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The effect of basic building materials and their paving shapes on the thermal performance of walls in Iraqi residential buildings

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Abstract
Iraq's high climatic temperature affects buildings' thermal performance, leading to increased electrical energy consumption due to population growth. Researchers are exploring methods to reduce this consumption, such as heat gain reduction, heat transfer prevention, thermal insulators, high-thermal resistance materials, positive building design, useful orientation, and clean energies. The study investigates solar heat transfer in Iraqi air-conditioned spaces using nine models to analyze the impact of building elements on residential walls and their cross-section shape. The aim is to determine the best model for the Iraqi climate and the optimal approach for achieving optimal solar heat transfer. The study reveals that Model A has negative thermal performance, while Model C and I offer superior thermal performance. Model C offers 47.34% energy savings and Model I 43.99%, aligning with the global trend for green buildings and low energy expenditure in Iraqi residential unit.

Keywords: Building thermal evaluation, cooling load calculation, wall heat gain, and wall construction materials

1. Introduction

The high climatic temperature in Iraq has a significant impact on the thermal performance of Iraqi buildings, especially in the summer, and this rise in temperature leads to a large consumption of electrical energy on an ongoing basis with increasing population growth, especially in the recent period. The researchers were interested in methods that reduce this consumption and studied the positive extent of each method. The research directions were either focused on developing the thermal performance of the building by reducing its heat gain or preventing heat transfer to the building, such as using thermal insulators and building materials with high thermal resistance and other ideas, or using new ideas in positive building design, selecting useful orientation for buildings, and using clean energies to reduce waste. At first glance, the research was about saving energy by using thermal insulators inside the building structure these methods had an effective effect on the thermal performance of buildings, but they were faced with the problem of material cost the use of the insulator mainly affected the increase in the initial cost of the building, even if there was an obstruction to the transfer of thermal energy throughout the building structure, thermal insulation can reduce energy consumption by 5-10%, especially in areas with high temperatures and in cases where insulators are used to calculate the heating load more than the cooling load it is worth noting that thermal insulation has an effect if the building is perfectly oriented, it can reduce energy consumption by 11-39% (Kohansal *et al.*, 2022; Tzoulis & Kontoleon, 2017) [10, 14]. In order to overcome the obstacle of the economic cost of thermal insulation materials, the trend was to recycle environmentally waste materials and evaluate their performance in thermal insulation the effect of using environmental insulation materials such as sawdust, rubber, and barley cane ash in certain percentages was an increase in thermal resistance by 8.4–13% and an increase in the economic cost of thermal insulation materials in thermal insulation by 12%, the density of building materials varied, so there was an increase in the use of rubber and a decrease in the use of barley cane ash, or the use of phase-changing materials such as paraffin wax with different densities and the use of coconut oil despite the good results of using paraffin wax, the use of coconut oil It had a negative effect on the thermal performance of the walls (Irsyad *et al.*, 2023; Qatta, 2013) [8, 11]. As well as studying the geometric design of the building on the efficiency of buildings, when choosing the optimal shape for the building based on the relationship between length and width in terms of the building's exposure to wind and solar radiation, then by testing dimensional ratios such as (1:1, 1:1.25, 1:1.5, 1:2), the square shape with ratio of [1:1] has the best thermal performance compared to other ratios, and the percentage of saving in energy expenditure was 10%, while the effect of the building's orientation in relation to the solar radiation falling on it by choosing the optimal direction with the proposal to cover the roofs of Iraqi buildings was a percentage saving in energy consumption of 49. -55% (Danouk *et al*., 2017; Khaleel, 2020) [5, 9]. Phase-changing materials can be exploited to delay or obstruct the transfer of thermal energy because these materials have the ability to change their phase if they gain or lose thermal energy. Using 2 cm-thick gypsum boards may result in a decrease in the cooling load by 1.1% and a saving in energy consumption of 7.6% (Sangwan *et al*., 2022) [12]. In addition to exploiting the thermal properties of some materials, such as oil shale or hollow concrete blocks, which are characterized by strength and durability, it produced a great agreement in the results of experimental and practical tests and provided well-spent energy-saving values (Bai *et al*., 2017; Fogiatto *et al*., 2016) [4, 6]. Some studies have taken the comparative aspect of using covering materials for external surfaces and the possibility of cooling them, and using reflective glass, which is the ideal choice for external windows in the Iraqi city of Amara, compared to many traditional residential units. Also, the use of refractory bricks, especially in high-rise buildings, has a good effect. It is also possible to use heat sources with a radiant heat capacity distributed over the external surface area of (4.8 watts/m2) that give a fast and good response relative to the amount of heat leaking through these surfaces (Al-Yasiri *et al*., 2019; Šimko *et al*., 2022) [3, 13]. Also, some building materials can be recycled by mixing them in different amounts to improve their thermal performance by lowering the total thermal conductivity of the wall. This can be done with materials like concrete, which has a big effect on the thermal conductivity values, especially when recycled coarse aggregate is used (Al-Doury *et al*., 2021; Zhu *et al*., 2015) [2, 17]. Some computer programs that perform simulations on an analysis of the thermal performance of external surfaces have helped in understanding the significant impact of the type and shape of materials used in construction on the thermal load calculations of buildings, the time delay for the external heat to reach the air-conditioned space (Udawattha & Halwatura, 2018; Zainal & Yumruta\cs, 2015) [15-16], and even taking into consideration the exterior colors of the walls and ceilings, which have a role in developing their thermal performance (Abdullah & Faraj, 2022) [1]. From the above, and comparing it to the raw materials for construction and building units in Iraq, we can see that there are a number of factors that have direct and indirect effects on the thermal performance of buildings. For example, the thickness of the walls in the engineering design affects how buildings are built in Iraq. The number of these materials and the differences in their thermal specifications are what led researchers to do this work.

