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Investigations towards lower cooling load in a typical residential building in Kurdistan (Iraq)

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Abstract

Energy consumption in cooling the buildings and occupant's thermal comfort is significant, and any techniques to reduce this can bring great benefits, both locally in terms of reducing the need for expensive infrastructure and globally in terms of reduced carbon emissions. This study focuses on Northern Iraq, Kurdistan. This area suffers from a shortage of electricity production, alongside a high and growing demand due to the rapid expansion in the residential building sector over the last few decades through investment projects. The cooling energy performance of a typical house in Kurdistan was simulated, using DesignBuilder and EnergyPlus software. The study identified the most effective parameters of the building fabrications to be applied for enhancing the energy performance of residential buildings such as insulation, suspended ceiling, window glazing, overhang, and block type. The study found the parameters with the most impact on energy consumption to be suspended ceiling and insulation that could save a high rate of energy consumption. The impact of the clear double glazing and overhang of the windows are generally low, due to the low window/wall ratio and the availability of the internal curtain in the building. Finally, the optimum parameter values are identified and used in energy demand simulations, it showed that by using the optimum parameters of the building fabrications, 28.35% of the annual energy used could be saved from cooling in the house module.

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Keywords: Cooling energy; Thermal performance; Residential building; Kurdistan; Building thermal comfort; Building modelling

1. Introduction

The energy consumed in buildings represents 40% of the worldwide energy, and it grows by 2.2% a year [1–3]. Heating, Ventilation, and Air Conditioning (HVAC) consume the main portion of the energy in a building; it represents about 50% of the total supplied energy. Building cooling represents a significant function of the HVAC system [4,5]. In hot and dry areas such as the Middle East, North American far east air conditioning is a vital living need. Over the hot summer period [6,7], the air conditioning is in full operation in the mentioned areas. It extensively raises energy consumption, consequently increase carbon emission [8]. Orientation, geometry, construction materials have a considerable effect.

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Energy consumption for cooling in buildings [9–11]. This study focuses on buildings in the Kurdistan region located in the Middle East, specifically the north of Iraq. The climate of Kurdistan is semi-arid; Summer is very hot and dry [12], it extends from June to September, and hot extremes mostly are in July and August [13,14], where the temperature reaches 45 °C. This climate means that air conditioning is required from April to October [15]. In recent years, Kurdistan has suffered from political conflicts, resulting in a big economic crisis [3,16]. This has had a dual consequence, as there is a shortage in electricity production, alongside a high and growing demand due to the rapid expansion in the residential building sector in the last few decades [17,18]. Building fabrication in this context has a significant influence on energy consumption in the residential houses in Kurdistan. The supply shortage and demand increase mean that energy saving is a high priority in the region and the lack of studies about the area implies that this kind of studies are an important requirement at this time [17,18].

The rise in energy consumption in Kurdistan is not just an economic issue. It is a big environmental problem as nearly all electricity demand produced by fossil fuel [19,20], with a notable absence of renewable energy sources. Accordingly, electricity consumption produces a high rate of greenhouse gases with the consequent negative effects on the climate [20]. Therefore, the objective of the study is to predict the optimum parameters of building fabrication towards reducing the cooling load and energy consumptions of residential buildings.

The method used to investigate the energy consumption is to select an archetypal case study building for the region, construct a simulation model for the building using DesignBuilder and conduct a parametric study using the EnergyPlus simulation tool. The structure of the paper firstly describes the building archetype, followed by a description of the simulation model and parameterization. The results of simulation and analysis of parameter combinations are presented before concluding with recommendations for optimum parameters and implications for construction in the region and further study.

2. Case study building, description, and justifications

2.1. Building typology

The modern residential building in Kurdistan can be divided into three main types, typical houses (100 m^2–250 m^2) [21] one or two storeys, large one and two storeys houses (over 300 m^2) and apartments. Most people live in the first type of buildings, so houses under 300 m^2 are very widespread. Apartments are not desirable, as it is new to the Kurdish culture but have become increasingly popular in the last decade due to the high land prices. As the first type of house is very popular, local and foreign companies were encouraged to invest in substantial projects of thousands of units, resulting in such houses constituting a substantial proportion of private residential houses. Therefore, the study is investigating the first type of building, towards the main aim of reducing energy consumption. This type of residential building in Kurdistan (single storey buildings) is widely present in the new investment projects, with a slight difference from a project to another in the plan design with the same homogenously construction assembly.

