are accordingly boosting. It was reported that the building sector in developed nations uses about 40% of the world-wide total energy and contribute up-to 40% of GHG (Parameshwaran et al., 2012). (Hasan, 1999) used life cycle cost analysis to determine optimum insulation thicknesses in a building. The results showed that for rock wool as an insulation, 10 years is the saving lifetime with 21$/m^2. He reported payback periods of 1-1.7 years for rock wool and 1.3-2.3 years for polystyrene insulation depending on the type the wall structure. (Comakli et al.,2003) investigated the effect of insulation thickness on the energy used in the building. They optimized the thickness of the insulation when coal is used as a fuel. (Al-Sallal , 2003) studied the usages of polystyrene and fibre glass as insulations in warm and cold climates. He found that the payback period in cold climates is shorter than that in warm climates. The selection and optimization of the insulation layer formed the framework of (Al-khawaja , 2004). They found that the position of the insulation layer plays an important role in the overall performance of the insulated wall. (Ozkahraman et al., 2006) investigated the effect of using tuff stone as external building materials on the thermal behaviour of the building in cold climates. They concluded that a considerable energy saving can be achieved by using this type of stone as an outer finishing layer. In another study conducted by (Sisman et al., 2007) aimed to investigate the impact of applying insulation layer to ceiling and walls of residential house in Turkey, it was shown that considerable energy saving can be achieved by insulating the outer envelope of the building. They also proposed a correlation of optimum insulation thickness in terms of degree day. (Khalil et al., 2018) considered buildings' envelopes and the external skin configurations, due to its importance as the first element facing the external environment. ‘‘Low Technology” and ‘‘High Technology” notions were proposed for the environmentally-efficient envelopes of the residential buildings. (Evin et al., 2019) investigated a procedure for determining the optimum thermal insulation thickness to be applied to the envelope (external walls, column, floor and roof) of residential buildings by using the heating-cooling energy requirement. The heating and cooling loads and energy costs for different structures are calculated using the optimum thermal insulation thicknesses. With the increase in insulation thickness, annual fuel consumption was reduced and thus the emissions resulting from the burning of the fuels were decreased. (Adepo et al., 2018) conducted experiments on heat transfer for solid and hollow concrete blocks with evenly spaced cavities in them. The samples were tested based on their crushing strength and heat flow resistance. The results showed that a typical concrete block is much economical if it contains more number of cavities and better thermally efficient than when it has no cavity or the cavity size is reduced. The hollow concrete block with two cavities is preferred considering both strength and conduction resistance ability. (Mohamed et.al., 2015) investigated the domestic energy use and occupants' energy behaviour in Libya. A comprehensive survey was conducted to evaluate several aspects of domestic energy demand and characteristics in Libya. The findings indicated that there is a significant increase in energy demands in the household sector in Libya and it is significant to have a clear strategy to reduce carbon emission and energy use by improving occupants' behaviour as well as utilizing other sustainable measures. (Suleiman, 2012) numerically investigated the thermal loading performance of traditional buildings in Libya. The materials were limited to bricks, tiles, cement plasters, mortar and ground soils without any insulation components which are characteristics of such houses. According to the obtained results, the U-values were quite high and therefore, several suggestions have been proposed to improve the thermal loading performance that will lead to a reasonable human comfort and reduce energy consumption. (Bodalal, 2010) investigated the impact of building envelope construction materials on the thermal performance of residential buildings in Benghazi Libya using a commercially available software (Cymap). Three scenarios of envelope construction were considered in the investigation. The reference scenario was 12mm layer of cement plaster followed by a 200mm hollow cement block and a 12mm layer of cement plaster. The second scenario consisted of 12mm cement plaster, 150mm hollow cement block, 50mm air gap, 100mm hollow cement block, and a 12mm layer of cement plaster. The third scenario consisted of 12mm layer of cement plaster followed by 250mm hollow cement block and a 25mm decorative colour layer functioning as insulation (mixture of cement and perlite) known as Stucco. The results revealed that scenario 3 is the most energy efficient construction while the reference scenario, which is commonly used in Libya, was the worst among the three scenarios and the walls, windows and roofs contribute by about 70%, 20% and 10% from the total building fabric load respectively. (Korniyenko, 2015) evaluated the thermal performance of a residential building envelope based on the visual-and instrumental inspection. The results of the study serve as a basis for the development of methodological foundations for design, construction, operation and renovation of energy-efficient buildings. In general, typical Libyan buildings and its envelope are inefficient in terms of energy consumption. Thermally insulating materials are not employed in the construction of the external walls to improve the thermal performance of the currently popular wall construction. A simulation of an existing design and a thermally efficient design is the aim of the present study.

