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Effect of window-to-wall ratio and thermal insulation on building thermal energy in various Iraqi Cities

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Abstract: Building design is a key aspect of attaining thermally effective buildings and noticeably contributes to decarbonizing the environment in hot locations. In this paper, the effect of window-to-wall ratio (WWR) and thermal insulation thickness on the building energy has been studied numerically through a validated room model by EnergyPlus. Five WWRs (from 10% to 50% with a 10% increment) are examined under each study location. Later, the influence of various thermal insulation thicknesses (1, 3, 5, 7, and 9 cm) is investigated at the best WWR in each location considering the maximum mean temperature reduction and time lag. The study findings indicated that the best WWR for Al Amarah city is 20%, against 30% and 40% for Baghdad and Erbil cities, respectively. However, the indoor mean temperature increased slightly as the WWR increased in each city, influenced by the effect of the opaque elements. As for the effect of thermal insulation thickness, it could be stated that 3 cm is the best thickness for all locations at the best WWR, achieving maximum mean temperature reduction and time lag by 1.55 ºC and 3:33 h, 2.01 ºC and 4:03 h, 2.45 ºC and 5:57 h in Al Amarah, Baghdad and Erbil, respectively.

Keywords: Building energy; Building design; Building envelope; Thermal insulation; Time delay

Nomenclature

MMTR	Maximum mean temperature reduction (ºC)
Tm	Mean temperature (ºC)
TL	Time lag (min)
WNHGR	Window Net Heat gain Rate (W)
WNHTR	Window Net Heat Transfer Rate (W)
WWR	Window-to-wall ratio (%)

1. Introduction

In the recent era, the building sector has oriented towards passive insulation and sustainable technologies due to the anxieties of indoor air quality, energy cost, and environmental issues accompanying energy generation [1,2]. The majority of buildings located in hot and humid regions rely remarkably on the use of cooling and air-conditioning means to overcome harsh weather conditions and provide acceptable comfort levels for occupants. Nevertheless, these systems have been reported as the main consumers of energy in such regions, especially when talking about residential levels which reach the level of 42% of total energy use [3]. In most tropical countries, attaining thermal comfort without air-conditioning methods is challenging due to poor building design and thermally poor construction materials, which may worsen due to the global warming potential in recent years [4]. However, it has been conveyed that thermal comfort and energy saving could be achieved in high-energy consumption buildings considering various aspects,

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including the building envelope characteristics[5], occupant behaviour [6], and energy management strategies [7]. Since the usage of air-conditioning units is delimited due to energy poverty, the proper design of the building envelope is the other intrinsic option to achieve the required thermal comfort [8–10].

In hot regions, building energy-saving can be achieved by controlling different design parameters such as building orientation, construction materials, window-to-wall ratio (WWR), and many others [11–13]. Building configuration is the first phase in the building construction design process which even emanates before selecting building materials. Therefore, the building geometry plays an essential role in controlling energy efficiency in the earlier design phases and ensuring better thermal comfort requirements [14]. Considering building energy, the building geometry and glazing type are broadly approved to have a considerable effect on building thermal performance and energy efficiency.

Several attempts have been made to identify the impact of the building configuration (building shape) [12], envelope storage ability [15], glazing size [16], and thermal insulation implementation within building envelope materials on energy consumption [17]. For instance, Alghamdi et al. [18] numerically explored fifteen architectural building design parameters that could influence thermal comfort and energy use in Australian educational buildings. The study adopted the Latin hypercube sampling technique to evaluate the sensitivity and uncertainty analyses in terms of thermal discomfort hours and energy consumption in each study run. The research showed that the cooling set-point temperatures and roof construction have considerable influence on building energy, reducing the operative temperature by 14.2% and 20%, respectively. Accordingly, the reduction of energy consumption achieved due to these parameters was about 43.7% and 41%, respectively. Haddad et al. [19] numerically explored various passive strategies to enhance building efficiency, including night ventilation, building materials, thermal insulation, and window configuration in Algerian regions. The study outcomes using these techniques could minimize building energy needs for heating and cooling from 67.5 to 15.7 kWh/m2 and from 7.7 to 5.7 kWh/m^2, respectively. Accordingly, annual energy savings by 72% and CO_2 emissions reduction from 1772 to 499 kg/year were achieved. De Masi et al. [20] numerically quantified the effects of various window designs on the total energy and thermal comfort of an office in several European climatic zones. The study considered the window orientation, WWR, shading system installation, glass, and frame type as influential design aspects. The study outcomes showed that a double selective-pane window is the better option for the warm summer and at the worst, the annual energy saving will be around 26% compared to a clear double-pane window. Xing et al. [21] examined the correlation of building efficiency provided with electrochromic smart windows with the WWR to mitigate building energy losses and environmental influences. The study considered several cases including double electrochromic window, low-emissivity (low-E) window, and clear glazing window simulated for five WWRs (0%, 20%, 40%, 60%, and 80%), and four window orientations, under humid subtropical and Mediterranean climates. The study findings indicated that for humid subtropical climates, the southern-oriented building with 40% WWR electrochromic window achieved the best energy performance than all other examined configurations. Altun [22] numerically investigated the optimum parameters of envelope design considering the thermal insulation thickness, building orientation, window glazing type, and WWR for a room model in different Turkish cities. The findings showed that the annual energy consumption reduction is highly impacted by the selection of windows, room orientation, and thermal insulation thickness in which the double-glazed windows, south-west oriented, has the best performance. Besides, the outcomes showed that the best envelope (external wall) thickness was 9 cm in Hakkari City, while 6 cm was the best in Istanbul City.

