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Ceiling Height and Energy Performance in School Classrooms: A Simulation Study from Sulaimani, Iraq

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Abstract: The present study examines how classroom ceiling height can influence the energy use of school buildings in Sulaimani, the Kurdistan Region of Iraq. For this purpose, DesignBuilder software was used to simulate fourteen classroom cases. In these cases, the ceiling height was gradually increased from 2.70 m to 4.00 m, while all other conditions in the model were kept the same.
The simulation showed that higher ceilings required more annual energy. The main reason was the increase in indoor air volume, which needed more heating during the cold season. From the lowest to the highest tested height, the yearly electricity use increased by 19.3%, and the heating demand rose by almost 40%. In contrast, the lighting energy stayed almost the same in all cases.
From the analysed results, it was found that heights between 2.70 m and 3.00 m provide a better balance between energy use and indoor comfort under local climate conditions. These findings can be useful for future school design and planning in the region.

Keywords: *Ceiling Height; Environmental Performance Simulation; Energy Efficiency in Educational Buildings; Classroom Thermal Performance; Sustainable School Design.*

1. Introduction

In school buildings, students usually spend most of their day inside classrooms. Therefore, the quality of teaching space can strongly affect both their comfort and their learning performance. Indeed, indoor conditions such as temperature level, lighting quality, ventilation, and acoustic environment may influence concentration, attention, and academic achievement of the students [1–3]. For this reason, classroom design should not be seen only as a matter of building form, but also as part of the educational environment itself [4–7].

On the other hand, keeping these indoor conditions within the range of the comfort zone often requires a high amount of energy. In fact, according to the International Energy Agency (IEA), buildings are responsible for more than 30% of global electricity use and around 26% of energy-related carbon emissions [8]. This makes energy performance an important issue, especially in school buildings where occupancy hours are long and indoor comfort must be maintained continuously.

This issue is also important in the Kurdistan Region of Iraq, according to the Sustainable Energy Action Plan for Sulaymaniyah Governorate, schools and other non-residential buildings are responsible for nearly 8% of the region's emissions [9]. The same report shows that each classroom consumes about 2295 kWh annually on average. With an increasing population and the effect of climate change, this value is expected to increase in the future. Therefore, improving the energy performance of educational buildings has become an important local concern. Sulaymaniyah Governorate has also set a target to reduce emissions by 40% by 2030 [9], which is in line with SDG 4 and SDG 7 [10].

Although many studies discussed classroom environment and school design, few works have focused on the effect of ceiling height, especially in this region. Most of the previous studies mainly discuss floor layout, orientation, and indoor environmental quality in general. The effect of room height is still less clear. For this reason, the present study investigates how classroom ceiling height affects annual energy demand and indoor thermal performance in school buildings located in Sulaimani.

The study addresses the following research questions:

- How does ceiling height affect classroom heating and cooling energy demand?
- What is the relationship between ceiling height and indoor thermal performance?
- Which ceiling height provides the most efficient balance between comfort and energy use?

2. Literature Review

Ceiling height is one of the architectural factors that can affect both indoor environmental quality and building energy use. It has an influence on internal air volume, daylight penetration, acoustic behaviour, and even the way occupants psychologically perceive the space. In educational settings, its effect is not limited to physical comfort only, but may also extend to students' behaviour and learning experience.

For instance, Read, Sugawara, and Brandt examined the relationship between classroom spatial characteristics and children's cooperative behaviour. Their study, which was based on Gibson's Ecological Theory of Visual Perception, involved 30 preschool children who were exposed to classrooms with different ceiling heights and wall colour settings. The results indicated that the physical properties of the classroom space may affect social interaction and cooperative behaviour among students [11].

From an energy perspective, the effect of ceiling height has also been examined in previous simulation-based studies. One study conducted in Tabriz, Iran, used EnergyPlus software to investigate how ceiling height influences heating energy demand in educational buildings [12]. They revealed that reducing the ceiling height by 10 cm resulted in nearly a 1% reduction in heating load. This result provides a useful reference point for climates where heating demand is responsible for most of the annual energy consumption.