2. Calculation methodology and assumption

To figure out how much solar heat is transferred into an air-conditioned space, we will study the effect of the basic types of building elements on the main walls of residential buildings, as shown in Figure 1, as well as the effect of the shape of the cross-section of the wall (the thickness of the main layer) of the wall, because the wall can be set up in a certain way. For the building elements, Figure 2 shows the method by which the basic building materials are paved according to the required wall thickness. To implement this study, nine models will be assumed for walls in Iraqi buildings, as shown in Table 1, which shows the specific heat, thermal conductivity, and density of the wall, and the thermal energy transmitted through each wall will be calculated and compared with each other to reach the best model to be adopted according to the climate. Iraqi.

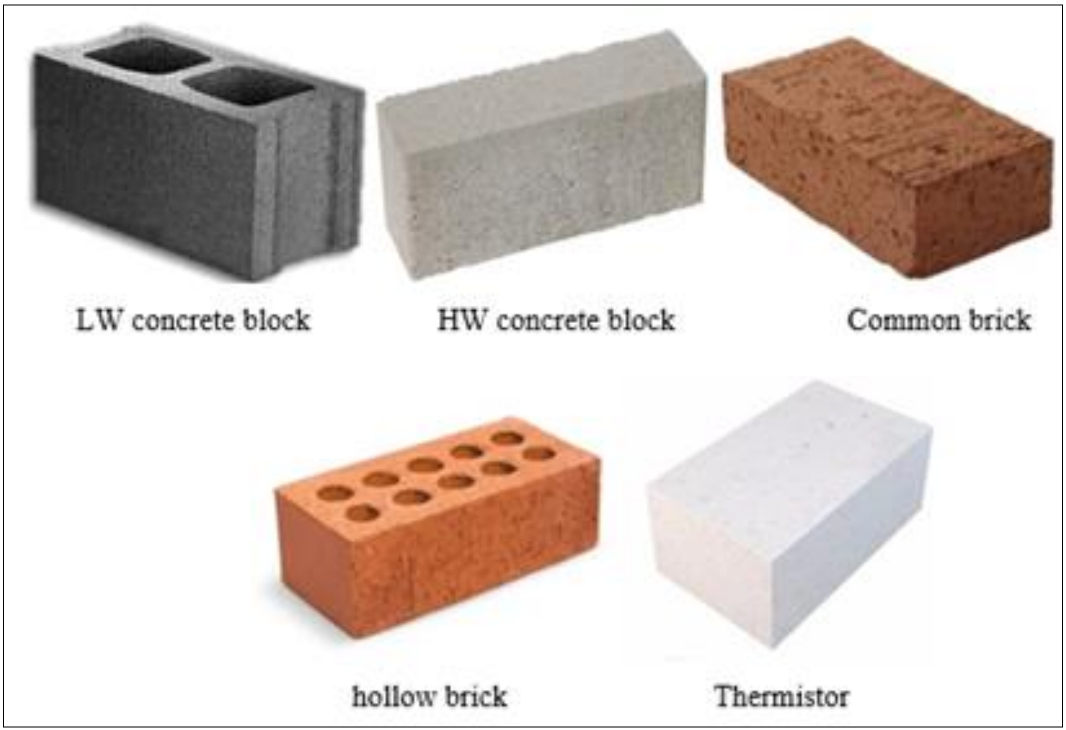