2. Model description

All the calculation of air temperature, cooling and heating loads required are performed using transient system simulation program, namely called TRNSYS. The total energy consumed in the building (in cooling and heating) is calculated in monthly and annual basis. TRNSYS is a complete and extensible simulation environment for the transient simulation of systems, including multi-zone buildings. It is used by engineers and researchers around the world to validate new energy concepts, from simple domestic hot water systems to the design and simulation of buildings and their equipment, including control strategies, occupant behaviour, alternative energy systems (wind, solar, photovoltaic, hydrogen systems). The simulated case in the present study is a traditional building with eight zones as illustrated in Fig. 1. The description of all envelope components, window and door types, and the thermal properties of different layer types, respectively is summarised in Table .1 through Table .3. The following assumptions are made:

- The thermal building response is simulated used TRNSYS for single-zone model. The model is an apartment with dimensions of 4m × 5m × 3m.
- The National Climate Data and Information Archive in Libya weather data are used. The daily ambient air-temperature variations are recorded based on hourly changes.
- Air change function is scheduled to allow the air change per hour (ACH) of 138 to be supplied into the building during the period of (6:00 AM in the early morning until 19:00 PM) and only allowed air change fraction of 2 for the rest of the day.
- The indoor air is recirculated and mixed with fraction of fresh air as performed in previous step in scheduled function as defined in prior. Fresh air-temperature is provided for July month, in Benghazi.
- To meet the thermal comfort requirement, the indoor air temperature is set at 20^{o}C.

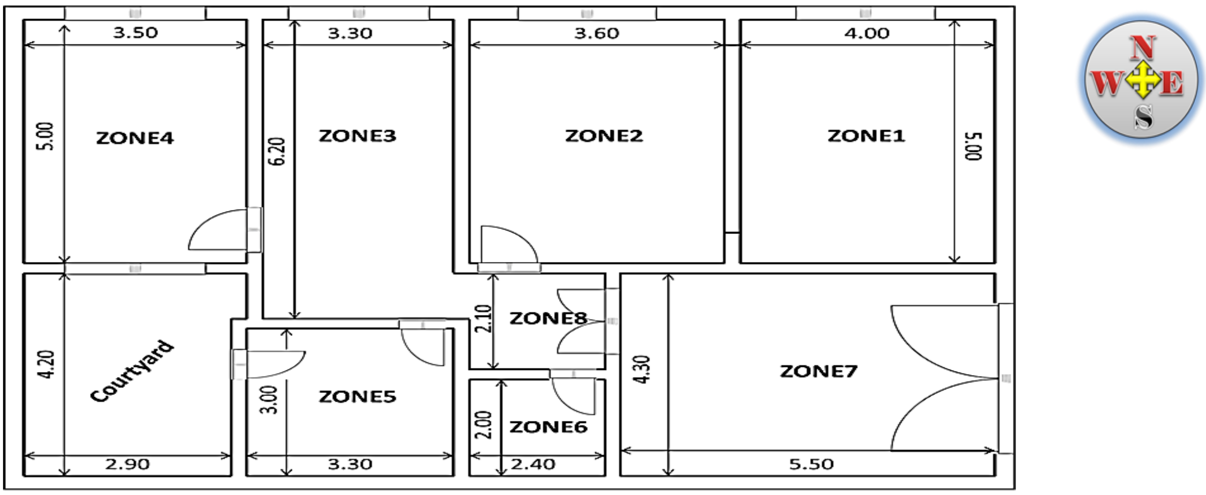


Fig. 1. Map of a residential building in Benghazi city.