Meanwhile, within the Kurdistan Region of Iraq, previous studies have mostly focused on general school design and indoor environmental quality rather than ceiling height specifically. For example, Tayib and Hassan examined the relationship between school interior spaces and student performance in selected primary schools in Sulaimani. Their results showed that students' physical and cognitive needs are strongly linked to the quality of the learning environment [13]. Similarly, Zewar analysed corridor design efficiency in foundation schools in Erbil by using field observations and spatial analysis. The paper examined two prototype designs of 18-classroom schools: an L shape (double-loaded corridor) and an O shape (single-loaded corridor). The results identified several spatial planning inefficiencies, recommended reducing internal circulation areas and enhancing outdoor learning environments to improve environmental quality and spatial organisation [14].

In addition, Swar, Khayat, and Amin also studied the design efficiency of foundation schools in Erbil by comparing local schools with UK standards. Their work mainly focused on floor area ratios and space efficiency rather than vertical volume. The study found that the average gross site area of schools in Erbil is more compact than that of UK schools. This difference is largely due to the UK's inclusion of various outdoor spaces that are designed to support physical education [15]. Daylighting has also been studied as an important environmental factor in local school buildings. Mustafa, Amin, and Swar performed daylight simulations for six schools in Erbil using digital modelling tools. They showed that proper spatial layout and orientation significantly influence daylight distribution and visual comfort in school buildings, but those parameters must be carefully considered during the design stage [16].

Despite the fact that these studies provide useful insights into school design in the Kurdistan Region, they do not directly address the role of ceiling height as an energy-related design parameter.

2.1 Research Gap

Previous international studies have already examined the relationship between room volume and building energy demand. However, many of these studies were carried out in climates different from the Kurdistan Region. For example, the work conducted in Tabriz [12] mainly focused on heating-dominated conditions.

Meanwhile, in Sulaimani, the situation is different because classrooms require both winter heating and summer cooling. Still, at the local level, most of the existing research has focused on school layout, daylighting, and general environmental quality. The effect of ceiling height as an energy-related design parameter has received limited attention. Because of this, there is still a need for local evidence that explains how room height affects classroom energy use and thermal conditions.

2.2 Aims of the Study

The main aim of this study is to examine how classroom ceiling height influences annual energy performance and indoor thermal conditions in school buildings located in Sulaimani. More specifically, the study seeks to identify a suitable ceiling-height range that can provide a practical balance between thermal comfort, energy efficiency, and reduced operational emissions.

In addition, the findings are intended to provide useful guidance for architects, planners, and decision-makers involved in the design of educational buildings in the Kurdistan Region.

2.3 Scope of the Research

This research focuses on a prototype classroom model located in Sulaimani, Kurdistan Region of Iraq. The analysis is limited to the effect of ceiling height on annual operational performance under the local climatic conditions of the city. Here, in the simulations, a single prototype classroom was intentionally selected. The reason for using one prototype classroom was to make sure that the influence of ceiling height could be observed more clearly, without the results being affected by changes in other building factors. The evaluation mainly considered heating demand, cooling demand, lighting energy use, indoor comfort hours, and the related CO_2 emissions.

3. Research Methodology

In this study, the investigation was carried out through building performance simulation. The analysis was conducted using DesignBuilder software (Version 6.1.0.006), which was selected because it provides a practical way to study the thermal and energy behaviour of buildings under fixed and controlled conditions [17].

In this work, classroom ceiling height was the main variable considered. To make the comparison clearer, all other parameters in the model, such as material properties, occupancy schedule, glazing, HVAC operation, and internal loads, were kept unchanged for all tested cases. In this way, any difference in the results can be linked directly to the change in room height.

3.1 Prototype Model

The simulation model was based on a standard classroom prototype developed according to established architectural references [18]. The standard recommends a rectangular shape for general classrooms, with a 2:3 or 3:4 width-to-length ratio and a longer external room façade, ideally, on two sides, to optimise daylighting. Besides, it encourages that the distance between the front wall where panels and boards are installed, and the furthest pupil's workplace at the back should not be more than 9.00 meters. Likewise, a maximum room depth of 7.20 meters should not be exceeded when there is the possibility of having windows on one side of the classroom only. Moreover, it is not advisable to have a clear height of less than 2.70 meters.