Fig 1: Basic wall elements

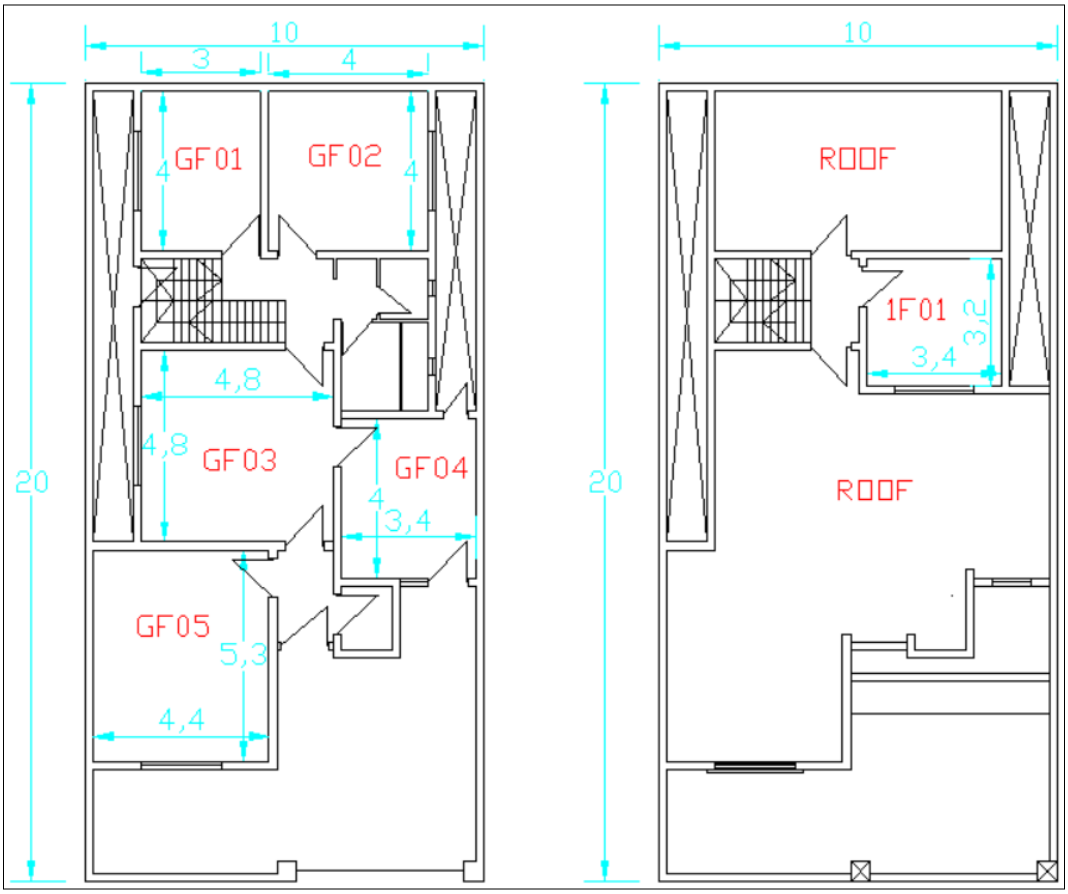
Fig 2: The techniques used for the construction of building elements determine the desired wall thickness and shape.

Table 1: Wall model description

No.	Models Symbol	Wall thickness descriptions	Specific heat	Thermal conductivity*	Density
1.	Model A	LW concrete block 200 mm thick	1.4	1.2	1440
2.	Model B	HW concrete block 200 mm thick	0.84	1.49	2300
3.	Model C	LW concrete block 400 mm thick	1.4	1.2	1440
4.	Model D	HW concrete block 400 mm thick	0.84	1.49	2300
5.	Model E	Common brick 240 mm thick	0 .84	0.54	1460
6.	Model F	Common brick 360 mm thick	0.84	0.54	1460
7.	Model G	hollow brick 240 mm thick	1.37	0.36	1200
8.	Model H	hollow brick 360 mm thick	1.37	0.36	1200
9.	Model I	Thermistor 200mm thick		0.21	760

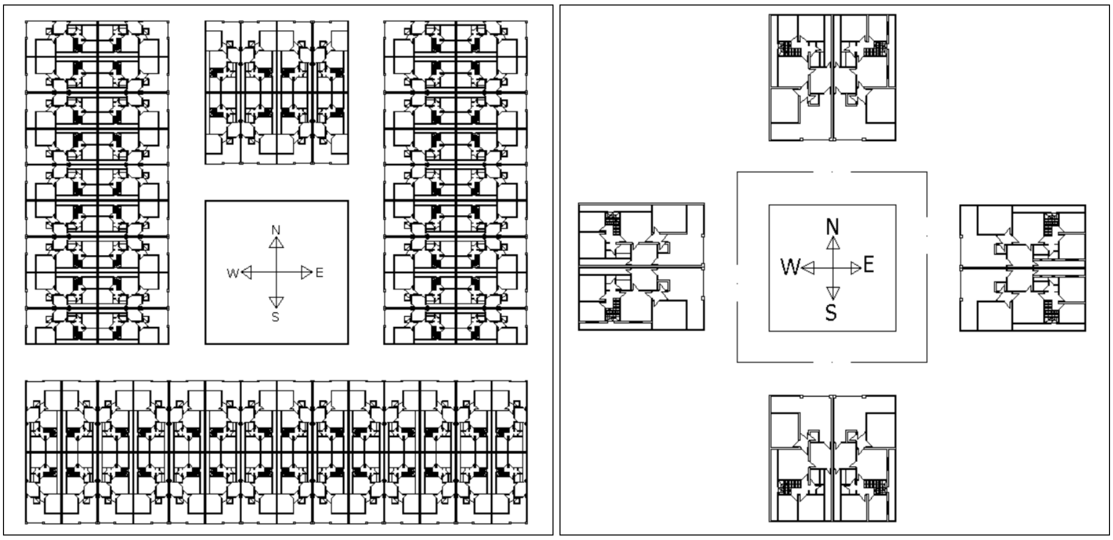
*The data of thermal conductivity from Iraqi articles and ASHRAE2009: (Al-Doury *et al.*, 2021; Al-Yasiri *et al.*, 2019; Handbook, 2009) [2-3, 7]

