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Case Study for Adopting a Sustainable Kindergarten Design in Baghdad to Improve Thermal Comfort

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ABSTRACT

Greenery strategies and shaded pedestrian passages have become essential for smart city planning in developed countries. This study focuses on a kindergarten project in the Al-Karada district of Baghdad, which will be constructed by the Iraqi Ministry of Education, comparing two design approaches—one incorporating environmental solutions and the other without. To assess the impact on thermal comfort during a typical summer day, ENVI-met software was utilized, analyzing key indices: *PMV* (Predicted Mean Vote); *Tmrt* (Radiant Mean Temperature); relative humidity, wind speed, sky view factor, and air temperature. The results revealed that the environmentally innovative design significantly reduces *Tmrt* and *PMV*, enhancing overall thermal comfort. Specifically, the proposed construction leads to a remarkable reduction in *Tmrt* across 41% of the total urban area for the temperature range (70-80)°C and a reduction in *PMV* of 18% between (7-9). These findings highlight the efficacy of the suggested design in creating a more comfortable climate on a typical summer day. The results of this study and the recommendations proposed in the analysis will be used in the upcoming construction project by the Iraqi Ministry of Education. These findings can be used to improve Al-Shorouq Kindergarten in the Al-Karadah district of Baghdad. The main goal is to improve the thermal comfort in the kindergarten area, following the sustainable and efficient design principles discussed in this research. The upcoming changes demonstrate our dedication to providing students and the wider educational community with the best possible learning experience, ensuring comfort and optimal conditions for all.

1. INTRODUCTION

This article's concise approach to constructing kindergartens for sustainability stresses the various factors that should be considered in creating optimal learning environments that promote the well-being of the young and their teachers.

The design of kindergarten buildings is increasingly leaning towards sustainability. This article delves into a comprehensive case study that strongly emphasizes adopting a sustainable construction design to enhance thermal comfort within kindergarten facilities. However, visitors experience the wonders of nature differently depending on the weather conditions, which is a great challenge. For instance, Schlembach et al. [1] established the impact of an environment on kids.

One of the most effective solutions to the issues of outdoor comfort is erecting horizontal shade structures over the streets instead of pedestrian spaces. Not only that, these structures, in a way, reduce the sky view factor, which indeed captures and retains some of the heat that would otherwise have dissipated into the sky during the night [2, 3].

The kind of paving materials used is another decisive factor since they can raise temperatures higher than the average level. Under the summer sun, the temperature of these materials can rise to as high as 65°C, warming the air above them. A possible solution involves implementing reflective and light-colored pavement materials instead, which could effectively solve such problems and make them less energy—and environment-related [4].

Combining vegetation and green spaces is crucial to the solution in hot climate areas. However, planting trees in arid conditions is fraught with some uncertainties, contributing to the inconsistent application of vegetation in urban designs in hot climates [5, 6]. Studies by Tsoka et al. [7] have shown the benefits of shady trees as a favorite option for reducing heat, which is evident in structural and people's well-being. These trees have evaporative transpiration, which helps cool the surroundings [7-9].

2. LITERATURE REVIEW

In 2014, Santamouris [10] studied the impact of urban heat islands and how vegetation and shade might help reduce them. The results demonstrated that a larger tree canopy lowers the sky view factor (*SVF*), reducing sun exposure and improving thermal comfort by reducing the surrounding temperature.

To evaluate the cooling advantages of different urban plans with vegetation, Taleghani et al. [11] used ENVI-met. The authors stated that a considerable decrease in surface temperatures and enhanced thermal comfort may be obtained through strategic tree placement.

Salata et al. [12] assessed the thermal performance of urban parks and green roofs. According to their data, evapotranspiration, and shade improve thermal comfort while increasing vegetation covering lowers the *SVF*. Authors showed that in regions with a higher tree density, the temperature reduced to 2℃.

