

Effects of building façade architectural design elements on thermal comfort and energy efficiency

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Abstract

Thermal performance, energy demand, and environmental sustainability in hot-arid climates—where cooling loads dominate—are strongly influenced by façade design. This study assesses the effectiveness of a passive curtain wall strategy through an experimental comparison of two structurally similar educational buildings in Iraq. Building A features a detached curtain wall positioned 1.40 m from the main envelope, while Building B employs a conventional single-skin façade. Field measurements were conducted in August 2025, during the hottest period of the year, under identical climatic conditions. Air temperature, relative humidity, heat flux, and indoor and outdoor surface temperatures were recorded at 30-minute intervals over five hours. Unsteady heat transfer through the envelope was analyzed using a one-dimensional steady-state heat conduction model. Results show that Building A achieved an average heat flux reduction of 11.35% compared to the reference building. This reduction led to lower surface temperatures, decreased heat transfer, and improved thermal comfort. The decline in heat gain implies reduced cooling energy demand and operational carbon emissions—an important consideration in regions with limited energy resources. The findings provide empirical evidence supporting climate-responsive passive façade strategies as an effective approach to enhancing energy efficiency and sustainability in hot-arid environments.

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Keywords: Façade, Architectural design, Thermal comfort, Energy efficiency

1. Introduction

The fast-growing urbanization and population in Iraq have caused a high-level increase in the use of energy for buildings, especially for cooling in these hot, arid regions. Because of longer hours of occupancy and high cooling load, educational and institutional buildings are major contributors to peak electricity demand. This increasing demand creates stress on an already constrained energy infrastructure heavily dependent on fossil-fuel-based electricity generation [1, 2].

In this backdrop, sustainability in the building sector is mandatory and not an option. The sustainability building design defined here seeks to minimize operational energy demand, minimize environmental impact, and



provide levels of indoor comfort that are acceptable to the occupants by architectural means that are responsive to climate. Of all the building elements, the façade is an essential determinant of thermal performance and energy behavior, as it is the primary interface of indoor and outdoor conditions [3, 4].

The previous researches have proved that façade parameters such as material selection, glazing ratio, shading devices, and façade geometry can have a vital effect on solar heat gain and cooling loads. But sim-based literature or those primarily focused on residential buildings are plenty. Despite several examples of simulation-based studies exploring potential sustainability performance of different designs, there is scarce empirical field-based research assessing sustainability performance of educational or institutional buildings in the real climatic conditions, particularly in a hot–arid region [5, 6].

The passive strategies involve the incorporation of air cavities within curtain wall and double-skin façade systems to serve as thermal buffers, thus minimizing heat transfer. They can block solar radiation, decrease conductive heat transfer, and maintain indoor thermal stability. While they are popular as architectural features, their performance and sustainability need to be tested further under extreme climatic conditions [7, 8].

This study fills the gap by experimentally assessing the sustainability performance of a passive curtain wall façade through in situ thermal monitoring. This research isolates the façade as the main variable that influences thermal comfort, energy performance, and operational sustainability by comparing the performance of two identical buildings under the same environmental conditions. The study's methods, findings, discussion, and conclusions are shown in Figure 1, and how curtain walls contribute to the high energy demand of buildings are also described.