2.2. The house module Ashti city 2

The baseline building is selected from an investment project called Ashti City 2 in Erbil (capital city in Kurdistan-Iraq). The module shown in Fig. 1 is a one-storey house consisting of a kitchen, living area, two bedrooms, reception, store room, bathroom, and a penthouse [22,23].

The house is built on a 204 m^2 land with a total building plan of 158 m^2, ground floor plan of 135.8 m^2 with a penthouse of 22.6 m^2 on the first floor as shown in Fig. 1. The details of construction that were used in the modelling is extracted from the Eskan company [25], and it is built according to the interim Iraqi construction code, as shown in Table 1.

3. Simulation model

In this section, the detailed simulation model and parameterization for the case study building are described. Design Builder software is used to outline the house module, the details of the construction such as floor plan, wall assembly, roof, floor, windows, the type and thickness of materials used in the building are extracted from the Ashti city [24] project (house type B). DesignBuilder was used to plan the baseline module with the orientation (0^0 South), then the modelled building was transferred to the EnergyPlus [26,27]. In EnergyPlus, simulations of energy

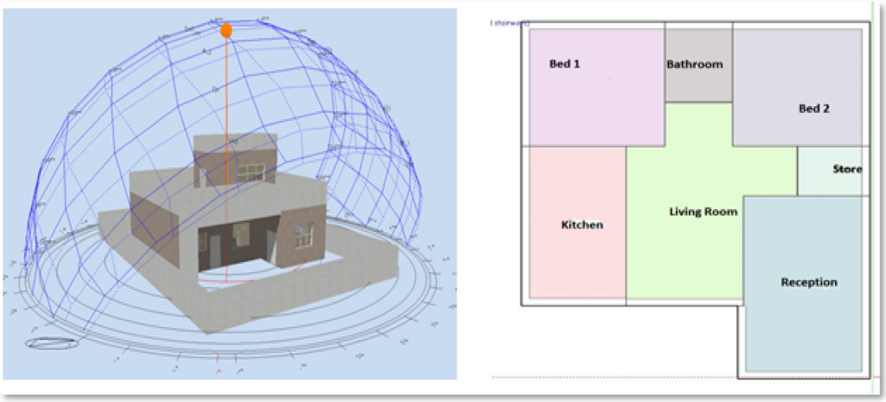

Fig. 1. The design of the module a building [24].

Table 1. Ashti house construction details according Iraqi construction code [22].

House module	Construction details	U value W/m^2 k
External wall	2 cm Cement & sand render+ 20 cm hollow concrete block + 2 m Gypsum	2.719
Internal partitions	2 cm Gypsum + 20 cm hollow concrete block + 2 m Gypsum	2.544
Roof	20 cm reinforced concrete with %1 steel bars + 2 cm Gypsum	3.645
Ground floor	Soil + 10 cm gravel + 10 concrete + 2.5 cm Terrazu Tile.	2.61
Internal floor	2.5 cm Terrazzo tile + 5 cm sand &cement mix + 20 cm reinforced concrete with %1 steel bars + 2 cm Gypsum	1.119
Windows	PVC (polyvinyl chloride) with one single pane of 6 mm	5.77
Façade or direction	Not considered	–

demand for combinations of possible changes to the fabrication can be performed, which can be analysed to find the optimum materials and geometric parameters of the fabrication towards reducing the cooling load. The overall simulation process is shown in Fig. 2.

Once the baseline module was designed by the DesignBuilder with the parameters that illustrated in Table 2, it is then transferred to the EnergyPlus for further analyses with six different parameters used such as orientation, building block type, external insulation thickness, glazing, window shadings, and suspended ceiling that shown in Fig. 3. Running a building simulation for each combination of parameters resulted in 384 simulations from April to October, every run was a simulation of 4392 h to estimate the energy saving, reduction in cooling load and the annual energy used in the house building.