Therefore, a rectangular classroom form was selected with dimensions (length: 9.00 m, width: 7.20 m, and baseline ceiling height: 2.70 m). The classroom, as shown in Figure 1, was assumed to accommodate between 24 and 32 students, which reflects an ideal classroom size in the above-mentioned reference. This provides approximately 2.00 m² floor area per student and 5.00–6.00 m³ air volume per student.

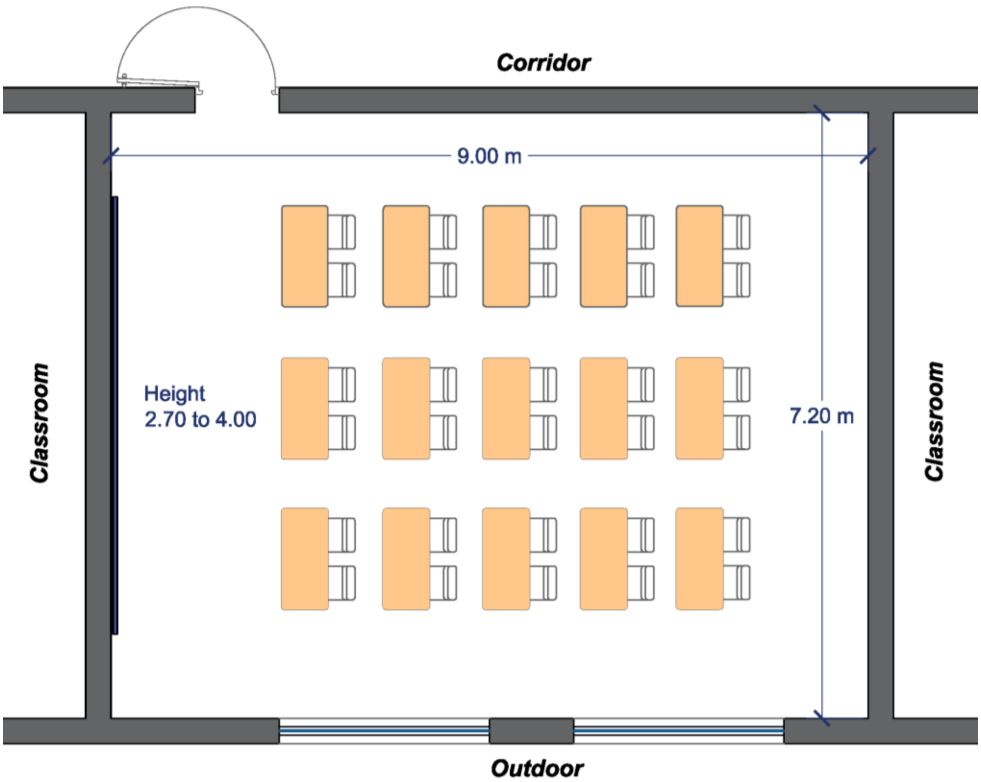

Figure 1: Prototype classroom model used for the simulation study.

The building envelope was modelled using typical local masonry wall construction; details are provided in Table 1. In addition, an infiltration rate of 0.7 air changes per hour was applied to the construction component in DesignBuilder. As for fenestration, the window system consisted of double-glazed units with thermal-break aluminium frames. Here, no external shading devices were included in the model so that the effect of space volume could be clearly evaluated.

Table 1: The construction materials used in the prototype model of the classroom space.

Elements	No. of layers	Material layers (outer to inner)
Roof	5	Gravel 1 inch (0.025 m) Acrylic Insulation (0.001 m) Reinforced Concrete (0.2 m) Air Gap (0.3 m) Ceiling Tiles (0.01 m)
External Walls	3	Cement Plaster (0.02 m) Concrete Block - Heavyweight (0.2 m) Gypsum Plastering (0.02 m)
Internal Walls	3	Gypsum Plaster board (0.025 m) Concrete Block - Heavyweight (0.2 m) Gypsum Plaster board (0.025 m)
Floor	2	Concrete (0.15 m) Epoxy resin (0.001)

3.2 Climate Data

The environmental conditions used in the simulation were based on a Sulaimani-specific EnergyPlus Weather (EPW) file. The dataset represents a typical meteorological year using hourly climate records up to the year 2023 [19]. Sulaimani is generally classified as a Mediterranean hot-summer climate (Csa) according to the Köppen-Geiger climate classification [20]. The city's climate is characterised by hot and dry summers and cold winters.