The window size concerning the wall area has been explored widely in recent research works [23]. For instance, Mohammed et al. [24] explored the influence of aerogel applied to window panes examined under the United Kingdom weather conditions. Their research considered eleven aerogel window samples applied to a two-story building to evaluate the thermal efficiency of these cases against a standard double-glazing window. The findings showed that aerogel has increased the total solar heat energy through windows which maximized the solar heat gain coefficient of 0.738 and lowered the U-values to 0.381 W/m2K. Besides, the study showed that increasing the WWR has reduced the building heating load but increased the building cooling loads. Considering window orientation, the south-oriented window had the highest cooling loads, especially when adding aerogel glazing. However, adding aerogel to the insulated window has increased the total heat transfer of the window by 33%, reducing the heating load by 15.5% in comparison to the standard double-glazing window. Ahmed et al. [25] investigated numerically the influence of window design parameters, including the WWR, window orientation, and glazing materials, on the energy consumption under the climate conditions of Kirkuk, Iraq. Their study verified an office building considering four WWRs, four window orientations, and three window glazing materials (clear, grey, and theoretical), compared to single and double-glazed windows. The findings showed that the building provided with double-pane, clear glass windows oriented to the south achieved a 100% heating consumption reduction. Moreover, minimal cooling consumption was achieved for the double theoretical-197 glass, north-oriented, with 25% WWR. Alwetaishi [26] investigated the optimum WWR (namely 5%, 10%, 20%, 30%, and 40%) for an educational building in various climatic regions in Saudi Arabia. The main outcomes of the study indicated that WWR= 10% is recommended for hot and humid climates to ensure suitable thermal comfort. Ashnavar and Bina [27] investigated the correlation of windows with solar radiation using Design Builder/Energy Plus software. The research examined the window configuration and orientation in different cases to quantify the building cooling load reduction and energy consumption. The findings revealed that the square-shaped window has poorer performance than other configurations and the horizontally and vertically-placed windows in the southern and northern orientations transferred lower solar radiation to the building space by about 59.86 and 29.19 kWh, respectively.

Given the influence of thermal insulation on building energy, Eddib and Lamrani [28] examined four thermal insulation materials locally available in Marrakesh to specify the best option with optimal thickness. The study examined the Expanded Polystyrene, glass wool, rock wool, and wood fibre numerically using TRNSYS software. The study found that the wood fibre insulation with 8 cm thickness could save up to 7% and 14% heating and cooling loads, respectively. Furthermore, using this insulator, the building temperature was averagely increased by up to 0.26 °C in January and decreased by up to 0.49 °C in July. Ahmed [29] assessed the effect of thermal insulation on the building energy efficiency under the Upper Egypt region climate conditions. The study employed the Design Builder software to quantify building energy efficiency for various thermal insulation types. Study results revealed that the use of a double-skin roof with a 20 cm insulator was the best for ceilings while using a polyurethane board with a 7 cm thickness was the optimal for walls. Yang et al. [30] numerically and experimentally studied the aerogel insulating panels for building energy efficiency in China considering the temperature time lag (TL), decrement factor, and heat losses. The study outcomes showed that the wall-enhanced aerogel panels have decreased the inside surface temperature and heat transfer by about 20% and 40%, respectively, as compared to a standard insulating wall. Cuce et al. [31] developed a plaster insulation comprised of expanded perlite, polymer fibres and cement materials. The insulation was tested considering the mitigation in temperature and overall heat transfer coefficient at different thicknesses. The results indicated that the temperature across the developed insulation was minimized by up to 7.1°C with an overall heat transfer coefficient of 2.86 W/m^2K compared to conventional insulation materials. Siciliano et al. [32] proposed bio-based insulation foam comprised of wooden chips. The developed porous insulation foam was tested thermally and mechanically, achieving a thermal conductivity of 0.038 W/m.K and 70% higher compressive strength than the traditional insulators. Kassim et al. [33] examined an agro-based biofiber waste thermal insulation comprised of 75%–80% gypsum, 15%–18% sawdust waste and 2%–10% polymer. The study examined the cooling and heating load demand reduction of buildings-integrated insulators in the walls and ceiling at various climate conditions. Study findings designated a reduction of 1%–1.6% and 1%–8.7% in the cooling and heating loads, corresponding to an average reduction in the cooling and heating energy demand by 1.2% and 3%, respectively.

As could be observed from the analyzed literature studies, it could be stated that the thermal insulation and window size have a significant influence on the building's thermal energy performance. Therefore, the current study aims to study different WWRs under various Iraqi locations in the south (Al Amarah), middle (Baghdad), and north (Erbil) to specify the efficient window size in each studied location. Besides, the influence of thermal insulation thickness under the best WWR for each study location will be examined to specify the best thickness for each case.

2. Methodology

The flow chart of this study is shown in Fig. 1, showing the step-by-step procedure followed to produce results. Each phase of the methodology was conducted as an input to the next stage. Further description of the phases is detailed in the following subsections.

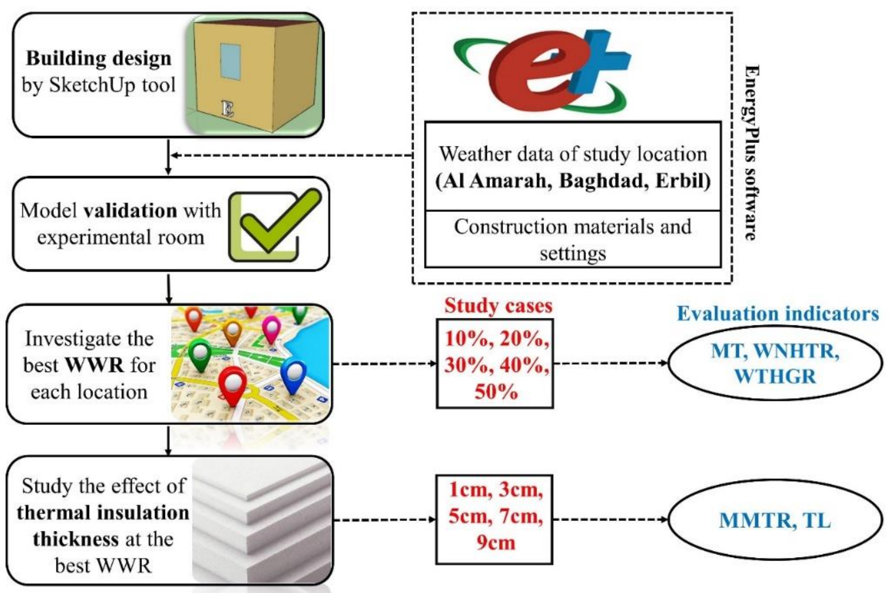

Fig. 1. Schematic for study methodology.