Table 2. Baseline case of Ashti model building detail.

Orientation	External wall	Insulation	Glazing	Window shading	Suspended ceiling	Internal set temperature
0° South	2 cm Cement & sand render+ 20 cm hollow concrete block + 2 m Gypsum	None	6 mm clear Glazing	Internal blind	None	25 °C

4. Weather and occupancy settings

In addition to the building parameters which could be varied between simulations, the climate, typical window to wall ratio, desired indoor setting temperature and occupancy of the building must be specified. These parameters shown in Table 3 are fixed across all simulations. The climate in Kurdistan is hot and dry, especially in summer, cooling is required for six months in a year from April to October. Based on this, the input of weather to the

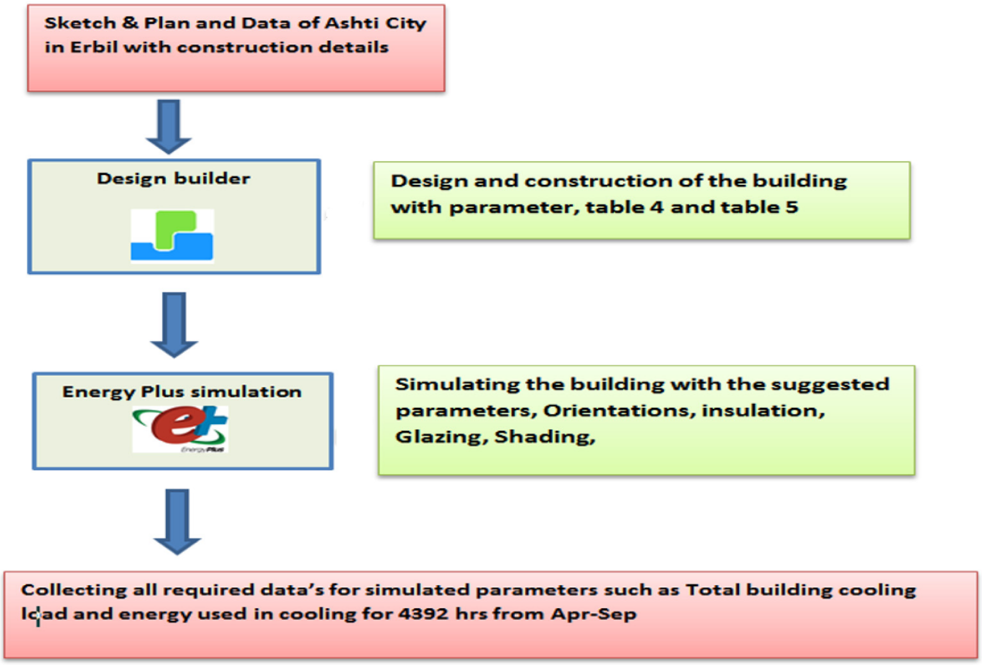

Fig. 2. Overall simulation layout.