Seasonal rainfall is concentrated in winter and spring. Whereas summer temperatures can frequently exceed 40°C, while winter temperatures may fall close to 0°C. These big seasonal differences make both heating and cooling important in school building performance; see Figure 2.

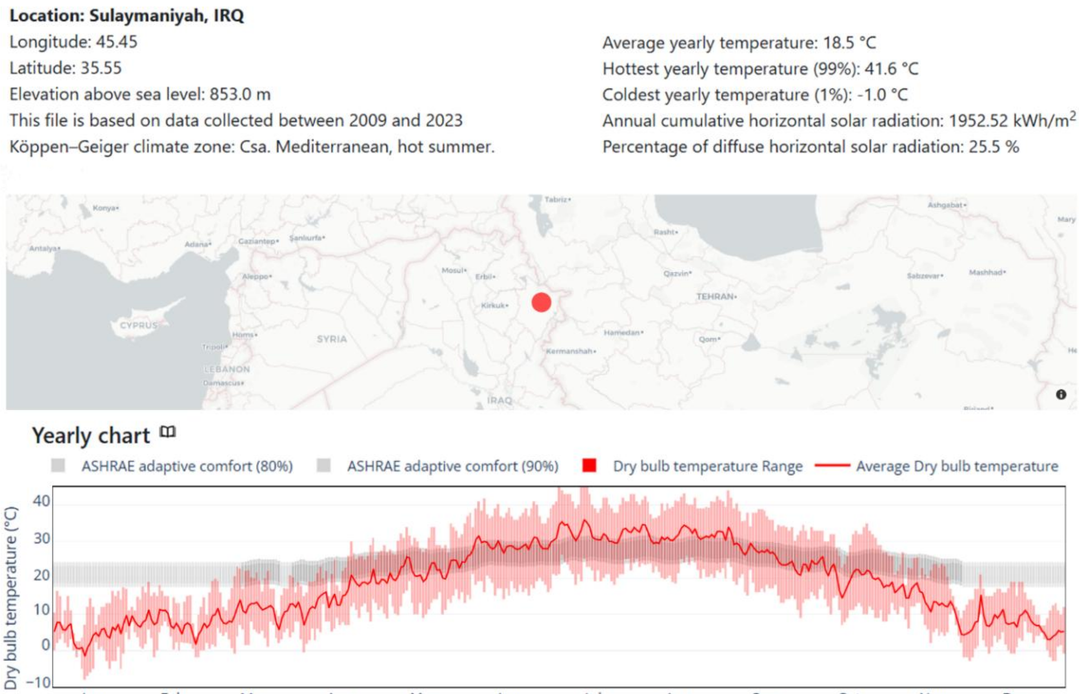

Figure 2: Outdoor dry-bulb temperature variation throughout the year using Sulaimani EPW weather data. Reproduced by CBE Clima Tool [21].

3.3 Operating Hours

In the simulation, the operational schedule was prepared based on the normal daily timetable followed by schools in the Kurdistan Region [22]. Classroom occupancy was assumed to start at 8:00 a.m. and continue until 4:00 p.m. each day. Furthermore, the academic period in the model was considered from September to July.

In DesignBuilder, the same schedule was applied to classroom occupancy, lighting use, and HVAC operation in order to reflect the typical daily pattern of school use as closely as possible.

3.4 User Comfort and HVAC Settings

For all analysed cases, indoor thermal conditions were maintained using a Variable Refrigerant Flow (VRF) system. This system was chosen because it represents a reasonable solution in school buildings within the region. Its operation followed the classroom schedule from 08:00 to 16:00.

In addition, the thermal and visual comfort parameters used in the model were selected in line with the recommendations given in CIBSE Guide A [23]. The heating set-point was maintained between 19°C and 21°C during winter, assuming a clothing insulation level of 1.0 clo. While, for the cooling period, the set-point was maintained between 21°C and 23°C based on 0.65 clo. Further, to ensure acceptable indoor air quality, an air supply rate of 10 L/s per person was applied. And for lighting, an LED system was modelled to maintain a target illuminance level of 300 lux with a maximum glare index of 22.0.