2.1 Case study building

A detachable room model with an area of 25 m^2 and 3 m height is designed using the Google SketchUp tool (Fig. 2). The model is then simulated using the Energy Plus program considering different WWRs, namely 10%, 20%, 30%, 40%, and 50%, for an east-oriented window. The room model was directed towards the east direction since the beam solar radiation hits the window in this direction for a long time during the first half of the day, resulting in high cooling loads. The thermal insulation thickness is examined later considering different thicknesses (1, 3, 5, 7, and 9 cm) at the best WWR for each study location.

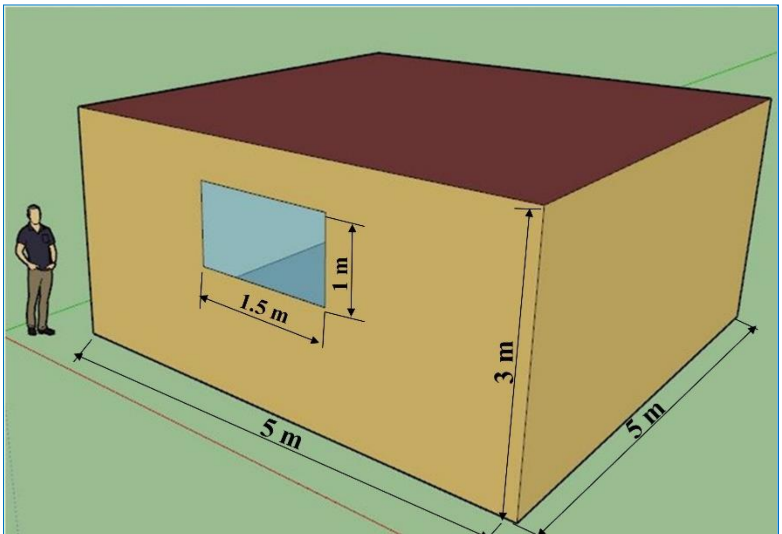

Fig. 2. 3D view of test room model in SketchUp.

The building is set to be non-conditioned to explore the effect of WWR and thermal insulation passively.

The thermal load for occupants, lighting, and appliances was neglected in each case to show the influence of the building envelope alone. The room's roof was constructed from an Isogam roofing layer placed above a concrete layer which was cladded from the inside using a gypsum mortar layer. In addition, the walls were constructed from commonly fired clay bricks cladded from the outside by a cement mortar layer and from the inside with a gypsum mortar layer. These construction combinations for roofs and walls are the worst thermal construction materials for the study location. Since the effect of the floor was an oversight in this work, a plane flooring layer made of plywood wood was suggested. The proposed window in this room construction is a clear, single pane placed in the east direction in all studied cases. The detailed description of building elements and their properties used in the simulation software are listed in Table 1.

Table 1. Construction materials properties delivered to the simulation tool [34,35].

Property	Concrete	Isogam	Flooring wood	Fired clay brick	Cement plaster	Gypsum mortar
Thickness (m)	0.05	0.004	0.3	0.07	0.02	0.002
Thermal conductivity (W/m.K)	1.49	0.35	0.18	0.54	0.99	0.23
Density (kg/m^3)	2300	1400	950	1460	2020	980
Specific Heat (J/kg-K)	800	1100	1200	800	1000	896

2.2 Simulation tool and setup

The room model was simulated using EnergyPlus software, which is extensively used to analyze building energy applications. This powerful tool was introduced and continuously developed by the US Department of Energy, based on a variety of building physics algorithms. The so-called "IDF file" is imported to the EnergyPlus software from the developed room modelled by SketchUp, while the weather conditions for study locations were produced from a separate input file called as "EPW file". The simulation was set to generate outcomes based on a specified time-step or hourly basis depending on the analyzed indicator. For instance, the TL was estimated based on a 3-minute time step due to fast indoor temperature variation, while the window total heat gain rate was accounted for on an hourly basis considering the time in which the sun directly hit the window.

2.3 Validation of room model

The developed model was validated against an experimental room built from the same construction materials employed in the current study [36]. The validation results indicated good agreement between the experimental and simulated with a deviation of no more than 7% (Fig. 3). This deviation could be attributed to the weather conditions which are dissimilar from the experimental and simulation studies since the weather file used in the simulation relies on approximations that overlook the changeable conditions effect in practice.

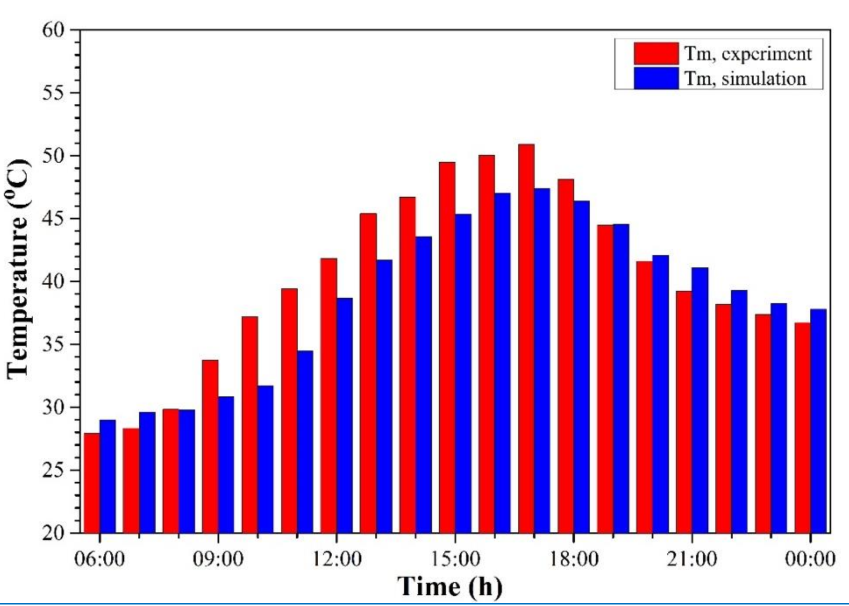

Fig. 3. Room model validation with experimental results [36].