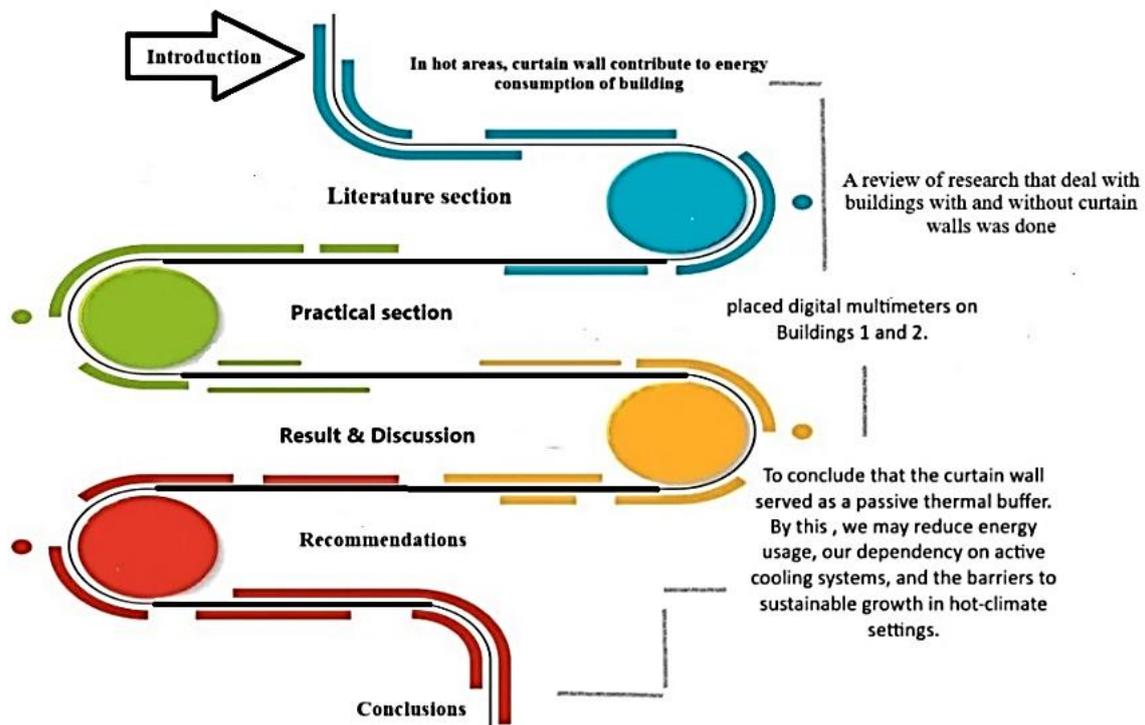


Figure 1. Flowchart- the study's procedures

The current paper is aimed at the enhancement of thermal conditions in buildings to increase the comfort and productivity of the users. The main aim of the study is to explain how curtain walls can be used to improve the thermal performance of the building fronts. To do this, the study will attempt to measure the influence of curtain wall facade on heat transfer of the building envelope, the effect of lower heat flux on cooling energy requirement, and the thermal stability of the interior as a vital measure of occupant comfort and sustainability. The research further aims to offer experimental evidence that will justify the use of passive facade strategies in designing sustainable buildings.

2. Materials and method

In this study, an experimental comparative design is used, which is modeled on on-site thermal measurements. The two educational structures of the University of Kufa were chosen because of the similarity in the materials used in construction, orientation, space planning, and exposure to climatic factors. The only difference between the two buildings is the facade arrangement [9, 10]. Building A uses a curtain wall set at 1.40 m outside the main exterior wall, forming an air cavity which serves as a passive thermal buffer. Building B is a reference case, and it uses a traditional single-layer facade, which does not have an air gap.

Measurements will be made in August of 2025, when the temperatures are at their highest in summer. The calibrated digital multimeters were used to measure the wall surfaces of the indoor and outdoor walls, air temperature, relative humidity, and the level of illumination. Measurements were made at 30-minute intervals with a constant five-hour duration to ensure the measurement of the short-term thermal behavior during an exposure to maximum sun.

A one-dimensional steady-state model of heat conduction through the building envelope was used in calculating heat transfer through the building envelope to enable consistency and comparability across cases [11, 12]. The remarkable campus of the University of Kufa, located in Kufa, Iraq, showcases the best examples of architectural design. This institution showcases the harmonious blend of academic building design and historical preservation. Established in the twentieth century, it boasts a superb site in the city of Kufa. It is located 170 kilometres south of the capital, Baghdad. There are historical places nearby, and it's a hub for government, business, and academia [13, 14]. Dry weather places severe limits on thermal comfort, energy consumption, and building performance in Iraq's Kufa city. The University of Kufa (Figure 2) is a huge educational institution that manages to function under these harsh climatic conditions. At the university site, this research looks at the local climate and how it affects planning and architectural design [15, 16]. The limited availability of power infrastructure in Iraq is a direct result of the country's rapidly expanding urban population and associated population boom. This problem arises from the city's population boom, which has not been matched by a corresponding increase in electricity generation [17, 18].



Figure 2. Location of case study based on Google Maps

The subject of this study is the two buildings located at the campus of the University of Kufa that have been examined. In this paper, we will examine the heat transfers from outside to inside for two buildings, Building A and Building B, along with their corresponding points of comparison (Figure 3).