In order to enhance the realism of the study, the researchers chose to employ a contemporary residential compound located in Kirkuk, Iraq, namely the Madinaty compound center, situated at a latitude of 35.5°. The chosen approach included applying the working assumption to a quadrilateral block model consisting of four distinct residential units with varying orientations. Given that the focus of this research is on wall models, it is deemed unnecessary to do calculations concerning cooling loads originating from the roof, windows, occupants, appliances, ventilation, infiltration, and other relevant factors. However, the thermal load of the external walls and partitions in the non-air-conditioned walls was only included in the building map model for the Madinaty compound. The dimensions and specifics of this model may be seen in Figure 3, with the arrangement of four models shown in the direction depicted in Figure 4.



1st floor 2nd floor

Fig 3: main map of studied residential unit



A simulation of the paving and arrangement of Iraqi residential buildings

The selected models are oriented towards four main directions.

Fig 4: Selection four models direction

Using Equation 1 and the CLTD approach described in the ASHRAE guidelines (Handbook, 2009) [7], it is possible to calculate the heat load through the wall.

$$Q_{wall} = U_{wall} \times A_{wall} \times CLTD_{wall,c} \quad (1)$$

Where:

Q_{wall}: heat gain from wall (watt) , A_{wall}:wall area (m^2) ,$CLTD_{wall,c}$: corrected cooling load temperature difference for wall and U_{wall} is the wall over all heat transfer coefficient ($w/m^2.°C$) that take in corresponding wall thickness ,wall element type (conductivity) and wall density, the value of U_{wall} by using eq. (2):

$$U_{wall} = \frac{1}{R} = \frac{1}{\sum_i^n \frac{L_i}{k_i}} \quad (2)$$

Where: n is wall layer number, R: wall thermal resistance ($m^2.k/w$), L: Layer thickness (mm), and k: wall thermal conductivity (W/m.k)

$$CLTD_{wall,c} = (CLTD_{wall} + L.M)K + (25.5 - T_r) + (T_a - 29.4) \quad (3)$$

$CLTD_{wall}$: cooling load temperature difference (°C) from ashrea tables

L.M: Latitude, month correction, K: wall color factor, T_r: Inside design temperature (°C) and Ta is from eq. (4):

$$T_a = \frac{T_{max} + T_{main}}{2} \quad (4)$$

T_{max} and T_{main}: Maximum and minimum outside design temperature (°C) respectively

3. Result and discussion

By entering the information and measurements of the map for the presidential unit shown in Figure 3, the areas of the outside walls of the rooms that are exposed to the air and sunlight were found. These are called the external walls. The external walls can also be walls that separate an air-conditioned space from a non-air-conditioned space, like the entrance to a residential unit, or walls that separate the kitchen from the living room. These partitions were called interior walls, and after creating and programming the HAP program for all the air-conditioned spaces of the residential unit, they were chosen. Four prototypes for the direction of the residential units are shown in Figure 4. The nine models were tested for the walls and the four main directions. As we mentioned previously in the work hypotheses, the focus was on testing the nine used models of the external walls of Iraqi homes, so it was necessary to neglect the rest of the heat gain of the residential units because its amount is fixed and is not affected by changes in the wall models that were tested, so only the amounts of thermal energy gained from the walls were recorded.

3.1 Heat gain for the walls of the air-conditioned spaces of the residential unit with the N and W directions

The heat gain from the external walls and partitions of non-air-conditioned spaces is an important source of cooling load and is no less important than other sources. From observing Table 2 and comparing the studied models of the north-facing residential unit, it showed a different thermal behavior in the air-conditioned spaces, which are the guest room, the living room, the cooking room, bedrooms 1, 2, and 3, as well as the storage room. At the end of the table, all the wall loads for the residential unit were completely collected. From observing the guest room loads, loads ranging between 412 to 772 watts were recorded for models C and B, respectively, and this is the difference: there is a reduction in the amount of heat gained for the same room under the same conditions by 46%, as well as the thermal loads in the living room, where the thermal loads of the walls ranged between 265 to 663 watts for models C and B, respectively, a reduction of 60%. As for the thermal loads of the kitchen, they ranged from 443 to 799 watts for models C and B, with a reduction in heat gain of 43%. This character was repeated for the thermal behavior of the three bedrooms, bedrooms 1, 2, and 3, and a variation of the thermal load was recorded with a range of (242 to 243), (244 to 440), and (613 to 1103) Watts for models C and B, with reduction rates of 45, 44.5, and 44.4%, respectively, with a difference of 372 to 668 watts for models B and C, with a reduction percentage of 44.3% for the storage room. Based on this presentation of the results, the best thermal behavior of Model C for most air-conditioned spaces is evident, even in the case of the total thermal load of the residential unit, compared to the rest of the models, especially Model B, as it achieved a reduction in the total load by 46.5%.