Lin et al. [13] investigated the effects of various kinds of vegetation and their layout on thermal comfort in urban regions. According to their study, broad-canopy trees are very good at lowering. *SVF* and providing shade, which reduces air and surface temperatures.

Skelhorn et al. [14] demonstrated that adding vegetation lowers *SVF*, which increases the cooling effects of shade. The strategic placement of trees and vertical greenery can significantly enhance outdoor thermal comfort, especially in the summer when heat is most noticeable.

In their study, Perini et al. [15] integrated vertical greenery systems to lower urban temperatures and enhance comfort. The study predicted how lowering the *SVF* constrained urban streets lead to lower ambient temperatures. The researchers concluded that generating shady, cooler microclimates in urban environments can significantly improve thermal comfort when combined with other vegetation types.

Middel et al. [16] determined how well urban trees may improve thermal comfort by lowering the *SVF* and they are offering shade. The findings indicated that planting more trees in public areas reduces surface temperatures and raises comfort levels. This is mainly because less sky is visible to pedestrians, a feature strongly associated with thermal radiation.

Javadian et al. [17] examined the potential benefits of light-colored cladding on urban facades in their study. The findings indicated that light cladding with increased reflectivity lowers building surface temperatures and helps to cool surrounding ambient air temperatures.

Nguyen et al. [18] studied the effect of reflective pavements on thermal comfort in urban environments. The author showed that, especially during the hottest summer hours, employing reflecting pavement materials significantly lowers air and surface temperatures. According to their study, incorporating high-albedo pavements into urban planning can be an affordable way to improve thermal comfort in highly populated places.

Mohammed and Li [19] approved the efficiency of various pavement materials, such as permeable and light-colored pavements, in enhancing outdoor thermal comfort. The findings demonstrated that light-colored pavements, particularly those coated with reflecting materials, can lower ambient and surface temperatures, making outdoor spaces more comfortable.

Mansour and El-Dessouky [20] investigated the effects of various steel shade designs—such as solid and perforated structures—on indoor and outdoor temperature environments. The results showed that steel shades dramatically lower surface temperatures and solar radiation on building facades, improving thermal comfort in shaded regions.

Zhao and Wang [21] examined various steel canopy and shade element combinations and evaluated how they affect summertime pedestrian comfort. According to the research, steel shades can considerably lessen temperatures by up to 3℃.

3. METHODOLOGY

3.1 Using ENVI-met software for microscale numerical modeling

The application of Microscale Numerical Modeling using ENVI-met software has been found to significantly improve our knowledge of plants and how they interact with the air in urban areas and with the ability to predict climate effects in various urban design scenarios. ENVI-met software runs weather forecasts for 24 to 48 hours, focusing on climate, location, building, soil, plants, and thermal properties. "In the three-dimensional realm, this AI simulates the intricate relationships between radiation, temperature, heat flow, humidity, and wind patterns within city environments [5]. Researchers, including Carfan et al. [22], attested to ENVI-met's accuracy in capturing real-world environments using limited numerical techniques. Numerous studies validated ENVI-met's reliability in modeling outdoor environments' thermal performance by demonstrating consistent alignment between local meteorological station measurements, observations, and simulated air temperatures [23-25].

Huttner [26] explained that the soil model calculates the temperature and humidity of the soil down to a depth of 1.75 m. Neglecting horizontal transfer, the soil is treated as a vertical column in which the distribution of temperature, *T* and soil volumetric moisture content η is given by (Eqs. (1) and (2)) [27]:

$$\frac{\partial T}{\partial t} = \mathrm{k}_s \frac{\partial^2 T}{\partial z^2} \tag{1}$$

$$\frac{\partial \eta}{\partial t} = \mathrm{D}_\eta \frac{\partial^2 \eta}{\partial z^2} + \frac{\partial K_\eta}{\partial z} - S_\eta(z) \tag{2}$$

where, η is the volumetric water content of the soil, $K\eta$ is the hydraulic conductivity, and $D\eta$ is the hydraulic diffusivity.