2.4 Energy evaluation variables and cases

Various energy indicators were considered in this work some of them were collected directly from the software output, while the others were calculated based on the time and values of temperature variation. The indicators considered to explore the influence of WWR and thermal insulation thickness under study locations are the window net heat transfer rate, window total heat gain rate, TL, and indoor mean temperature reduction. The Window Net Heat gain Rate (WNHGR) is consistently missing some amount of energy transferred out of the windows to account for the complete heat flow across the window. The Surface Window Net Heat Transfer Rate output variable is the sum of transmitted solar radiation, convective losses, etc. The TL is the period between the maximum outdoor ambient temperature and the indoor temperature. The indoor mean temperature is the average temperature of all surfaces surrounding occupants, including walls, roofs, and floors. Unlike air temperature, mean temperature considers the radiant heat exchange between the human body and its surroundings.

As stated earlier, two cases are considered in the current research, which are as follows:

Case I: Variable WWR

In the current work, different WWRs were considered to specify the best window area for the room in each study location. The proposed window areas are as follows:

At WWR =10%, window dimensions are (1.5 m ×1 m)
At WWR = 20%, window dimensions are (2 m × 1.5 m)
At WWR = 30%, window dimensions are (2.25 m × 2 m)
At WWR = 40%, window dimensions are (3 m × 2 m)
At WWR = 50%, window dimensions are (3 m × 25 m)
The properties of employed window glass are listed in Table 2.

Table 2. Glass properties considered in the simulation tool [34].

Name	Value	Unit
Heat transfer coefficient	5.48	W/m^2-k
Solar Heat Gain Coefficient	0.94	-----
Visible Transmittance	0.74	-----

Case II: Thermal insulation variable thickness

A locally accessible expanded polystyrene (cork) was suggested as an insulator in this research as it is a very good thermal insulator available at low cost in Iraq and used commonly in some constructions for thermal insulation purposes. Various thermal insulation thicknesses were studied, including 1 cm, 3 cm, 5 cm, 7 cm, and 9 cm, as they are standardized in the local markets. The thermal properties of the used thermal insulation are listed in Table 3.

Table 3. Thermophysical properties of thermal insulation (Expanded Polystyrene) [37].

Roughness	Conductivity (W/m.K)	Density (kg\m3)	Specific Heat (J/kg.K)
Medium Smooth	0.035	25	1400

2.5 Study locations

The current study was conducted in three different cities in Iraq, located in the southern, middle, and northern parts of the country. Al Amarah city, the centre of Misan governorate, is located in the south. Baghdad city, the capital of Iraq, is located in the middle part of the country, while Erbil city is located in the northern part of the country and represents the capital of the Kurdistan region. The climate in each city under study is presented in Table 4 according to the Köppen Geiger classification.

Table 4. Köppen Geiger climate classification for study locations [38].

Location	Climate classification	Latitude / Longitude
Al Amarah city	Hot desert climate with extremely hot and dry summers and cool, wet winters (BWh)	31.84° N / 47.14° E
Baghdad city	Hot-dry summers and mild to cool winters (BWh)	33.3152° N/ 44.3661° E
Erbil city	Mediterranean climate with arid summers and wet winters with occasional flooding (Csa)	36.1877° N/ 44.0107° E

3. Results and discussion

3.1 Effect of WWR

Typically, it has been reported that about one-third of the total heat losses occur through the building windows [39], not to mention that most air infiltration arises at the window edges. Despite the undesirable energy performance of windows, they are an essential building envelope element for aesthetic concerns, daylight provision, and solar heating sources in winter. Besides, windows have a lower cost than opaque elements in general. The effect of WWR on the energy conservation of the study room under different locations is analyzed as described in the following subsections.

3.1.1 Indoor mean temperature reduction

The simulation results of the WWR effect on the indoor mean temperature of room under all study locations are presented in Fig. 4. It could be observed that the mean indoor temperature for all cities has increased from 9:00, reaching its peak at 18:00 although the sun starts shining around 6:00 every day. The reason is attributed to the sun's position concerning the window in which the solar radiation becomes direct to the window placed on the east wall around 8:30-9:00.