Clearly, this thermal behavior is repeated from the observation of Table 3, and with the same previous comparison for the models studied for the residential unit facing west, the guest room loads ranged between 471 to 850 watts for models C and B, respectively, and this difference reduced the load by 44.5%. As for the living room, it was for models C and B, the heat load for the walls was between 220 and 574 watts, which is a 61.6 percent reduction in heat gain. For models C and B, the heat load for the kitchen was between 454 and 820 watts, which is a 44.6 percent reduction in heat gain. For models C and B, the heat load changed by (232 to 427), (202 to 359), and (651 to 1172) watts, which is a 45.6, 43.7, and 44.4% reduction in heat gain for bedrooms 1, 2, and 3, and between (427 and 76 In general, the thermal behavior of Model I is close to the thermal behavior of Model C, but with a slight difference from it, for Tables 2 and 3.

Table 2: Wall heat gain from North direction model

Wall heat gain (external and internal walls) – The main direction of the house - N								
Models Symbol	**Guest room**	**Living room**	**Kitchen room**	**Bedroom1**	**Bedroom2**	**Bedroom3**	**storage**	**Total load**
Model A	623	385	642	354	345	888	538	3775
Model B	772	663	799	442	440	1103	668	4887
Model C	432	265	443	243	244	613	372	2612
Model D	579	355	595	326	326	821	498	3500
Model E	661	411	684	380	379	945	572	4032
Model F	530	326	545	300	301	754	457	3213
Model G	645	399	665	367	367	919	557	3919
Model H	586	321	537	295	295	742	450	3226
Model I	412	332	456	281	305	621	397	2804

Table 3: Wall heat gain from west direction model

Wall heat gain (external and internal walls) – The main direction of the house - W								
Models Symbol	**Guest room**	**Living room**	**Kitchen room**	**Bedroom1**	**Bedroom2**	**Bedroom3**	**storage**	**Total load**
Model A	684	315	659	341	290	944	619	3168
Model B	850	574	820	427	359	1172	767	4969
Model C	471	220	454	232	202	651	427	2657
Model D	631	295	608	311	271	872	573	3561
Model E	730	333	704	368	306	1006	657	4104
Model F	580	269	559	288	248	801	526	3271
Model G	708	326	683	354	300	977	640	3988
Model H	634	266	549	282	245	788	517	3281
Model I	486	221	489	285	194	680	438	2783

3.2 Heat gain for the walls of the air-conditioned spaces of the residential unit with the E and S directions

The proposed wall models for the two residential unit models facing S and E are shown in Table 4. The loads in the guest room ranged from 453 to 819 watts, which changed the load reduction by 44.6%. For the living room, the loads changed from 264 to 819 watts, which decreased heat gain by 60.2%. heat range from 453 to 818 watts, with reducing heat gain by 44.6% for the kitchen and heat load variation by 244 to 440, 243 to 442, and 609 to 1091 watts, with reduction rates of 45.6, 45, and 44.1%, respectively, for bedrooms 1, 2, and 3. While heat gain increased from 372 to 668 watts with a reduction percentage of 44.3% for the storage room, the residential unit achieved a reduction in the total load of 46.6%. All results for the air-conditioned spaces, Models B and C found that Model C recorded the good model and compared it with the most negative model, which is Model B. In general, the thermal behavior of Model I is close to the thermal behavior of Model C, but with a slight difference from it. Likewise, the thermal behavior of Model F is close to that of Model B, with a greater difference than that of Model I.

By looking at Table 5 and comparing the results, we can see that Model C is again the best option. When we compare it to the bad thermal behavior of Model B, we can see the difference in the thermal load values for each room and between the two models in the total thermal load for the residential unit. Therefore, the preference for Model C over the rest of the models is clear, as is Model I, which is somewhat close to it.

Table 4: Wall heat gain from south direction model

Wall heat gain (external and internal walls) – The main direction of the house - S								
Models Symbol	**Guest room**	**Living room**	**Kitchen room**	**Bedroom1**	**Bedroom2**	**Bedroom3**	**storage**	**Total load**
Model A	659	385	658	354	354	880	538	3828
Model B	819	664	818	440	442	1091	668	4942
Model C	453	264	453	244	243	609	372	2638
Model D	608	354	607	326	326	816	498	3535
Model E	703	412	703	379	380	936	572	4085
Model F	559	326	559	301	300	748	457	3250
Model G	682	399	682	367	367	911	557	3965
Model H	613	320	549	295	295	737	450	3259
Model I	504	305	525	305	281	663	397	2980

Table 5: Wall heat gain from east direction model

Wall heat gain (external and internal walls) – The main direction of the house - E								
Models Symbol	**Guest room**	**Living room**	**Kitchen room**	**Bedroom1**	**Bedroom2**	**Bedroom3**	**storage**	**Total load**
Model A	668	371	614	290	341	916	619	3819
Model B	827	648	759	359	427	1134	767	4921
Model C	462	252	426	202	232	634	427	2635
Model D	620	338	571	271	311	850	573	3534
Model E	708	400	649	306	368	971	657	4059
Model F	568	313	523	248	288	779	526	3245
Model G	691	385	635	300	354	948	640	3953
Model H	623	306	515	245	282	767	517	3255
Model I	511	310	448	194	285	625	438	2811