**Building A****Building B**

Figure 3. The chosen buildings, A and B

The technical specifications and equipment used to measure the environmental parameters (Figure 4). When undertaking our calculations, we carefully factored in a series of factors that are critical in determining the level of thermal comfort, such as temperature, relative humidity, and the level of illumination in the building. These parameters are essential in the research of the interplay between the occupants and their environment and in promoting their comfort. We also added some data from sensors that detected the exterior and interior temperatures of the covering materials of the building. This two-fold mode of measurement enabled us to learn the thermal performance of the facade and the effect it has on the overall indoor climate. Combining all these aspects, the analysis should offer the complete picture of the interactions between building materials and the environmental state, and finally, lead to increased occupant comfort and energy efficiency [19, 20].



Figure 4. The digital multimeter, which is a piece of equipment used in data collection

We have also conducted an extensive data collection project that can be considered as a major part of integrated engineering plans creation, as in August 2025, we were required to conduct a thorough site assessment, collect detailed data regarding the buildings, and make accurate measurements. This field information is vital background and context for our study. The interior spaces of Building A and Building B are what we measured and which we will make reference to in this section. This paper will compare and contrast the exterior-to-interior heat transfer in the two buildings, which have a number of similarities that affect their thermal performance. It is important to note that they obtain an equal share of solar heat because they are exposed to sunlight during the day, and they are made of the same materials. Also, their interior designs, such as the location of doors and windows, are similar. Nevertheless, they differ strongly in that Building A has a curtain wall with an exterior

distance of 1.4 meters from the exterior wall; hence, it will be the initial wall to receive the sunlight compared to Building B, whose outer wall is the main wall that directly receives sunlight. These differences will be instrumental in our analysis of the process of heat transfer in each building that will enable us to come up with relevant conclusions regarding the thermal performance of each building [21, 22].



Figure 5. Building A with a curtain wall at 1.40m from the outside wall, and it's the first recipient of the sunlight