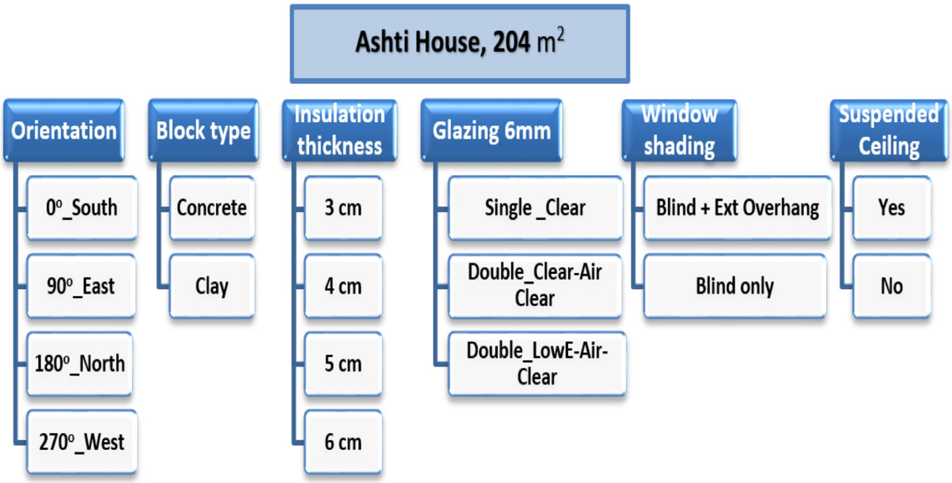

Fig. 3. Main investigated parameters for the module.

EnergyPlus simulation was obtained from EnergyPlus weather data library (EnergyPlus). Window to wall ratio is relatively low, the maximum ratio is 18.2% in the living room, and the lowest ratio is 4.71% in the penthouse, the average ratio of 9.43% for the entire conditioned zones of the building.

Split air conditioning systems are very common in Kurdistan, with a 25 °C cooling set in summer. The cooling load is also dependent on the internal activities of the occupants, including use of lighting, occupancy schedules, and use of each zone with equipment in the building. In this study, six occupants are of the module are considered, distributed between zones as detailed in Table 3. The schedules and occupancy, clothing, activity, and the usage of the building with cooling in the house are according to the typical Kurdish family's daily life in Erbil city [28,29].

Table 3. Kurdish typical family energy consumption in residential units under Iraqi construction code.

Zones	No of Occ	Cooling supply schedule	Lighting schedule	Occupancy schedules	Equipment schedules	Activity & Metabolic	Zone Cooling set temp^{0}C
Bed1	3	Midnight–9am 10pm–midnight	12–3pm & 7pm–11pm	11pm–9am	10pm–midnight	Resting/sleeping	25
Bed2	2	Midnight–9am 10pm–Midnight	12–3pm & 7pm–11pm	11pm–9am	10pm–midnight	Resting/sleeping	25
Living	4	9am–10pm	12–11pm	12–5pm (half-Occ) 5pm–11pm	1pm–5pm 7pm–11pm	Eating & drinking	25
Kitchen	2	9am–10pm	12–11pm	9am–1pm & 5pm–8pm	Midnight–9am 9am–1pm 5pm–8pm	Cooking	25
Penthouse	0	9am–10pm	12–11pm	6pm–8pm	0	Walking about	25
Reception	5	6pm–11pm	6pm–11pm	6pm–9pm	6pm–11pm	Seated quietly	25
Store & bathrooms	1	Not cooled	6pm–10pm 12–22pm	0 9am–12 & 5pm–8pm	0 9–12	–	NA

5. Results and analysis

5.1. Primary results for the baseline module

The primary result of the baseline module for the simulated season from April to October indicated that the greatest part of the energy consumed in the building (78%) is used by the cooling system to reach the desired set temperature of 25 °C for the occupants. Other electrical equipment uses (15%), then the lightings consume (7%) of the total annual energy used of (13 104 kWh) as shown in Fig. 4. The greatest heat gain of the module is from the building fabric, solar and the assembly of building a shell. Consequently, 93% of the cooling load is sensible cooling, the rest (7%) represents the latent cooling.

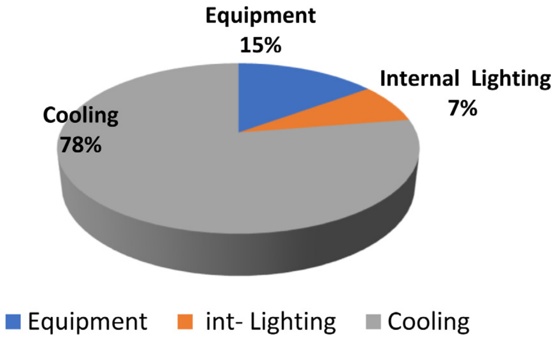

Fig. 4. The annual energy consumption in the baseline module house.