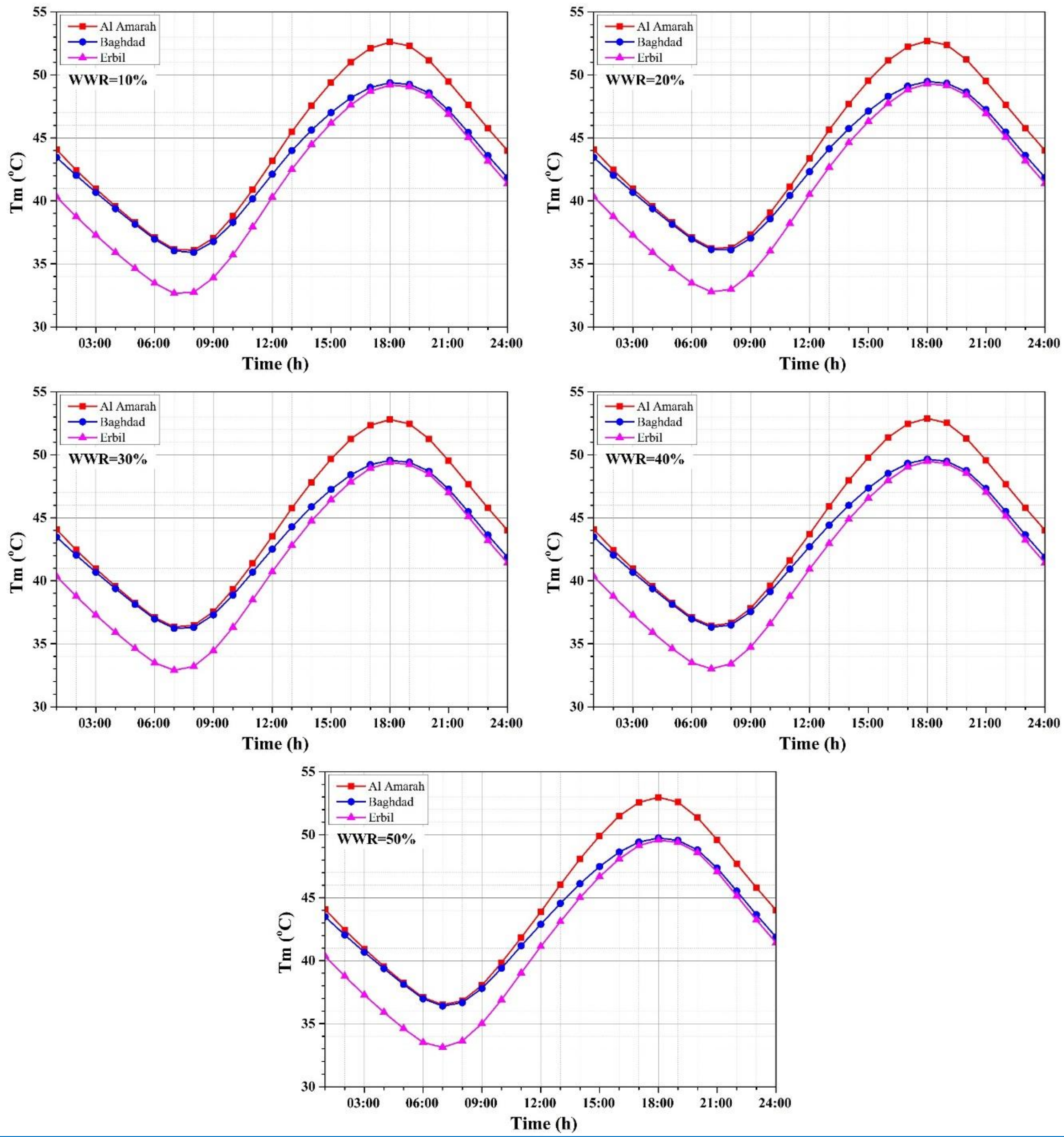

Fig. 4. Effect of WWR on Tm.

Referring to Figs. 5 where the WWR = 10%, the maximum and minimum mean indoor temperature difference is remarkable at about 16.4 °C, 13.5 °C, and 16.5 °C in Al Amarah, Baghdad, and Erbil city, respectively. These temperature values indicate how poor the construction materials used in the cities are and how air-conditioning systems are necessary during the summer season. It could be observed that the effect of increased WWR on the mean temperature of the room is slight in each city. For instance, the average mean temperature of the room in Al Amarah city has increased by only 0.26 °C, 0.51 °C, 0.76 °C and 0.99 °C when the WWR enlarged from 10% to 20%, 30%, 40%, and 50%, respectively. Correspondingly, the mean temperature in Baghdad case was increased by 0.23 °C, 0.46 °C, 0.68 °C and 0.90 °C, while in Erbil city was about 0.26 °C, 0.51 °C, 0.76 °C and 0.99°C. Such a slight mean temperature increment as the WWR increases is attributed to the effect of other building envelope elements, other than the window. In other words, the room mean temperature is not only impacted by the enlarged WWR but also by the interior surface temperature of walls and roof which are too large compared with the window area. However, it is logical that the mean temperature was influenced by the window size in each city by relatively the same values due to considering the same construction materials.

3.1.2 Window Net Heat Transfer Rate (WNHTR)

Fig. 5 presents the effect of various WWRs on the WNHTR under various weather locations in Iraq during July. It could be observed that under all WWRs the WNHTR in Al Amarah city is higher than that of Baghdad and Erbil cities. This is attributed to the noticeable diurnal temperatures and solar radiation values incident in the southern part of Iraq compared to the middle and northern cities. Considering the elevation in WNHTR in each city, it could be found that increasing the WWR in Al Amarah city from 10% to 20%, from 20% to 30%, from 30% to 40% and from 40% to 50% has increased the WNHTR by about 96%, 47%, 29% and 22%, respectively. Correspondingly, the increment of WNHTR in Baghdad city at the same WWR increment was about 94%, 44%, 25%, and 19% while in Erbil city was about 89%, 40%, 21%, and 15%, respectively.