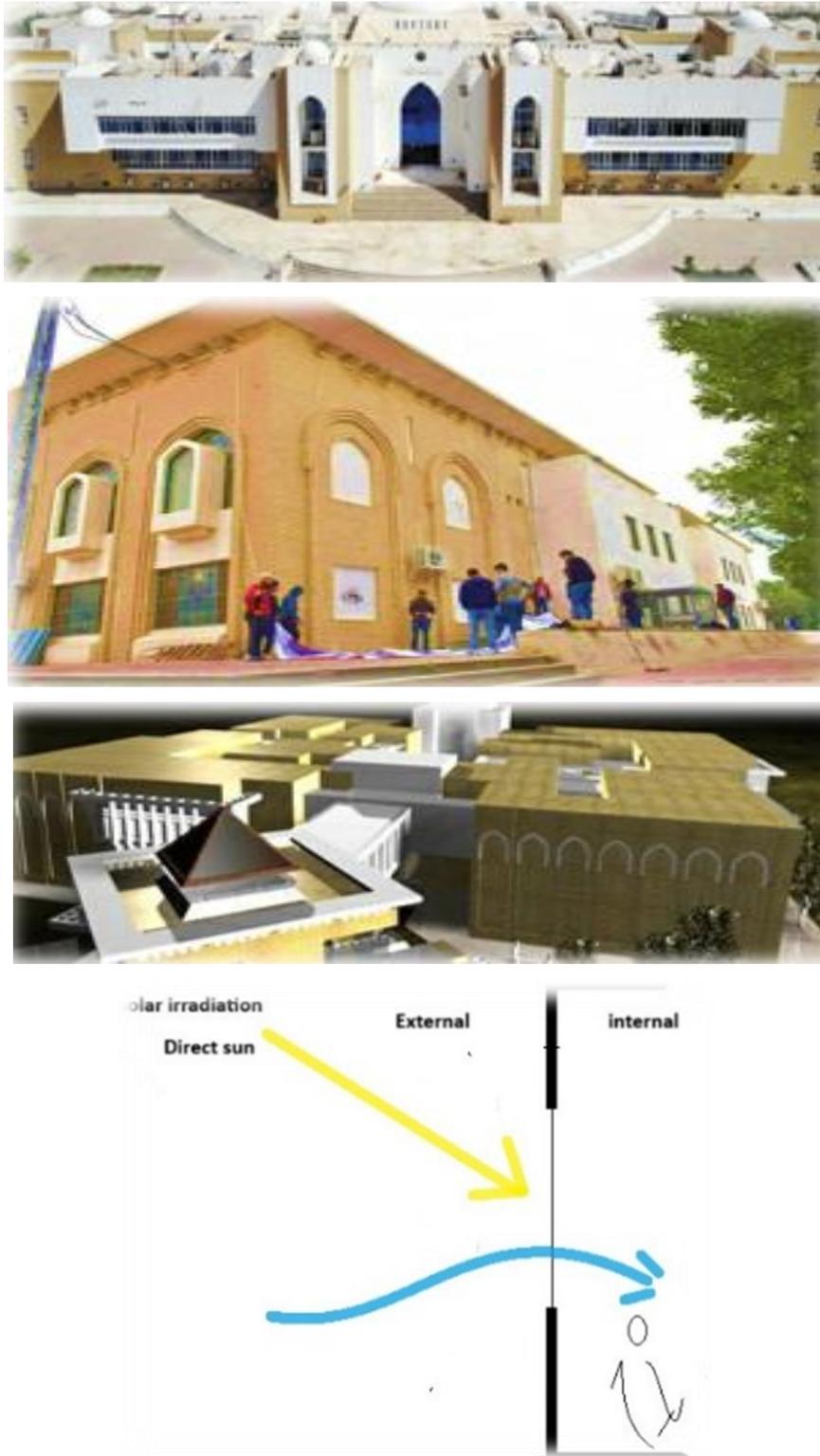


Figure 6. The recent photos of Building B show that the outside wall is the first recipient of the sunlight.

3. Results and discussion

The data measured reveal that over the course of the monitoring, Building A had lower exterior and interior wall surface temperatures than Building B. The highest temperature variation was 2.6 °C on sun-exposed surfaces on the hottest afternoon. This dramatic difference in surface temperatures indicates that Building A has an advantage in its special architectural design, which is helpful in averting the effects of the solar radiation. The reduced surface temperatures directly minimize radiant heat exchange in the interior spaces, which leads to

better thermal comfort and less cooling. Consequently, the residents of Building A should be able to enjoy a more stable and comfortable indoor environment, especially during the hottest time of the day.

When analyzing the trends of surface temperature and thermal profile, we took temperature readings of six periods of half an hour between 10:00 AM and 2:10 PM. We had measured the average surface temperature on the inner and outer walls at three random points. The measurements demonstrated the presence of uniform temperature variations in the two structures. It is worth noting that the exterior walls of Building B, which faced the sun, were on average 2.6 °C hotter than those of Building A, and also Building B recorded higher internal wall temperatures, especially when the sun was at peak heat between the hours of 12:30 PM and 2:10 PM. This tendency means that heat was spreading faster into the inner areas of Building B, and this fact may cause more frequent use of cooling systems.

The results are consistent with the previous studies regarding the thermal insulation value of facade and support the idea that efficient building design is also a key factor in controlling thermal loads. The outcomes also confirm the widely accepted opinion that a balance between the construction aspects, including curtain walls and insulation layers, can considerably reduce the heat transfer and improve the overall energy efficiency. With such knowledge about these thermal principles, architects and engineers can make good choices when designing buildings that consider the comfort of occupants and the conservation of energy.

In order to further explain the processes of these observations, we used a steady-state one-dimensional heat transfer model to discuss heat flux and thermal gradients in both buildings. The equation to be used in this analysis is:

$$Q = -k A (dT/dx)$$

In which Q is the heat flux (in watts), k is the thermal conductivity (which is assumed to be the same in both buildings), A is the area of walls in square meters, and dT/dx is the difference in temperature between both sides of the wall. Using this modeling method, we have found that Building A has a lower heat flow of 11.35 percent compared to Building B. This can be explained by the fact that Building A does have the curtain wall that adds another layer of air that serves as a buffer against convection and radiation.

The consequences of these results are not limited to comparisons of temperature, but they also show the need to carefully design the architecture to increase building performance. Designers can also develop and maintain environments by using features like curtain walls that are not only conducive to thermal comfort in the premises, but also use less energy in terms of heating and cooling mechanisms. With the growing impact of climate change and the growing importance of energy efficiency, these thermal interactions will be needed in future construction practices in the name of sustainability and resilience. Finally, our discussion supports the necessity of further research and development of building design in order to achieve maximum thermal performance and environmental stewardship.