The influence of heat gains on the cooling load was investigated. The highest effect is from the external walls, which represent 35.13%, then the roof 30.19%, internal walls 12.5% and solar gain are 9.6% respectively. The solar gain from windows was expected to have a much higher effect, but due to the internal shading (blinds), which covers the windows especially in hot and high solar radiation days minimized its effect on the general cooling load of the building. All other parameters like occupants, equipment and infiltration have a low effect which is around 6% for each one. Thus, the results show that the walls and roofs are the main factors that affect the cooling load.

The daily cooling load based on the hottest day in Kurdistan (21st of July in the weather file) was simulated using the traditional air conditioner. The maximum cooling load per each zone, per m^2, and total house average are predicted as shown in Table 4. The penthouse requires the highest portion of load (294 W/m$^{2\cdot}$) as it is exposed to the direct solar radiation from all sides (walls and roof), and the average load for the whole building is 243 W/m^2, that covers 127 m^2 conditioned spaces.

Table 4. Maximum July day cooling load for each zone/m^2.

	Bed 1	Bed 2	Kitchen	Living	Reception	Penthouse	Total house average, conditioned 127 m^2
Zone max cooling load W/m2	240	219	260	159	286	294	243
Total zone max cooling load, W	3824	3482	3873	3565	6102	3714	4093

The overall cooling capacity of the combined cooling in the building (all zones) is simulated, the peak cooling load is 17.47 kW on (21st of July) at 11–12 pm as illustrated in Fig. 5.

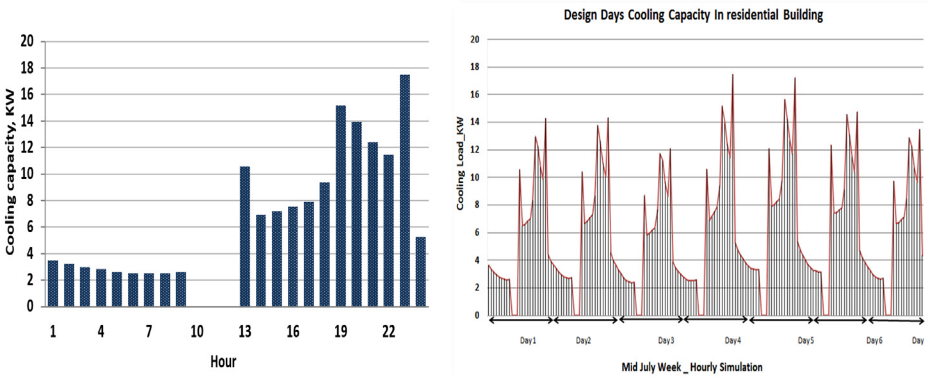

Fig. 5. Hourly Cooling Load of hottest day and week in July.

5.2. *Impact of different parameters*

The annual cooling energy (kWh) and the maximum cooling load (kW) of the baseline module was simulated, then simulation run repeatedly with a change in one of the main parameters shown in Fig. 6 and keeping the rest of the other parameters unchanged to evaluate the influence of each parameter alone without interference of other's effect on the baseline module's load. The baseline module parameters are (cement block, no insulation, 6 mm single clear window with blind, no suspended ceiling, and no overhangs) as shown in Table 2. The maximum daily cooling load for the baseline module is 17.47 kW, and the annual cooling energy is 13 104 kWh, this represents the first column in Fig. 6.

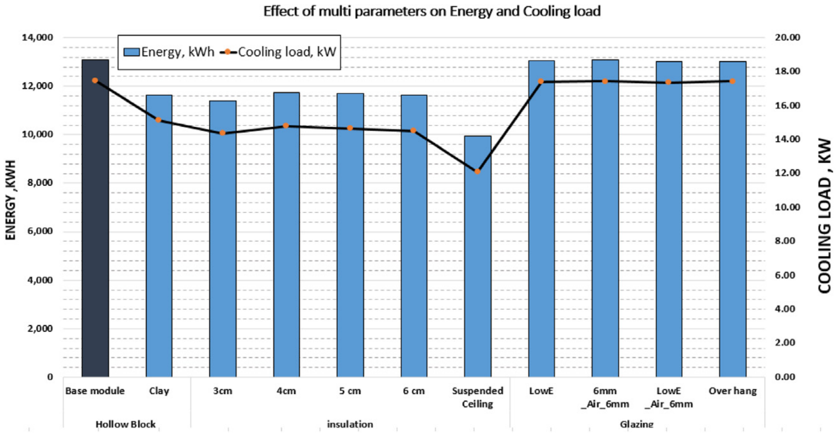

Fig. 6. Effect of Fabric on cooling load and energy/season.