Huttner [26] indicated that the vegetation in ENVI-met interacts with the atmospheric model and the soil model. The direct heat flux can explain the interactions between the vegetation and soil $J_{f,h}$, and the evaporation flux $J_{f,evap}$, and the transpiration flux $J_{f,trans}$ (Eqs. (3)-(5)).

$$J_{f,h} = 1.1 r_a^{-1}(T_f - T_a) \tag{3}$$

$$J_{f,evap} = r_a^{-1}\Delta_q \delta_c f_w + r_a^{-1}(1-\delta_c)\Delta_q \tag{4}$$

$$J_{f,trans} = \delta_c (r_a - r_s)^{-1}(1 - f_w)\Delta_q \tag{5}$$

where, *Ta* (*K*) is the air temperature; *Tf* (*K*) is the foliage temperature; *q* is the specific humidity of the air, and Δq is the humidity difference; δc defines whether the evaporation is possible (δc=1) or not (δc=0), *ra* the aerodynamic resistance is a function of the leaf diameter and wind speed.

Simon [28] stated that the boundary model extends to an altitude of 2500 meters (the average height of the planetary boundary layer) to ensure stable laminar conditions.

The distribution of receptors can handle thermal parameters in areas where the sun hits, entrance points, and walkways. The decision of receptors' positions in the area's internal and external parts is essential for creating a comprehensive view of the thermal behavior throughout the space. It facilitates the analysis of the various impacts of environmental factors on the measured parameters.

3.2 Study area

Nestled at the geographical core of the nation, Baghdad, the capital of Iraq, holds a central position with coordinates situated at a latitude of 33 North and a longitude of 44 East. Spanning across both banks of the Tigris River, Baghdad is subject to a semiarid, subtropical continental climate marked by cold winters and blistering, arid summers [29]. The forthcoming kindergarten construction in the Al-Karada district (Figure 1) is the outcome of a careful and detailed design orchestrated by engineers employed within the Iraqi Ministry of Education. This strategic location and meticulous design underscore the significance of considering the region's climatic nuances and environmental characteristics in the construction and planning processes. Figure 2 shows a 3D view of the project.

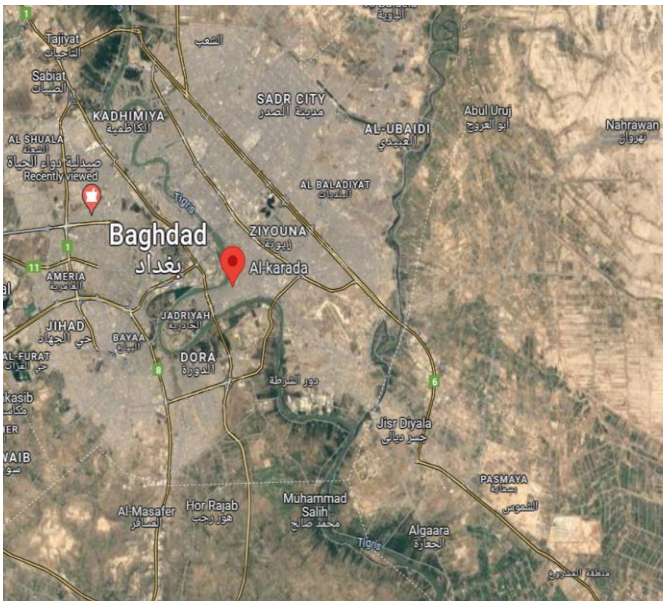


Figure 1. Location of Karadah-Baghdad map **(**Al-karada - Google Maps**)**

The simulated area encompasses 1680 square meters, as illustrated in Figure 3. The dimensions of the grid cells within this area are meticulously defined, with a spacing of *dy*=2 meters, *dx*=2 meters, and *dz*=1 meters. Notably, the entire model is rotated 90 degrees in the primary North direction, as depicted in Figures 3a and 3b. This strategic rotation ensures a comprehensive and detailed simulation, capturing the intricacies of the environment with precision. The specific dimensions and orientation of the model underscore the meticulous approach taken in the simulation process to accurately represent the spatial characteristics and dynamics within the designated area.