The installation of a curtain wall system that is 1.4 meters in front of Building A has turned out to be a critical move towards improving the thermal performance of the building. This new structure has a significant effect of reducing heat transfer, hence controlling the heat retention and the heat dissipation effectively. The curtain wall provides a buffer with an air gap, which minimizes various important thermal effects, such as direct solar heat gain (DSFG), surface temperature increase, and the transfer of heat to the building interior, the phenomenon of which can be summed up in the principles of heat dynamics proposed by the Indikona Foundation.

It has been found that passive architectural interventions, especially the use of ventilated curtain walls, are very important in modulating the impact of heat waves. These systems add to a more comfortable and stable environment by decreasing the speed at which external temperatures mediate on the indoor condition of occupants. The capability of the curtain wall to slow the changes in temperature implies that the spaces inside Building A will not be subjected to such extreme shifts, and eventually, there will be a decrease in the dependence on mechanical cooling systems, which will result in increased energy efficiency.

When determining the effect of wind and environmental conditions on thermal behavior, it was established that wind and environmental conditions on Building A and Building B were largely similar. The structures had a certain level of exposure to the sun's radiation and wind due to their close proximity, which was approximately 15 meters close to each other. This consistency makes the internal temperature measurements made more legitimate because there was little effect of other factors, and the thermal performance can be distinguished more clearly as a result of facade design.

Methodological considerations were another way of verifying the reliability of the data collection process. The 30 minutes between scans of temperature were considered to be enough to capture short-period variations without overloading the data and causing great delays in data collection. Repeated results of the digital tools and sampling methods were found to be correct by the consistency of repeated results, which fell within the standard deviation range of $\pm 0.3^{\circ}\text{C}$. Such a degree of accuracy gives the findings a very solid base on which the study conclusions are based, which validates the efficiency of passive facade designs in streamlining thermal performance.

Overall, the conclusions underscore the importance of careful consideration of passive design features, such as having ventilated curtain walls, as a way of helping significantly in thermal management of a building. These architectural strategies reduce direct solar heat gain and stabilize the interior temperatures, thereby not only ensuring the comfort of the occupants but also ensuring that energy efficiency is achieved, which is a vital consideration in modern building strategies with a view to being sustainable. Physical parameters for Buildings A and B are depicted in Table 1.

Table 1. Physical parameters for Buildings A and B

Parameter	Building A (Curtain Wall)	Building B (No Curtain Wall)
Avg. Internal Wall Temp	Lower (by 1.5–2.2°C)	Higher
Avg. Heat Flux	11.30% lower	Baseline
Passive Element	The curtain wall acted as a buffer	None
Comfort Implication	Improved comfort & lower load	Increased thermal stress

Table 2 shows the heat transfers from outside to inside for Building A. Table 3 shows the heat transfers from outside to inside for Building B.

Table 2. The measurements of indoor and outdoor for Building A

STEP	TIME	T _{air} (°c)			T _{ab} (°c)			T _{wall out} (°c)			T _{wall in} (°c)			Q(W)
1	10:00 AM	36.4	36.2	36.4	35.8	36.2	35.7	35.2	35.7	35.2	31.1	31.5	31.3	10.76
			36.3				35.9				35.2		31.1	
2	10:50 AM	37.2	37.6	37.2	36.3	36.5	36.6	35.8	35.2	35.3	31.3	31.5	31.7	10.76
			37.3				36.4				35.4		31.5	
3	11:40 AM	37.6	37.2	37.9	36.2	36.5	36.6	36.3	36.2	36.5	31.9	32.2	32.7	11.31
			37.5				36.4				36.3		32.2	
4	12:30 PM	37.9	37.1	37.6	36.5	36.8	36.1	36.7	36.8	36.7	32.2	32.8	33.1	11.9
			37.5				36.46				36.7		32.7	
5	01:20 PM	38.2	38.5	38.2	36.9	37.2	37.4	37.6	37.7	37.3	33.3	33.2	33.4	13.2
			38.3				37.1				37.5		33.3	
6	02:10 PM	39.2	38.8	39.3	37.2	37.5	37.6	38.5	38.7	38.9	33.9	33.8	33.7	13.8
			39.1				37.4				38.7		33.8	