3.5 Simulation Settings and Reproducibility

To ensure the reliability of the study, strict simulation boundary conditions were maintained for all scenarios. Ceiling height was the only variable changed between the simulation cases. The tested ceiling heights ranged from 2.70 m to 4.00 m. In the settings, all other parameters remained unchanged, including (wall and roof materials, glazing ratio, infiltration rate, occupancy schedule, occupancy behaviour and patterns, lighting settings, HVAC schedule, thermal set-points, and internal heat gains), ensuring that any variation in the results can be directly attributed to the change in ceiling height.

4. Analysis Framework

The analysis framework was based on comparing the simulation outputs across all ceiling-height scenarios. Every time, the following performance indicators were evaluated: annual total energy consumption, heating load, cooling load, lighting load, thermal comfort hours, and CO_2 emissions. Then, the outputs from each case were compared to identify how the performance indicators changed as the ceiling height increased.

5. Results

The simulation results show that all classroom cases maintained acceptable indoor thermal comfort during occupied hours. This was measured by calculating the annual percentage of comfort hours within the total 2072 hours of occupied time during a full academic year. This indicates that all tested heights were capable of maintaining indoor comfort conditions, as seen in Table 2. The main difference between the scenarios was found in annual energy demand and emissions.

- The total annual comfort hours ranged between 1939 and 1948 hours, which represents approximately 94% of the total occupied hours.
- Indoor temperatures rarely fall below 19°C, for only 0.5-1 hour per year.
- The total number of discomfort hours (above 23°C) with the running HVAC system remains almost unchanged in all circumstances, with an average of 123 to 133 hours per year that never exceeds 29°C.

Table 2: Air temperature data for classrooms with variable ceiling heights. Displaying the numbers and percentages of thermal comfort and discomfort hours for a full academic year.

Ceiling Height (m)	Comfort Hours		Discomfort Hours					
	Hours Between (19°C and 23°C)	%	Hours Below 19°C	Min. Indoor Temp.	Hours Above 23°C	Max. Indoor Temp.	Total Discomfort Hours	%
2.7	1939	94%	0	19°C	133	29°C	133	6%
2.8	1940	94%	0	19°C	132	29°C	132	6%
2.9	1940	94%	0	19°C	132	29°C	132	6%
3.0	1940	94%	0	19°C	132	29°C	132	6%
3.1	1941.5	94%	0	19°C	130.5	29°C	130.5	6%
3.2	1943.5	94%	0	19°C	128.5	29°C	128.5	6%
3.3	1944.5	94%	0	19°C	127.5	29°C	127.5	6%
3.4	1944	94%	0.5	18°C	127.5	29°C	128	6%
3.5	1945	94%	0.5	18°C	126.5	29°C	127	6%
3.6	1946.5	94%	0.5	18°C	125	29°C	125.5	6%
3.7	1945	94%	1.5	18°C	125.5	29°C	127	6%
3.8	1947	94%	1	18°C	124	29°C	125	6%
3.9	1947	94%	1	18°C	124	29°C	125	6%
4.0	1948	94%	1	18°C	123	29°C	124	6%

5.1 Energy Performance

The results in Table 3 show a clear relationship between ceiling height and total annual energy consumption. The following facts indicate that as ceiling height increased, the total energy demand also increased in an almost linear manner. From this, it can be understood that this increase is mainly related to the larger indoor air volume that must be thermally conditioned.

- The baseline case at 2.70 m showed the lowest annual energy use with 1798.42 kWh.
- Once the height reached 3.00 m, annual consumption exceeded 1874 kWh.
- At 4.00 m, the total annual demand increased by 347 kWh compared to the baseline, which is a 19.3% increase.

Table 3: Annual classroom energy demand and associated CO_2 emissions across all ceiling-height scenarios.