Fig. 6 illustrates the hot summer day load and annual cooling energy with the change of one parameter, and Fig. 7 shows the annual energy save of each parameter's application. The hollow clay brick could minimize the maximum daily cooling load from 17.47 kW to 15.13 kW and an annual cooling load from 13 104 kWh to 11 626 kWh when it replaced the hollow cement block of the baseline module, the saving in annual energy consumption is 11.3%. The 3 cm insulation is the optimum thickness to reduce the maximum daily cooling load from 17.47 kW to 14.35 kW and the annual cooling energy from 13 104 kWh to 11 382 kWh with an annual energy save of 13.1%, so there is no need to use thicker insulation as it results in extra cost and could have negative effect. Increasing the thickness of outer insulation from 3 cm to 6 cm would result in increasing the maximum cooling load from 14.35 to 14.51 kW while the energy increases from 11 382 to 11 620 kWh. The suspended ceiling impact is the most obvious among all the other parameters, it could reduce the maximum daily cooling load from 17.47 kW to 12.08 kW with a reduction in the annual cooling energy from 13 105 kWh to 9952 kWh, and annual energy save of 24.1%. This high effect of the suspended ceiling is due to the high thermal conductivity of the roof, and because the module is one storey building, which means it is directly exposed to the hot sun radiation strike. The impact of the double-glazed window and low emissivity glazing is generally very low on cooling load and energy savings. The annual energy saving is between 0.1–0.6%, that is because of the low window/wall ratio and the availability of the internal curtain, these reasons could reduce the importance of the overhang as well, as it records only 0.5% saving as it had only 0.5 m projection without tilting angle.

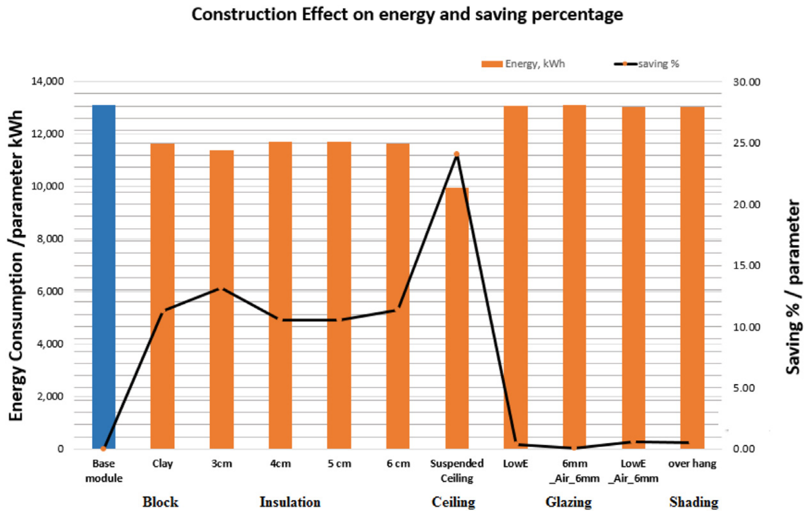

Fig. 7. Energy saving percentage per fabric.

The baseline module orientation is facing the south 0°, but the other orientations [90° -West, 180° -North, and 270° -East] were simulated as well to investigate their influence on the cooling load and energy. The result showed that the west orientation has a minimum daily cooling load of 17.2 kW, but the energy consumption is the maximum over 13 600 kWh, while the minimum consumption is at the north orientation as low as 12 949 kWh as shown in Fig. 8. So, the minimum cooling load at a time does not mean the minimum energy consumption.