Table .1 Details of wall components in a traditional building.

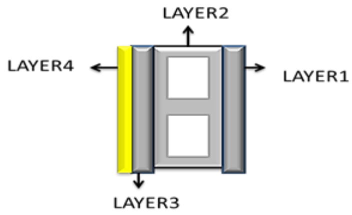
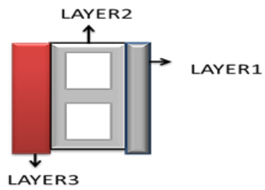
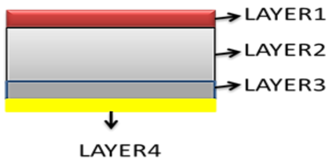
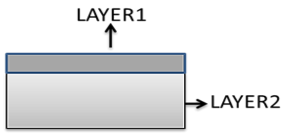
Wall Type	Description	Wall Layer
External and Internal walls Zone number (1,2,3,4,7,8)		1.cement-out 2.hollow block 3.cement-in 4.paint-in
Kitchen and Bathroom Walls Zone number (5,6)		1.cement-out 2.hollow block 3.ceramics
Roof Zone number (1,2,3,4,5,6,7,8)		1.ceramics 2.reinforced concrete slab 3.cement-in 4.paint-in
Floor Zone number (1,2,3,4,5,6,7,8)		1.ceramics 2.plain concrete slab
Divider Zone number (1,2)	-	1.air

Table .2 Description of window and door types in a traditional house.

Type	Shape	Area (m^2)	Width (m)	Height (m)
Window I	Single glass	1.2 m^2	1 m	1.2 m
Window I	Single glass	0.64 m^2	0.80 m	0.80 m
Door (room)	Spruce-pin	2.20 m^2	1 m	2.20 m
Door (kit., bat.)	Spruce-pin	1.98 m^2	0.90 m	2.20 m
Door (main entrance)	Spruce-pin	7.50 m^2	3 m	2.50 m
Door (house enter)	Spruce-pin	3.08 m^2	1.40 m	2.20 m

Table .3 Description of thermal properties of different layer types of a traditional building [15-16].

Layer Type	Thickness (cm)	Conductivity $\frac{kJ}{hr.m.k}$	Capacity $\frac{kJ}{kg.k}$	Density $\frac{kg}{m^3}$
Cement-out	1	2.592	0.840	1762
Hollow Concrete Block	20	2.592	0.835	2083
Cement-in	1	2.592	0.840	1762
Paint-in	0.5	0.13	2.09	40
Ceramics	3	0.6117	0.980	280
Reinforced concrete slab	30	6.09	0.840	2000
Plain concrete slab	10	0.648	1	704

3. Proposed building envelope

The scenario to be investigated is the use of an insulation board (made of mineral wool boards) to the interior walls that their external walls are facing irradiation and rain along with the replacement of single glass windows with double-glazed ones. The insulation is applicable to the north-east walls located in zones (1,2,3,4,7) and the roof including all zones. The thermal properties of alternative envelope components are demonstrated in Table .4.

Table .4 Description of layer types and their thermal properties used in proposed envelope [15-16].