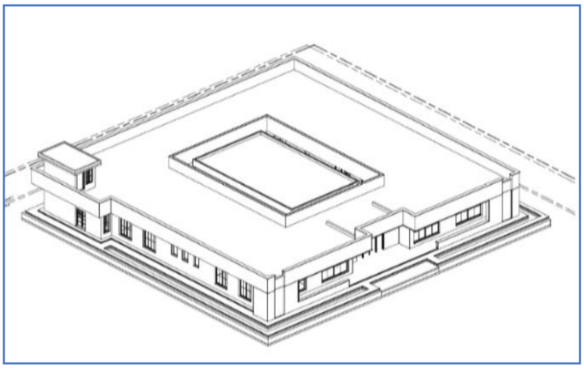
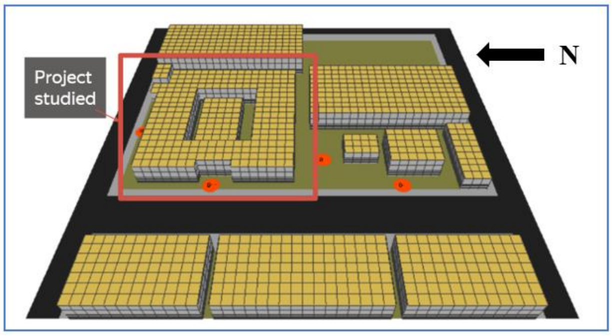
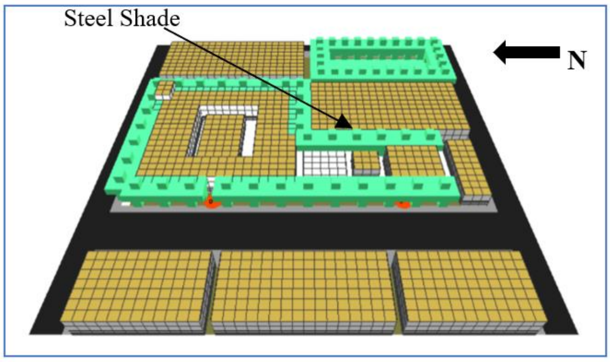


Figure 2. 3D drawings of kindergarten to be built in Baghdad



a) without using solutions



b) Proposed model (PM)

Figure 3. Perspective view of kindergarten; a) without using solutions (case 1); b) proposed model (PM) (case 2)

4. RESULTS AND DISCUSSION

4.1 Criteria for the proposal model design

The antecedent evaluation findings are the foundation for establishing the criteria that guide the selected design. In conjunction with these results, due consideration is given to the specifications and recommendations outlined by Iraq's Ministry of Education. The overarching objective is to evaluate and enhance the outdoor weather conditions through thoughtful modifications to the design. The model design is meticulously crafted based on the following criteria to achieve a more optimal and comfortable outdoor environment:

1) Building structure:

• A single-story educational kindergarten structure featuring an internally isolated multipurpose hall is proposed.

• The elevations of the main building are set at 3 meters, while the hall is designed with a height of 4 meters.

• The elevations of parapets and slab thicknesses are incorporated into the building blocks.

2) H/W aspect ratio:

• The Height-to-Width (H/W) aspect ratio is critical in determining the distance between buildings.

• A specific H-to-W ratio at an elevation of 1.8 meters is selected, as depicted in Figure 4.

3) Orientation:

• The chosen direction for the structure is Northwest to Southeast, as recommended by the engineers of the Ministry of Education.

4) Cladding and albedo:

• Recognizing the impact of albedo on thermal comfort, walls are clad with aluminum, boasting a reflective value of 0.8.

• Concrete pavement lights with an albedo of 0.5 are chosen for pathways, considering their influence on thermal conditions.