Table 3. The measurements of indoor and outdoor for Building B

STEP	T _{air} (°c)	T _{ab} (°c)			T _{wall out} (°c)			T _{wall in} (°c)			Q(W)
1	10:00 AM	36.2	36.4	36.3	36.3	36.3	36.4	31.9	31.5	31.6	12.97
			36.3			36.4			31.7		
2	10:50 AM	36.8	36.7	36.9	37.3	36.9	36.9	32.2	31.3	32.1	13.52
			36.8			37.1			32.2		
3	11:40 AM	37.1	36.8	37.3	38.1	37.7	37.5	32.8	32.5	32.7	13.8
			37.1			36.3			32.7		
4	12:30 PM	37.4	37.6	37.4	38.4	37.9	38.3	33.1	33.1	33.2	14.1
			37.5			38.2			33.1		
5	01:20 PM	38.2	37.8	37.7	39.3	39.5	39.3	33.3	33.8	33.6	16.28
			38.2			39.4			33.5		
6	02:10 PM	39.1	39.2	39.1	39.9	39.8	39.9	33.7	33.9	33.8	16.8
			39.1			39.8			33.8		

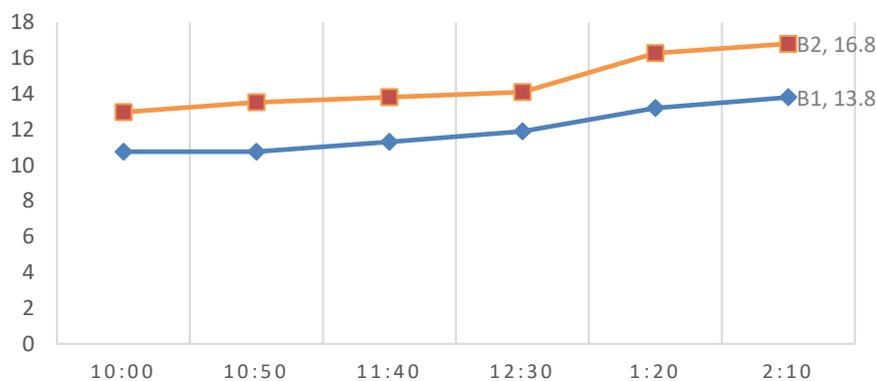


Figure 7. Heat transfers for two buildings, Building A & Building B

Figure 7 shows the heat transfers for two buildings, Building A & Building B. It becomes clear that an appropriately designed curtain wall greatly enhances the thermal performance of a building. The envelope of a building remains a critical feature and plays a significant role in deciding thermal comfort and energy efficiency. Among different facade technologies, air gap inclusion, as seen in double-skin facades, ventilated curtain walls, and cavity walls, is rapidly emerging as an efficient solution for regions that have extreme temperatures. Different aspects pertaining to the inclusion and exclusion of air gaps, as seen in non-gap and air gap walls, have been explored within this research article.

The main modes of heat transfer across a wall are by conduction, convection, and radiation. Walls with an air gap feature an air gap, which acts as a low-conductivity region highly disrupting conductive heat flow. It should be noted that the presence of an air gap region, which has a higher thermal resistance, serves as a buffer and contributes to the significantly higher R-value. That merely implies that there will be significantly less influx and outflow of heat from/to the house, and thus there will be an overall significantly lower U-value measured in watts per square meter-Kelvin. Regular/solid walls refer to walls without an air gap and have reliance solely on the thermal mass and overall conductivity of materials, including concrete, brick, and stone. Although these will provide an advantage--thermal inertia--they will end up with higher conductive heating flux and with no insulation. Based on regions with higher temperatures, there will be additional heat within. Conclusion: The air gap walls demonstrate significantly better performance with regard to conductive and convective heating.

Internal surface temperatures, operative temperatures, and radiant heating are primarily responsible for thermal comfort as per ASHRAE 55 and ISO 7730 guidelines. Where there is an air gap, this wall helps ascertain a relatively stable indoor environment, as it reduces fluctuations in wall surface temperatures and, thus, radiant temperature asymmetry, especially with glazing systems. The opposite occurs with all walls without air gaps,

which have large temperature fluctuations due to external ambient conditions. Examples include single-layer masonry walls and uninsulated walls. These have a high potential for excessive heating gains during the summer. Conclusion: Walls with air gaps and a balanced indoor thermal environment promote comfort even at extreme ambient temperatures.