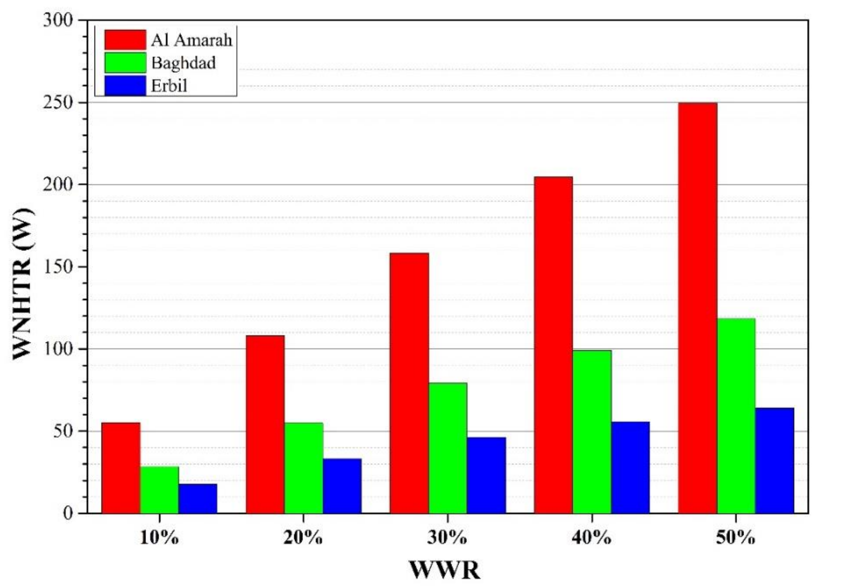

Fig. 5 Effect of WWRs on WNHTR

The WNHTR is a vary indicator concerning the sun's position, and managing its values is achievable by controlling the shading of windows. However, the time in which the sun radiation incident on the window is necessary to be identified. For instance, Fig. 6 shows the WNHTR for Al Amarah city conditions for one day in July. It could be noticed that the WNHTR is changing remarkably from 6:00 to 12:00. The highest WNHTR value reached at 9:00 which is obviously due to the sun's position with respect to the window location placed on the east wall. Afterwards, the WNHTR decreased as the sun's position changed, reaching its lowest value at 1:00, and only reflected solar radiation was affecting the WNHTR in the later hours.

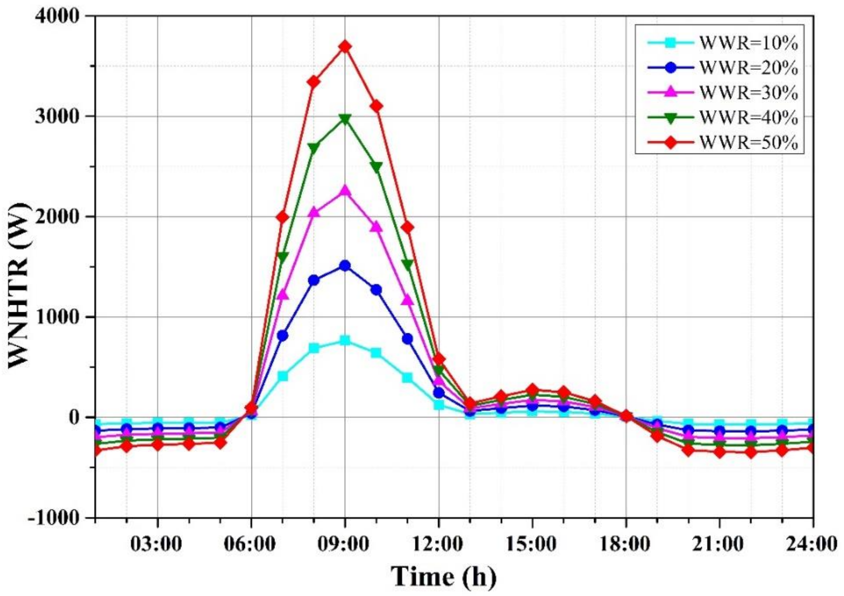

Fig. 6 Effect of WWRs on WNHTR of Al Amarah city.

3.1.3 Window total heat gain rate (WTHGR)

Fig. 7 shows the effect of changing WWR on WTHGR for study locations (Al Amarah, Baghdad, and Erbil). For Al Amarah city, it could be noticed that increasing the WWR from 10% to 20% has increased the WTHGR slightly by about 10 W. Comparatively, increasing the WWR from 20% to 30% has increased the WTHGR by about 60 W, and the increase continues relatively at the same ratio as the WWR increase. The figure indicates that WWR= 20% is the best option for Al Amarah City to avoid high WTHGR in summer.

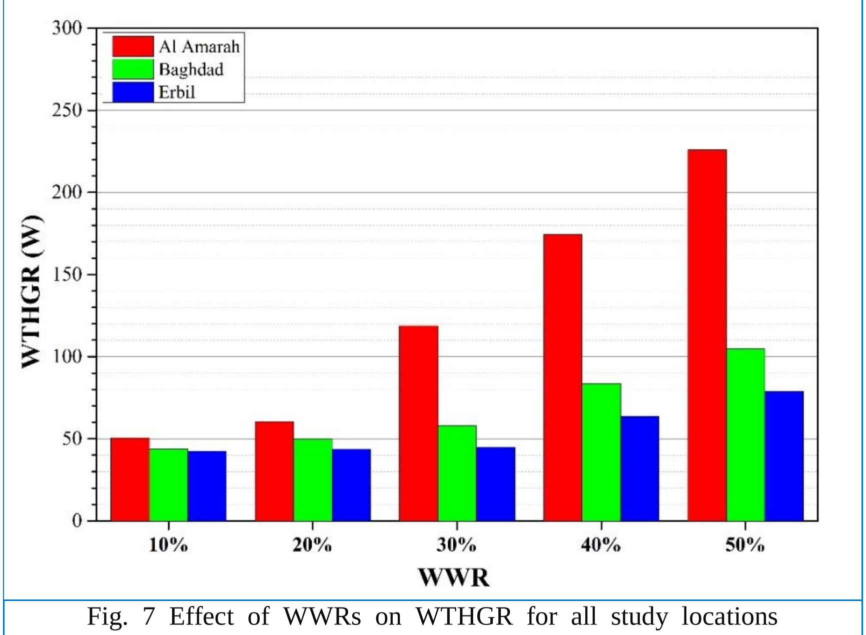

Fig. 7 Effect of WWRs on WTHGR for all study locations

For Baghdad, increasing the WWR from 10% to 20% has increased the WTHGR by 10 W, which is the same value when increasing the WWR from 20 % to 30%. However, increasing the WWR from 30% to 40% has increased the WTHGR by about 30 W and the same rate when the WWR increased from 40% to

50%. Therefore, it can be concluded that the WWR= 30% is the best option for Baghdad city. As for Erbil, an increase of WWR from 10% to 20% has a slight effect on the WTHGR that is almost the same when the WWR increases from 20% to 30%. However, increasing the WWR from 30% to 40 % has increased the WTHGR by 25 W and a larger effect could be noticed when increasing the WWR from 40% to 50%. Therefore, it could be said that the best WWR for the city of Erbil is between 30% and 40%. According to the above analysis, it could be stated that the best WWR options for Al Amarah, Baghdad, and Erbil City are 20%, 30%, and 40%, respectively.