3.3 Comparing the overall load of the residential units in relation to the main four directions

The effect of the residential units' orientation on Iraqi architecture is obvious, but evaluating the suggested wall models has a bigger influence on the building's four directions. As a result, it is now important to evaluate the models in addition to the building's direction. The external walls of bedrooms 1, 2, and 3 would face west and east, respectively, if the residential unit were facing south. The same rooms above, on the other hand, become oriented to the north and south if the residential unit is, for example, oriented towards the west. Because it is generally known that the direction obviously impacts heat load, it was required to evaluate at least four directions while conducting any study on the installation of walls for residential units.

Given that model A is the most common and least expensive shape in Iraqi architecture, Figure 5 compares the total heat load of the residential unit from the exterior walls and external partitions for the nine wall models. This concept is preferred by investment firms, especially those who focus on residential complexes in Kirkuk. In order to ensure that the study has a beneficial result and provides an accurate representation of the amount of energy savings spent on the thermal load, it is at least acceptable to compare the rest of the models with this model. The building is oriented in the N direction, as shown in Figure 5-a, and the model with the best thermal behavior is Model C, with a total heat load of 2612 watts. Model I also produces results that are comparable to those of Model C, with a total heat load of 2884 watts. Even though conventional Model A provides the baseline for comparison with the other models, Model B is thought to exhibit the highest heat gain behavior. Figure 5-b indicates that some models, such as models B, E, and G, perform insufficiently, while model C leads with a total energy saving percentage of 30.8%.

The residential unit facing S in Figure 6 has a total thermal gain that has been analyzed in terms of thermal performance. In Figure 6-a, Model B and Model I both achieved good thermal performance with total heat loads of 2638 and 2980 watts, respectively. The residential unit's Model B thermal load was the greatest, reaching in at 4942 watts. According to Figure 6-b, when comparing the results of the models to the conventional model A, the models (B, D, E, and G) have a negative impact on the overall energy consumption, whereas the models (C and I) have a positive impact on the overall amount of energy expended.