Ceiling Height (m)	Total Electricity (kWh) includes Lighting	HVAC Load (kWh)		Lighting (kWh)	CO2 Emissions (KG)
		Heating (kWh)	Cooling (kWh)		
2.7	1798.42	721.12	941.31	135.99	1089.84
2.8	1824.04	742.15	945.33	136.56	1105.37
2.9	1849.59	763.19	949.29	137.11	1120.85
3.0	1874.60	784.05	952.87	137.68	1136.01
3.1	1900.68	805.58	956.85	138.25	1151.81
3.2	1926.80	827.37	960.63	138.8	1167.64
3.3	1953.67	849.74	964.56	139.37	1183.93
3.4	1979.86	871.87	968.05	139.94	1199.79
3.5	2006.83	894.67	971.65	140.51	1216.14
3.6	2033.87	917.72	975.08	141.07	1232.52
3.7	2060.77	940.64	978.49	141.64	1248.82
3.8	2088.23	963.53	982.51	142.19	1265.47
3.9	2116.41	986.48	987.17	142.76	1282.54
4.0	2145.08	1009.70	992.05	143.33	1299.92

5.1.1 Heating Loads

From analysing the outcome data, heating demand showed the strongest sensitivity to ceiling height variation. Certainly, this increase is mainly caused by the larger air volume that needs heating during winter.

- When the ceiling height increased from 2.70 m to 4.00 m, heating demand increased by approximately 40%.
- The baseline case required around 721 kWh annually, while the highest case exceeded 1000 kWh.
- On average, each 10 cm addition to the vertical dimension increased the heating power requirement by 2.4% to 2.9%.

5.1.2 Cooling Loads

In contrast, cooling loads showed only a limited increase compared to heating demand. This is likely because schools are not fully occupied during the hottest summer months.

- Across all cases, cooling energy ranged from 941.31 kWh to 992.05 kWh.
- The increase per 10 cm increment was relatively small, only about 0.5%

5.1.3 Lighting Loads

On the other hand, the data shows that lighting energy remained almost unchanged across all ceiling-height scenarios. Remarkably, the annual demand ranged between 135.99 kWh and 143.33 kWh. Anyways, this was expected because floor area, window size, and lighting settings remained constant.

5.2 CO2 Emissions

In terms of greenhouse gas emissions, from Table 3, it can be seen that CO_2 emissions followed the same pattern as total electricity consumption. It can also be concluded that the rise in pollution is mainly linked to the increase in heating energy demand.

- The baseline case produced approximately 1090 kg CO_2 annually.
- Each 10 cm increment in height added between 15 kg and 17.5 kg of CO_2 to the building's operational profile.
- At 4.00 m, emissions increased to nearly 1300 kg CO_2, which represents an increase of around 19% compared to the baseline.

6. Conclusions

The findings of this study indicate that classroom ceiling height has a noticeable effect on the annual energy performance of school buildings in Sulaimani. As the ceiling became higher, the yearly electricity use also increased. Among the analysed energy components, heating demand showed the most significant increase, rising by up to 40%. Whereas cooling and lighting loads changed only slightly. This mainly happened because a higher classroom contains more indoor air volume that needs thermal conditioning. Also, due to the longer school period in cold seasons.

These results suggest that increasing classroom height beyond a certain range may lead to additional operational energy demand because of the larger indoor air volume that needs to be conditioned. Based on the analysed cases, a ceiling height between 2.70 m and 3.00 m appears to provide a more suitable balance between indoor comfort and energy efficiency under the local climate conditions.

7. Limitations

This study has several limitations. Firstly, the analysis is limited to the climatic conditions of Sulaimani. Then, only a single-zone classroom model was used. In addition, occupant behaviour and real-life variations in operations were not included. Lastly, HVAC performance and operating schedules were assumed to remain constant throughout the academic year. All these factors may influence actual building performance.

8. Recommendations for Future Research

To strengthen the practical applicability of the findings and support evidence-based school design guidelines for the region, future research is recommended to investigate:

- full-school multi-zone energy simulations
- natural ventilation strategies
- daylight optimization
- lifecycle cost analysis
- embodied carbon implications of increased spatial volume
- post-occupancy validation using monitored data from existing schools

Author's Contribution

The author is responsible for all roles in this paper (Conceptualisation; methodology; software; validation; formal analysis; investigation; resources; data curation; writing—original draft preparation; writing— review and editing; visualisation; supervision; project administration; and funding acquisition). The author has read and agreed to the published version of the manuscript.

Conflict of Interest

There is no conflict of interest for this paper.

Use of the AI tool declaration

The authors declare that any AI tools used in the preparation of this manuscript were limited to language and readability improvement only, and were not used to generate scientific content, data, analyses, or conclusions, with full responsibility retained by the authors.

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