3.1.4 Effect of Thermal Insulation Thickness

Thermal insulation usage is necessary in hot climates to mitigate the heat transfer through building envelope elements. Researchers have reported remarkable advancements in building thermal energy employing various thermal insulation materials worldwide [17]. However, the optimal position of thermal insulation within building envelope elements and its thickness are key parameters in each location [40]. It has been reported that the most effective thermal insulation position for hot-location buildings is at the exterior edge of the building elements (near the outer envelope layer), while the optimal thickness is critical [41]. As stated earlier, the influence of thermal insulation thickness is analyzed in the current work at the best WWR concerning several indicators, as follows:

3.1.5 Maximum mean temperature reduction (MMTR)

The MMTR in the room at the best WWR in study locations is shown in Fig. 8 at different thermal insulation thicknesses. For Al Amarah city, it could be observed from the figure that when the thermal insulation thickness is increased from 1cm to 3 cm, the MMTR was about 1.55 °C, while increasing the thickness from 3 cm to 5 cm resulted in 0.42 °C MMTR only. The MMTR decreased more when increasing the insulation thickness from 5 cm to 7 cm and from 7 cm to 9 cm by 0.17 °C, and 0.07 °C, respectively. Consequently, it could be said that the best thermal insulation thickness for Al Amarah at the best WWR = 20% is 3 cm since the MMTR was slightly reduced afterwards.

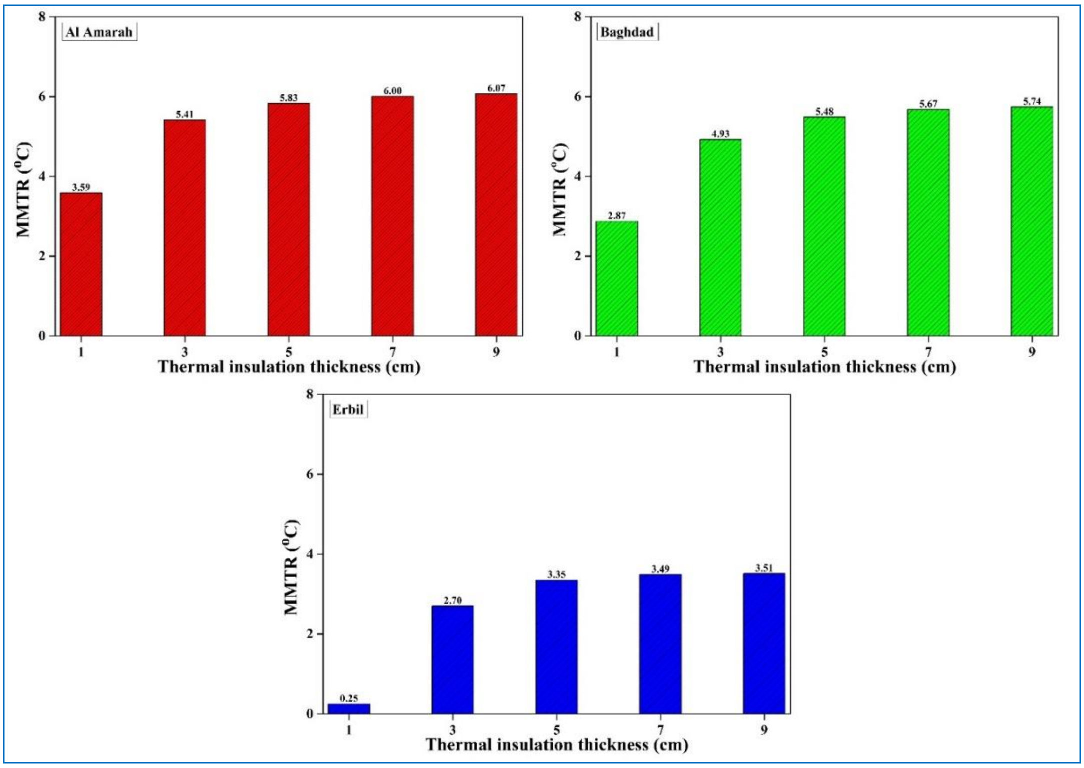

Fig. 8 Effect of thermal insulation thickness on MMTR

As for Baghdad city in which the thermal insulation was studied at the best WWR = 30%, it could be noticed that increasing the thickness from 1cm to 3 cm has achieved MMTR by 2.01 °C. Furthermore, increasing the thickness from 3 cm to 5 cm has achieved MMTR by 0.55 °C, while increasing the thermal insulation thickness from 5 cm to 7 cm and from 7 cm to 9 cm has resulted in 0.19 °C and 0.06 MMTR, respectively. Henceforward, it could be concluded that 3 cm is the best insulation thickness for Baghdad city at the best WWR.

Considering the MMTR trend for Erbil city in Fig. 8, we could observe that increasing the thermal insulation thickness from 1cm to 3 cm resulted in MMTR by about 2.45 °C. However, increasing the thickness further from 3 cm to 5 cm achieved MMTR by about 0.65 °C, while thickness increments from 5 cm to 7 cm, and from 7 cm to 9 cm attained MMTR by 0.14 °C, and 0.02 °C only. These results show that the best thermal insulation thickness for Erbil city at WWR= 40% is 3 cm as well.