5) Shading solutions:

• Steel sheds on columns are strategically incorporated to provide essential shade, shielding children from the direct impacts of solar energy.

6) Vegetation integration:

• A focus on utilizing vegetation involves the introduction of grass (with an albedo of 0.2) and palms reaching a height of 5 meters, aligned with the kindergarten's height. This deliberate incorporation aims to amplify the impact on ambient thermal comfort.

These criteria collectively shape the thoughtful design modifications, demonstrating a holistic approach to creating an environment that prioritizes functionality and comfort for the occupants of the educational kindergarten.

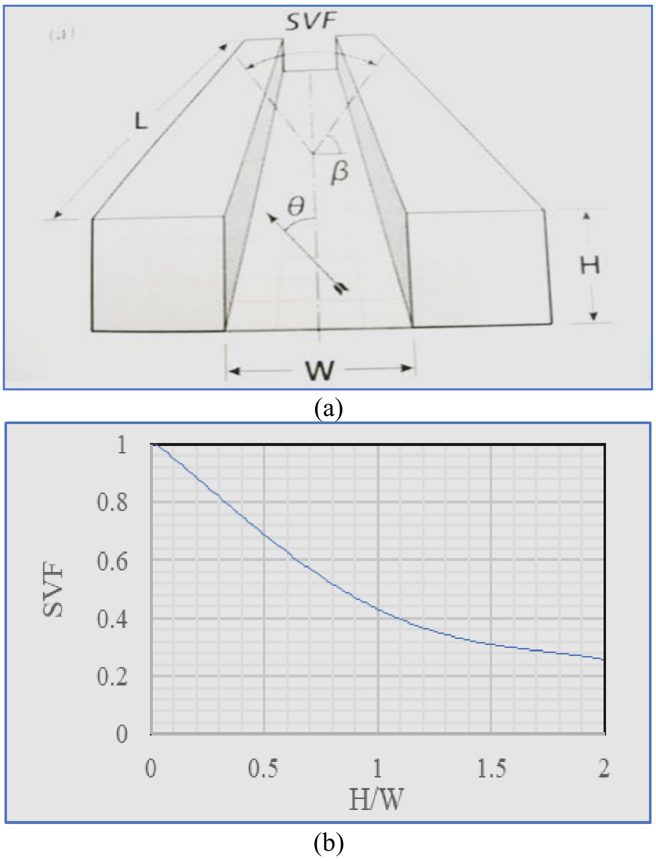


Figure 4. Schematic view of a symmetrical urban canyon and its geometric descriptors (a) and sky view factor (SVF) as a function of the canyon aspect ratio (H/W) (b) [6]

4.2 Indicators of thermal comfort

Human thermal comfort is intricately linked to a psychological state where the sense of pleasure is intricately connected to the surrounding temperature; when it comes to being comfortable outdoors in cities, the most crucial factor is the Mean Radiative Temperature (*TMRT*) [30, 31]. This refers to the combination of long and short-wave radiation that our bodies absorb, significantly impacting how comfortable we feel and our energy levels.

Improving our knowledge of Thermal Mean Radiant Temperature (*TMRT*) reveals its importance in defining human comfort, highlighting the significance of the amount of radiant energy the body absorbs. The Predicted Mean Vote (*PMV*) index is a critical measurement for evaluating external thermal comfort [32], drawing on heat balance and temperature perception factors. It is essential to mention that indices created from human energy balance models, like the Predicted Mean Vote, are very sensitive to the Mean Radiant Temperature (*TMRT*). This highlights the significant impact of *TMRT* on the physiological thermal indices, significantly affecting how people feel and experience thermal comfort [5, 33].

4.3 Summer day evaluation

The microclimate parameters considered the relative humidity and air temperature data on July 12, 2010, on a summer day in Baghdad. The simulation started with the initial setup of a wind speed of 5 m/s and a wind direction of 315 degrees [6].