Layer Type	Thickness (cm)	Conductivity $\frac{kJ}{hr.m.k}$	Capacity $\frac{kJ}{kg.k}$	Density $\frac{kg}{m^3}$
Cement-out	1	2.592	0.840	1762
Hollow Concrete Block	20	2.592	0.835	2083
Cement-in	1	2.592	0.840	1762
Paint-in	0.5	0.13	2.09	40
Ceramics	3	0.6117	0.980	280
Reinforced concrete slab	30	6.09	0.840	2000
Insulation-in (mineral wool boards)	3	0.169	0.84	80

4. Results and discussion

The variation of ambient and the indoor air temperatures for the basic envelope and the proposed envelope are shown in Fig. 2 for a whole week. The peak to peak temperatures of sinusoidal indoor variation of basic envelope and enhanced envelope are 30.27°C and 27.97°C, respectively during July month. This enhances the temperature profile of proposed envelope with a reduction of 7.6% compared to that of basic envelope. It can be seen that the difference between the ambient and indoor air temperatures on average basis is closer to 3.25°C. On the other hand, when using the proposed envelope, the difference between the ambient and indoor air temperatures has increased to 4.47°C. Adopting the enhanced envelope resulted in saving the cooling energy as shown in Fig. 3 when deduced from the operative cooling of the system which is fixed for both cases.

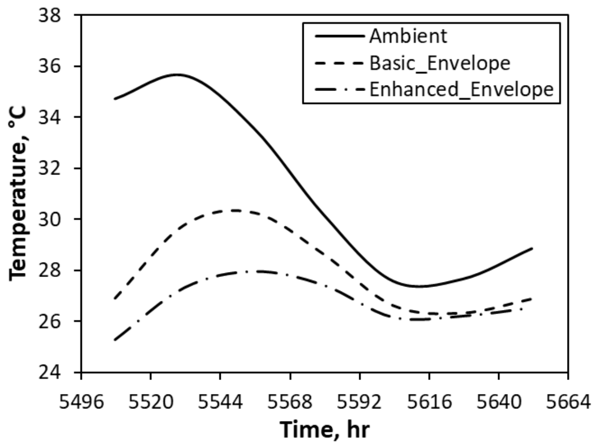


Fig. 2. Indoor air temperature variations for basic and enhanced building envelopes.

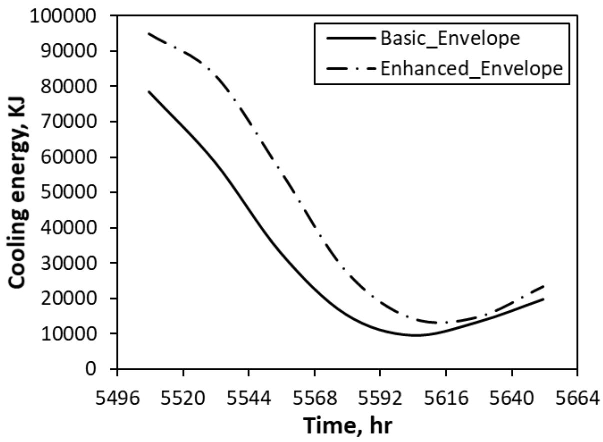


Fig. 3. Comparison of saved cooling energy for basic and enhanced building envelopes.

5. Conclusion

A simulation tool was developed to analyse the thermal performance of a ventilation cooling system using TRNSYS. TRNSYS is a transient system simulation program primarily used in the fields of renewable energy engineering and building simulation for passive as well as active solar design. The simulations are performed through summer months for three scenarios based on building's envelope construction. The control function is used to select the air stream which has a lower air-temperature to be supplied into the building. The control strategy for a ventilated room is established to ensure that the internal air room temperature did not exceed 20°C. The National Climate Data and Information Archive in Libya weather data are used. The daily ambient air-temperature variations are recorded based on hourly changes. The simulation is performed over the entire summer time-from the beginning of June to the end of August. Simulations were carried out to study the impact of building's envelope construction on improving the thermal performance for ventilation cooling application. The transient cooling load calculations are considered based on hourly changes of outdoor air-temperature. The reduction of the indoor air-temperature is found to be close to 1.5°C and 2.5°C based on average and peak-to-peak difference, respectively.

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