3.1.6 TL

Increasing the TL is of most importance form including thermal insulations into building elements in addition to the MMTR. The calculation results of this important indicator are shown in Fig. 9. For Al Amarah City, increasing thermal insulation thickness has augmented the TL. For instance, using thermal insulation with 1 cm has shifted temperature by 186 min (3:06 h) compared with no thermal insulation used. Besides, increasing the insulation thickness from 1 cm to 3 cm has enlarged the TL by 213 min (3:33 h). However, increasing the thickness from 3 cm to 5 cm, from 5 cm to 7 cm, and 7 cm to 9 cm has shifted the peak temperature by 3:39, 3:45, and 3:51 h only.

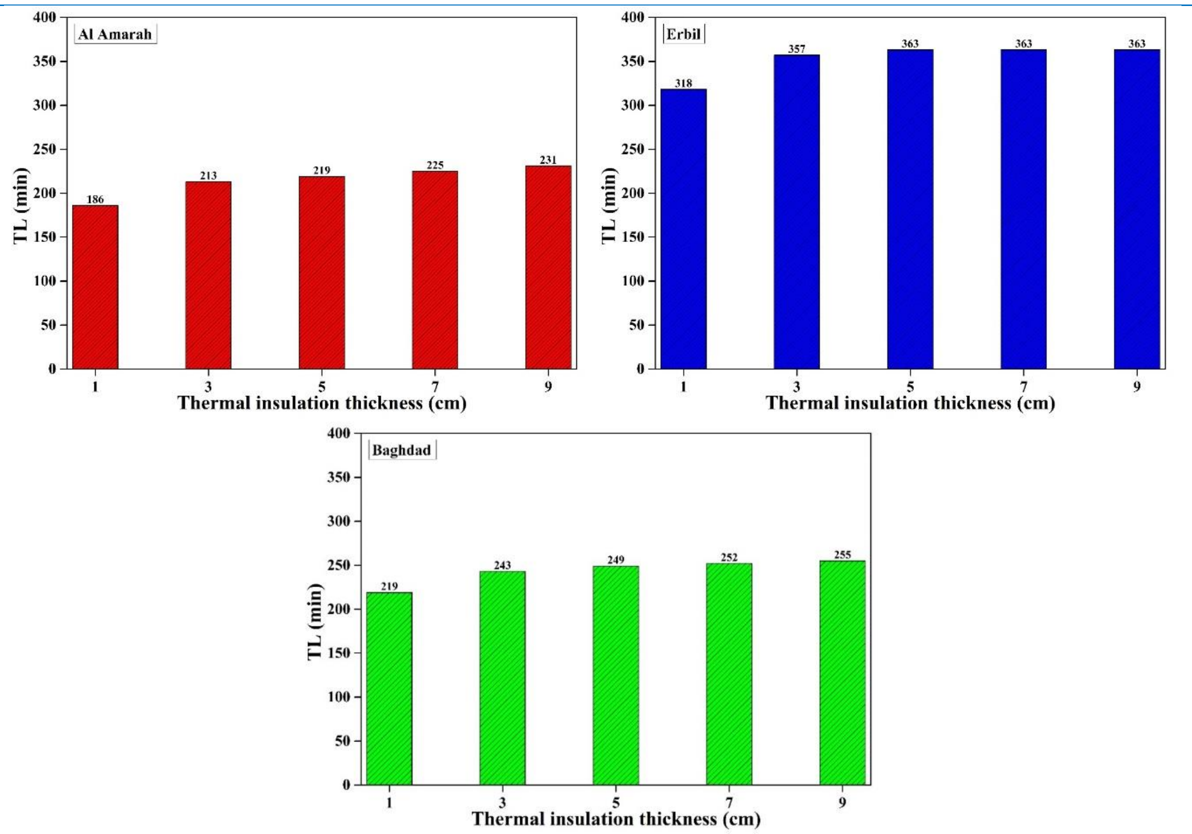

Fig. 9. Effect of thermal insulation thickness on TL.

As for Baghdad city, the TL has increased by 3:39, 4:03, 4:09, 4.12, and 4.15 using 1, 3, 5, 7, and 9 cm insulation thickness, respectively. For Erbil City from the other side, the TL has augmented by 5:18, 5:57, 6:03, 6:03, and 6:03 h at the same increased thermal insulation thickness order, respectively. From the TL results for all study locations, it could be stated that the thermal insulation thickness above 3 cm is worthless at the best WWR in each location.

4. Conclusions

The current research work tends to explore numerically the effect of window-to-wall ratio (WWR) and thermal insulation thickness on building energy in various Iraqi cities. Five WWRs ranging from 10% to 50% were explored along with five various thermal insulation thicknesses to specify the best arrangement for each study location. The outcomes of the current work showed that the best WWR for each studied location varies, depending on how high the ambient temperature is in the location. For Al Amarah City, the best WWR was found to be 20% to achieve an acceptable negative mean temperature increment while for the case of Baghdad City and Erbil City, the best WWR was found to be 30% and 40%, respectively. As for the thermal insulation studied at the best WWR in each studied location, it has been noticed that 3 cm thermal insulation thickness was the best in all locations regardless of WWR in which minimal energy saving could be achieved afterwards. Accordingly, it could be concluded that the WWR in each city has a higher influence over the thermal insulation thickness.

Although the current work has provided useful outcomes, several recommendations could be suggested for further research, as follows:

- Thermal insulation should be studied at each WWR to determine the best thickness and balance of the two techniques.
- The WWR could be influenced by the building's shape. Therefore, other building configurations, such as rectangular and L-shaped buildings, could be studied to find out the best WWR and the best shape to reduce building energy consumption.
- Other passive considerations, such as the building orientation, light coatings, shadings, etc. could be investigated to explore the best passive methodologies in each location. A numerical simulation procedure for predicting directional typhoon wind fields over complex terrain has been proposed in this study.

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