A simple forcing technique was applied to air temperature and relative humidity for a one-day simulation. This kind of weather pattern matches the sunny weather of the standard summer day, with 50°C recorded as the maximum temperature at 4 p.m. and 35°C as the minimum air temperature was observed at 6 a.m., at 4 p.m., it was observed that the relative humidity was at its lowest point at 24%, and the maximum relative humidity of 36% was recorded at 7 a.m.

The whole simulation time was 24 hours, accompanied by a rotation of our position at 90 degrees concerning the north. A comparative study was carried out on the given day, the summer usual day, comparing the results of air temperature, Mean Radiant Temperature, and Predicted Mean Vote (*PMV*) between the proposed design and the authoritarian model because of the percentages of air temperature at noon and *PMV* were concerned. This study aimed to investigate the kindergarten design's thermal performance on these critical parameters during daytime peak hours.

4.4 Receptor locations

Different receptors were located in various spots, allowing us to assess the broad spectrum of thermal aspects where *TMRT*, *PMV*, air temperature, humidity, *H/W* ratio and wind speed were attractive. *R*1, the first receptor was positioned on the left side so that it was in a shaded area. Correspondingly, the other three receptors—*R*2 at the entrance and *R*3 and *R*4 positioned along walkways—were selected to ensure the measurements were collected in diverse settings, as demonstrated in Figure 5. No receptors are located on the back of the kindergarten due to the location of the fence of the neighbor building and the small attendance of children and visitors in this area through the daytime.

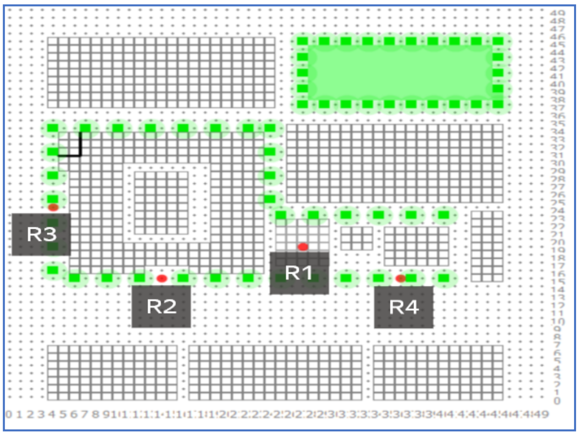
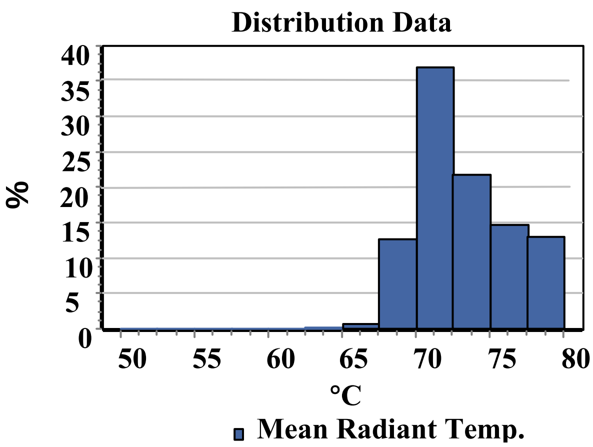


Figure 5. Receptors' locations

As per the data in Figure 6, the proposed model demonstrates a substantial decrease in Mean Radiant Temperature (*Tmrt*) over 41% of the urban area, specifically within the temperature range of 70-80℃. This decline underscores the noteworthy influence of shading components and greenery [34, 35]. The visible effects emanate from heightened shading in walkways and recreational spaces, where the absorption of solar fluxes by walkways and building facades is systematically alleviated. This amelioration is achieved by incorporating lightweight pavement and aluminum cladding in the proposed model (PM).

The Implemented solutions play a pivotal role in augmenting shading features, effectively obstructing the transmission of long-wave radiation among structures, the ground, and the sky. Consequently, this hindrance leads to a consistent reduction in heat absorption throughout the diurnal cycle. Integrating shading elements not only diminishes direct exposure to solar radiation but also cultivates an atmosphere that limits the absorption of solar fluxes. This is particularly salient in walkways and recreational zones, where the proposed model tactically integrates design elements to optimize thermal conditions.