The building was simulated again to find the optimum parameters combination with the lowest energy consumption and cooling load. It is predicted that the parameters of [hollow clay brick, 6 cm insulation and adding the suspended ceiling, low emissivity glazing and overhang] with the same orientation (South) give the best output. It showed that the peak load could be minimized from 17.47 kW to 11.02 kW as shown in Fig. 9, while if only the block and 3 cm insulation with the suspended ceiling added, the load will be reduced to 11.16 kW, this is a strong indication that the optimum insulation is 3 cm and the window glazing replacement with low emissivity and adding the overhang externally is not changing the energy consumed and have no extra effect on reducing the cooling load.

The maximum combination of parameters (clay block, 6 mm insulation, low Emissivity-Air- 6 mm clear glass window, suspended ceiling, and overhang) could minimize the annual energy from 13 104 kWh to 9389.9 kWh as shown in Fig. 9. The reduction represents 28.35% of the annual energy consumption, and the building's maximum cooling load reduced from 17.47 to 11.02 kW as shown in Fig. 9, while only clay block, 3 cm insulation and suspended ceiling added the reduction is only 10 142 kWh and the annual saving of 22.5%.

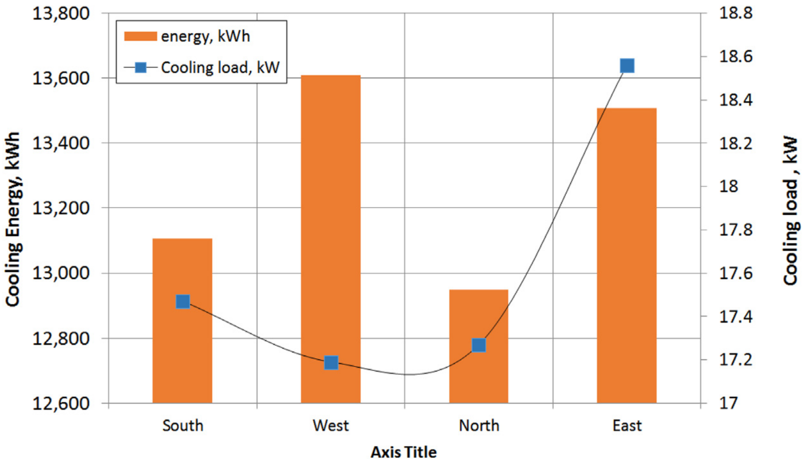

Fig. 8. Orientation effect on the load and energy on the baseline module.

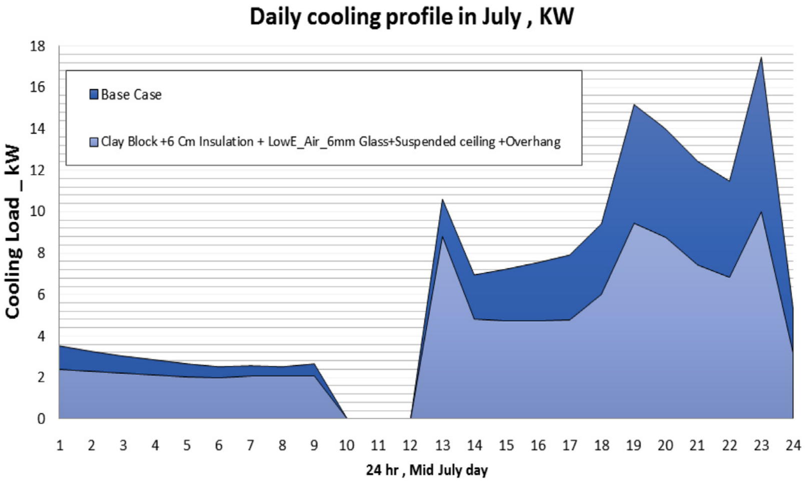

Fig. 9. Cooling load reduction with maximum parameters on a peak day.