The thermal resistance value of the envelope is directly associated with energy consumption, and more specifically with air-conditioning consumption in warmer climates. Various research simulations using EnergyPlus and DesignBuilder have shown that air gaps within walls can potentially achieve a 25–35% reduction in air-conditioning consumption, provided they are ventilated, an effect known as the "stack effect," and are properly oriented for solar control. Furthermore, walls without air gaps and without using heavy insulation would increase internal gain and consumption based on air-conditioning usage and thus would raise Energy Use Intensity and Carbon Use Index. Adding air gaps within wall constructions proved more efficient and significantly reduced air-conditioning consumption.

Moisture management plays a critical role in maintaining material integrity and indoor air quality. The air gaps within the wall enable a capillary barrier with a natural gap for draining and drying, particularly useful within cavity walls or double-skin facades. The air circulating within the ventilated cavity will evaporate any water, which will not provide sustenance for microbial growth. A solid wall might be vulnerable to trapped water, especially within more humid environments and poorly ventilated areas, causing interstitial condensation that can compromise insulation and structural materials and encourage microbial growth. By incorporating air gaps within these walls, they become more immune to water accumulation and condensation.

Those air gap wall systems with better performance have higher complexity levels and more detailed designs with regard to ventilation and structure, and with higher costs. Examples would be double-skin facades and ventilated curtain walls, which might also demand more intricate structural designs and easier access for maintenance. Airtight walls cost less and are easier to build, and can be done with local expertise. However, it should be noted that working costs might be offset by a lower capital outlay. Although costlier initially, air gap walls are frugal and efficient.

The airspace wall contains an enormous adaptive capability with regard to varying climatic conditions and hence can be altered and adapted variously based on the surroundings. Hot environments can be aided by air gaps for ventilation. Temperature-controlled climates require enclosed air gaps with insulation in order for them to trap heat.

Hybrid systems function best in variable climatic conditions and have vent control. The solid walls are more brittle without air gaps, except when active insulation and phase-change materials are incorporated. Air gap systems are more flexible with varying climatic conditions. In architectural and building science terminology, air gap walls are an extension within the passive envelope and architectural and engineering synthesis that bridges the gap. Without air gaps, the walls could be adequate for conventional building systems, but they will lack all the dynamics of thermal and energy performance and environmental resilience that an air gap or insulated wall could have. Walls with air gaps would thus be extremely scientifically necessary for buildings in arid and hot climatic regions and even for modern and efficient 'green buildings.'

Their effects would be highly desirable with the addition of intelligent materials and adaptive facades. An air gap, as seen in double-skinned façades and cavity walls, would be highly advantageous and superior compared to conventional 'solid walls' without air gaps. An air gap functions as a thermal separator and enhances the overall R-value of a structure with remarkable benefits against traditional solid walls without air gaps. The air gap functions as a 'thermal separator' and enhances the overall R-value of a structure. In hot climates, the use of air-gap stacking can lead to passive heating and cooling, achieving a significant reduction in cooling needs by 25-35%, in contrast to the mere 0-10% reduction seen with traditional walls lacking air gaps. Air gap walls rely heavily on the characteristics of structural materials like concrete or masonry, which can lead to increased thermal bridging and solar gain, while also providing better insulation. Despite their clear "thermopacitive

advantage" and being simpler and more cost-effective to design and construct, these walls may not work as effectively with more energy-intensive thermal comfort solutions. However, air gap walls do help mitigate radiative heating effects, maintain consistent internal temperatures, and better meet the thermal comfort standards outlined by ASHRAE 55.

Cavity walls benefit from improved water management due to the air gap effects, allowing for condensate evaporation, while water buildup is less likely to occur; instead, water stratification is more common compared to solid walls without air gaps, where water accumulation is frequent. Whereas the air gap walls are usually more costly, energy-consuming, and complicated, they encourage long-term energy conservation and thermal comfort, which are congruent with the code of sustainable and green building. Aerated walls are, therefore, usually better than curtain walls in almost all regards of thermal comfort, energy conservation, and water handling. In addition, air gap walls are scientifically valid, high-performance, climate-adaptive hot and variable weather designs. Table 4 depicts swift effect details for weather, construction, cost, and sustainability on buildings.