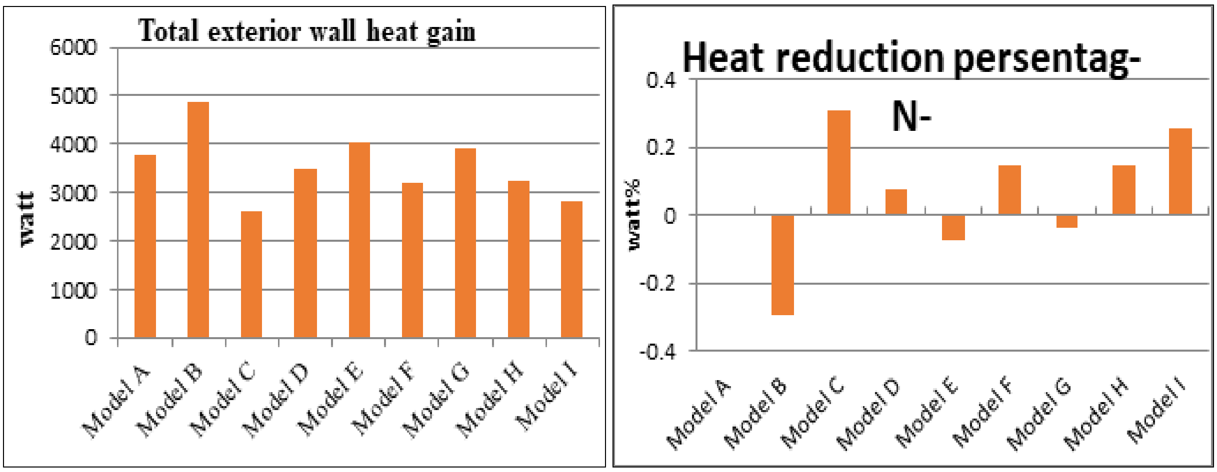


Fig 5: Total heat for exterior wall in N-direction

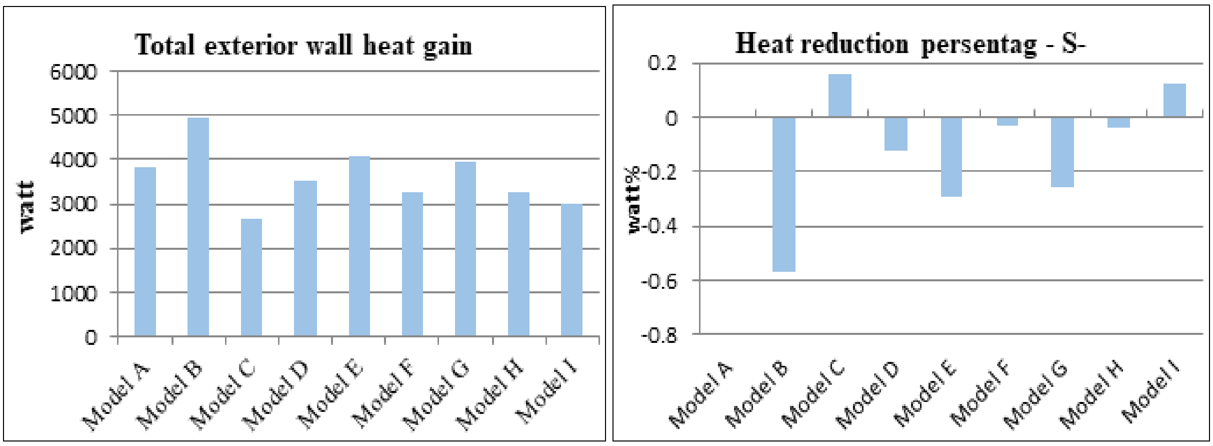


Fig 6: Total heat for exterior wall in S-direction

An analysis of the overall thermal gain of the housing unit facing direction E is shown in Figure 7. Figure 7-a shows that Model B, which has good thermal performance and a total heat load of 2635 watts, is superior to Model I, which has a total heat load of 2811 watts. Model B also has an increased thermal load for the residential unit, which is higher by 4921 watts. Models (B, D, E, F, G, and H) have a negative impact on reducing the total energy consumed when compared to the traditional model A, while models (C and I) recorded a positive impact on the amount of total energy employed. This is shown in Figure 7-b when comparing the results of the models with the traditional model A.

Although some results in Figure 8 differ significantly from one another, the general behavior of the test models is nearly constant when the residence is facing west. Model C records a total heat load of 2657 watts in Figure 8-a, which shows the residential unit's total load for the test wall models. Model I came in second with an energy consumption of 2783 watts. As a result, Model B had the highest rate of heat load, which was measured at 4969 watts. Figure 8-b illustrates the comparison between all the models examined with respect to the conventional Model A, the typical model in construction. The Model C (16.1%) and Model I (12.1%) energy savings percentages A negative impact was noted for the remaining models.