Fig. 10 shows the effect of the combined parameters of (hollow clay brick, 6 cm insulation, low Emisivity_Air_6 mm clear glazing, suspended ceiling and with external shading overhang) except orientation on the cooling load, this adjustments reduced the load from 17.47 kW to 11 kW, this represents a very promising save in terms of capital cost and the energy used by the system, consequently reduction in CO_2 emissions.

The adjustment of the building fabrications, the internal parameters, and schedules unchanged resulted in a big rate of energy savings, without any compromising from the human comfort or changing the usage schedule e of the facilities. Fig. 11 shows the annual hourly cooling load profile and outdoor temperature. Figure A is the hourly cooling load for the baseline building and Figure B shows the cooling load after the adjustments (with the optimum parameters), the figure illustrates an obvious reduction in cooling load after the modifications.

6. Conclusion

Building fabrication has a major effect on the cooling load in Kurdistan, the study showed that the suspended ceiling, hollow clay blocks, and insulation have obvious impact on cooling load reduction and energy consumption, while the double glazing, external overhang have a very small effect due to the low window/wall ratio and the internal shading. The optimum insulation thickness is 3 cm to be added externally. The optimum combination parameters were determined as (suspended ceiling, 3 cm insulation with the hollow clay block). By applying the

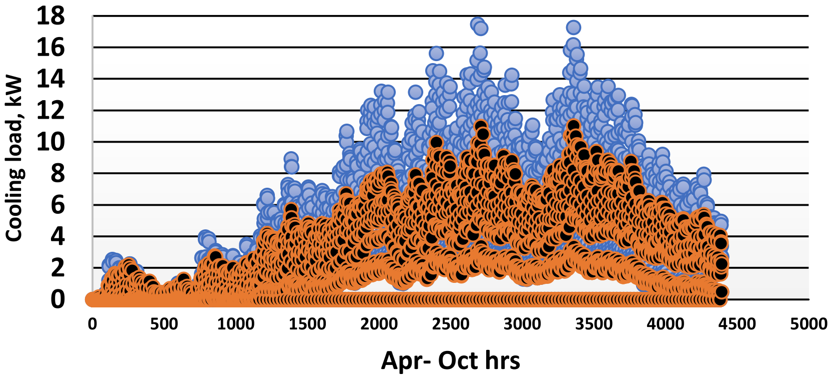

Fig. 10. Annual load reduction with all parameters (hollow clay brick, 6 cm insulation, low Emisivity_Air_6 mm glazing, suspended ceiling with external overhang.

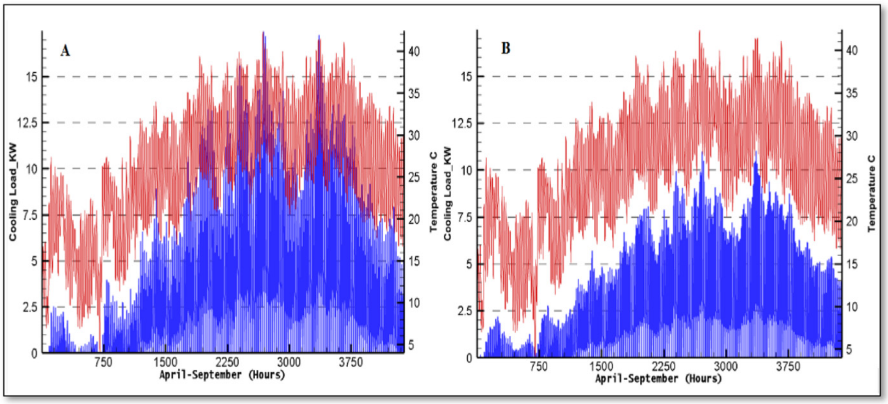

Fig. 11. Reduction in cooling load versus outdoor temperature (A) before and (B) after applying fabric intervention.

optimum parameters to the original building, the cooling load would decrease from 17.47 to 12.2 kW, and the energy consumption will be reduced from 13 104 to 10 142 kWh representing the annual saving of 22.5%.

Further studies are required to save more energy in cooling, concentrating on improving the building code to other types of building with improved current building code, as Iraq generally including Kurdistan does not have a proper building code, and depends on the interim building code.

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