Table 4. Summary effects of weather, construction, cost, and sustainability on buildings

Criterion	Wall with Air Gap	Wall without Air Gap
Thermal Resistance	High (due to cavity insulation)	Lower (depends on material only)
Cooling Load	Reduced significantly due to thermal buffering	Typically higher
Thermal Comfort	More stable, reduced radiant asymmetry	Greater fluctuation, higher surface temps
Moisture Control	Excellent (drainage & ventilation)	Limited risk of condensation
Construction	Complex, detailed	Simple, conventional
Cost	Higher upfront, lower operational	Lower upfront, higher operating cost
Sustainability	High (adaptive envelope performance)	Moderate (material-dependent)

Application of a large air gap (1.4 m) in between two walls presents significant benefits in relation to both thermal comfort and energy efficiency. It is a passive thermal storage which decreases the heat gain, slows down the transmission of heat, and stabilizes the temperatures indoors. Properly ventilated, this air space can also serve to improve performance as it removes heated air, reduces the cooling requirements, and makes the occupants more comfortable without using active cooling systems. Consequently, the system of walls can be viewed as a climate-receptive and sustainable design solution, particularly one that can be applied to hot and arid conditions and even to deserts. Curtain wall systems can be used to propel the future of sustainable buildings by integrating the technical performance and architectural intent.

To increase thermal comfort and energy efficiency, architectural façade strategies can incorporate cutting-edge design concepts from engineering and communications, such as fractal geometry and environmental adaptability. This cross-disciplinary exploitation demonstrates innovative idea integration and enhances the literature review [23, 24].

3. Conclusions

Amid the bustle of urban life, a stage is amassed with noise and melds with a riotous melody. Tall light apartments, ray ships that are raised momentarily, those palaces below are also beginning to turn to their futuristic clothing. Glancing at the stream of these individuals in between buildings, each and every one of them is an individual globetrotter in the middle of all the hustle and bustle. Pungent odors of cooking food and engine exhaust ha will continue to brew intoxicating smells into your nostrils. The busy, bewildered life in which she has lived can be filled only with vitality running through the city--just a bare pulse running at the rhythm of music at every other message.

The quantitative analysis revealed that Building A, which had a curtain wall system, had lower external and internal temperature of its surfaces all the time. The heat flux reduction of Building A using the curtain wall system was 11.35 per cent lower than that of Building B.

These findings support the hypothesis that the passive architectural strategies have the potential to become effective thermal buffers, i.e., ventilated walls or air chambers. The thermostat wall minimized the sunlight penetration as well as the spreading of thermal waves, improving thermal stability of the interior, which leads to reduced cooling and high thermal comfort of occupants. In the context of the current energy crises and critical energy conservation in Iraq, the results of the present study support the importance of the application of climate-sensitive facade systems in architectural design.

4. Future scope and recommendations

As the next step towards further development of knowledge on curtain wall systems and their effect on energy savings and comfort of people living inside, it is necessary to expand the research scope to the annual performance simulations. This will allow an in-depth analysis of the possible energy saving and the decrease in CO₂ that can be achieved when curtain walls are implemented under the different climatic conditions. Also, it is urgently required to explore dynamic curtain walls which would vary in real-time according to the position of the sun and seasonal variations. These innovations may contribute greatly to building thermal performance through maximum solar gain and minimum heat loss in a year-long building.

More so, the occupant discomfort must be strictly evaluated based on the known parameters such as predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) values, along with the accurate temperature indicators. This composite analysis will give a more accurate vision of how the design approach of the facades affects not just the energy saving but also the well-being of its occupants. Lastly, it is important to carry out the research in different climatic conditions since this would provide information on the performance of curtain walls across different environmental conditions, hence informing the best practice and design strategies that should be applied to specific areas. Future research can help enhance more sustainable and comfortable built environments by covering these areas.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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Author contribution

Hiba Salih Meften: Conceptualization of the study, design, and writing of the original draft. Noor A. M. Aalhashem: Conducted simulations and analysis of the filter performance, contributed to the methodology, and assisted in manuscript preparation. Mayyadah L Abdulwahhab, Ashwaq Fadhel Muhkaber Alomare: Provided insights into the design process, performed experimental validation, and contributed to the discussion of results.

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