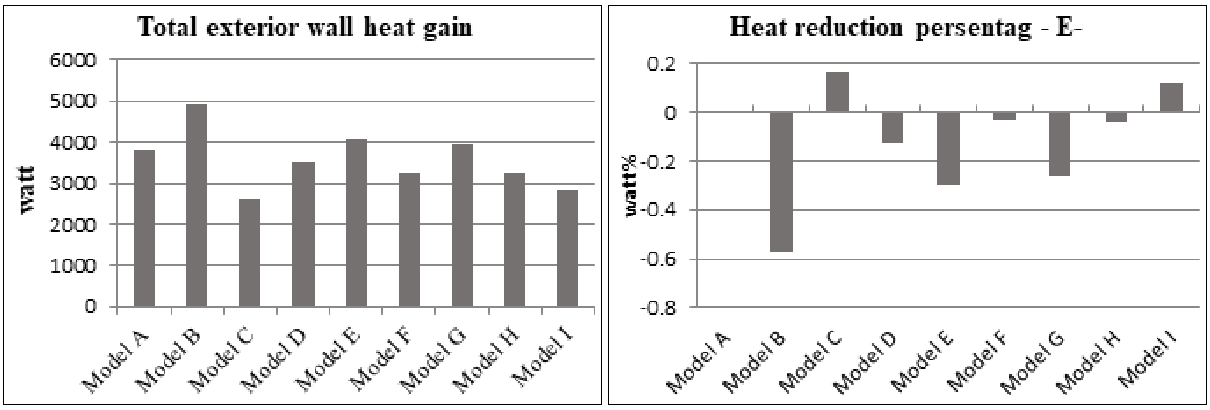


Fig 7: Total heat for exterior wall in E-direction

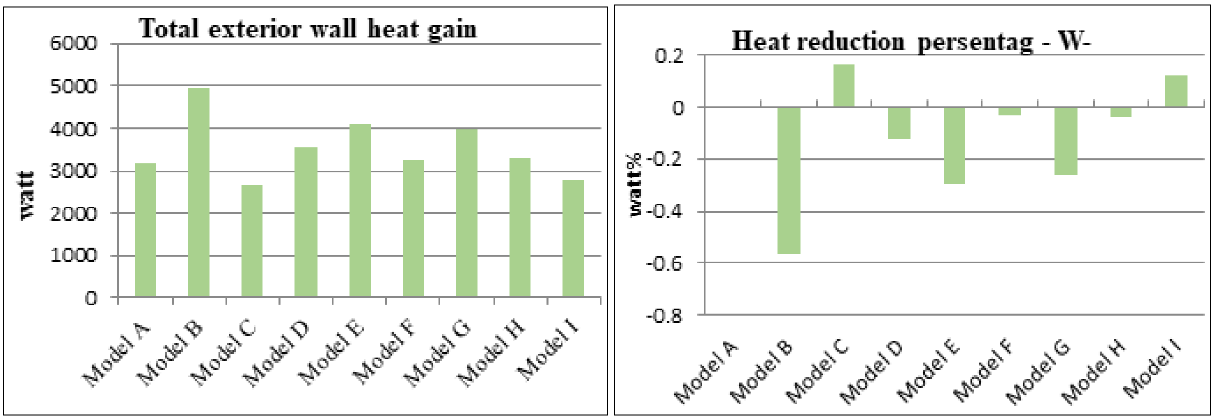


Fig 8: Total heat for exterior wall in W-direction

4. Direction's impact on the effective thermal performance model (Model C)

After examining the nine models' effects on the quantity of heat that was transported from the outside atmosphere to the residential unit, Model C's superior thermal performance to the conventional Model A was identified. It was important to calculate the amount of energy saved and to research the effects of the direction of the residential unit on this specific model. The energy transported via model C varies in each of the four directions, as shown in Figure 9. The maximum amount of energy was transferred while the building was facing west, reaching 2657 watts, and the lowest amount was transferred when it was facing south, coming in at 2638 watts. When the building was oriented in two directions, E and N, with one direction being weighted more heavily than the other, the results converged in a respectable way. The residential unit received 2612 watts of heat, which is the lowest individual and is represented by the letter N.

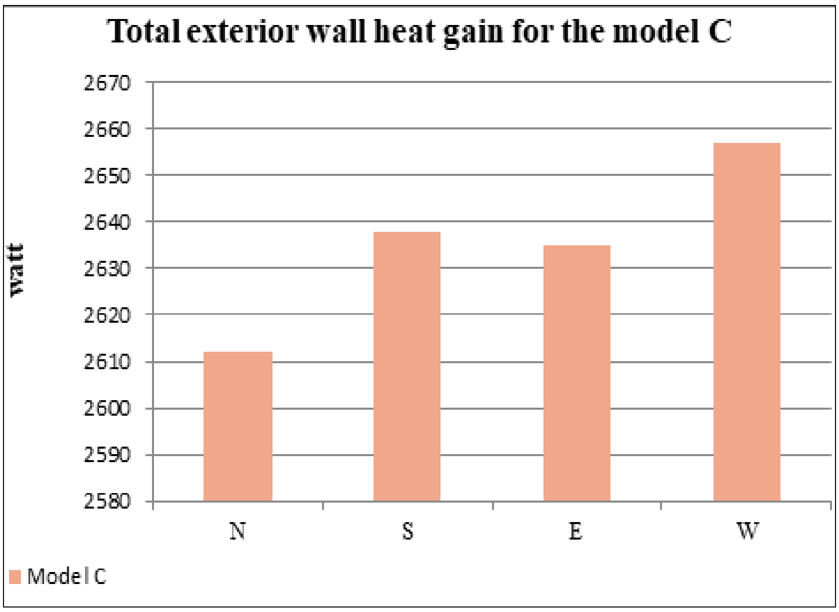


Fig 9: Total heat for exterior wall model C in all direction

In order to calculate the best savings in heat transferred to the residential unit, the comparison will typically be between the best model of the studied models in the best direction and the worst thermal performance of the models with the highest value in the four directions. In this case, the comparison will be between Model C in the N direction with a value of 2612 watts and Model B in the W direction. Figure 10 displays the percentage of energy savings spent overall with a value of 4969 watt, which is 47.43%.

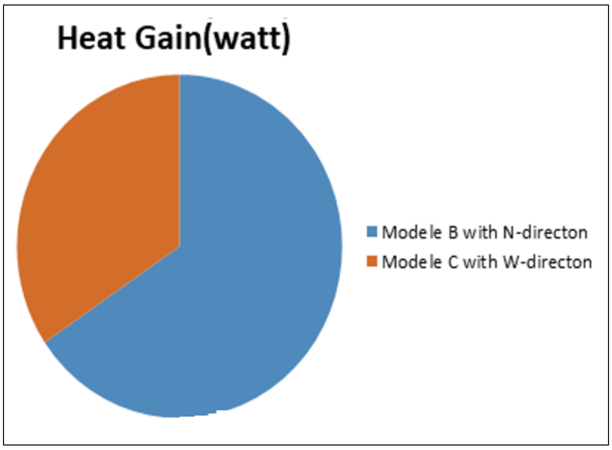


Fig 10: Heat gain comparison between Model A and C with direction effect

5. Conclusion

In general, studying the available proposed models for Iraqi architecture, particularly in the city of Kirkuk, provides an in-depth investigation of the thermal performance of these models. Of particular note are the effects of the main directions of the Iraqi buildings and the impact of these models on the amount of energy used as a result of the thermal gain of these walls. It is evident from the aforementioned findings that there is In comparison to the conventional model for the Iraqi building, Model A, with a more negative thermal performance, and Model B, two alternative models - Model C and I - had superior thermal performance. The comparison included comparing the thermal loads of the complete residence unit, which led to energy savings for the two Models C when compared to the conventional model, with 47.34% for Model C and 43.99% for Model I for the four directions. Accordingly, the research has presented a proposal for Iraqi residential units, especially in the city of Kirkuk, which is the best model in terms of thermal performance and least energy expenditure and is in line with the global trend for green buildings or buildings with low energy expenditure

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