Moreover, utilizing light-colored pavement and aluminum cladding in the proposed model contributes significantly to the overall decline in *Tmrt*. These materials possess lower thermal absorption properties, thus curbing excessive heat accumulation. The resulting positive influence on *Tmrt* spans a substantial portion of the urban landscape, underscoring the efficacy of the implemented strategies in alleviating the adverse consequences of heightened temperatures.



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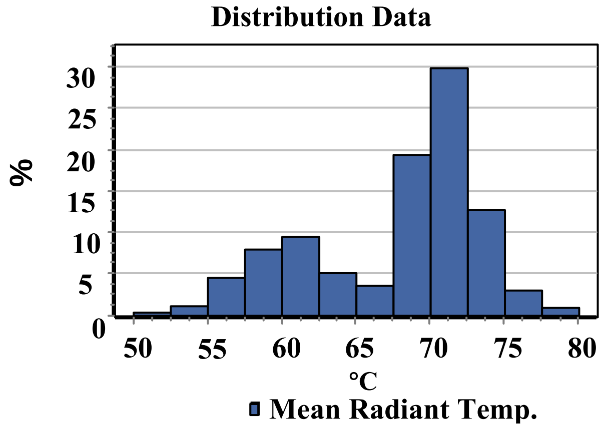
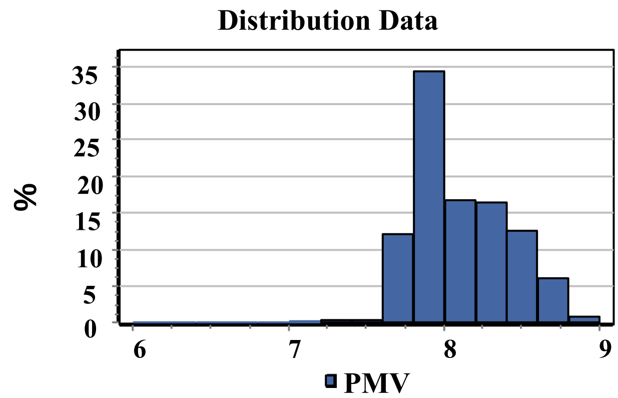


(b) proposed model (PM)

Figure 6. *Tmrt* (%) for kindergarten

As depicted in Figure 7, the contrast is evident. During a typical summer day, the innovative design concept provides notably improved thermal conditions at noon, registering a *PMV* between 6-7.5 for over 36 percent of the time and surpassing 7.5 for 60 percent of the duration. From a mathematical standpoint, these findings are deemed accurate, even though they extend beyond the conventional Predicted Mean Vote (*PMV*) scale typically spans from -4 (indicating very cold) to +4 (indicating very hot) [6]. This departure from the standard *PMV* scale underscores the nuanced nature of the results, capturing a broader range of variations and emphasizing the substantial enhancement in thermal conditions achieved by the new design.



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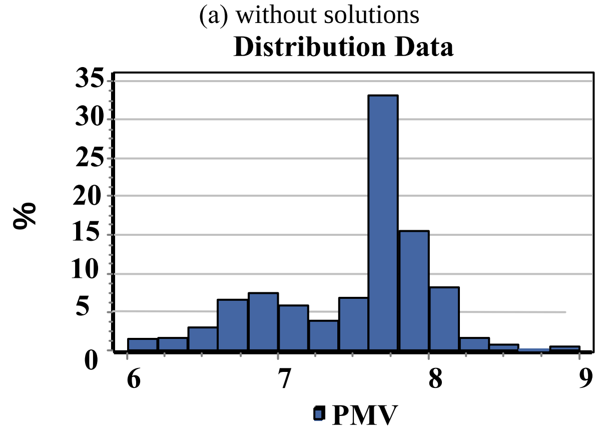
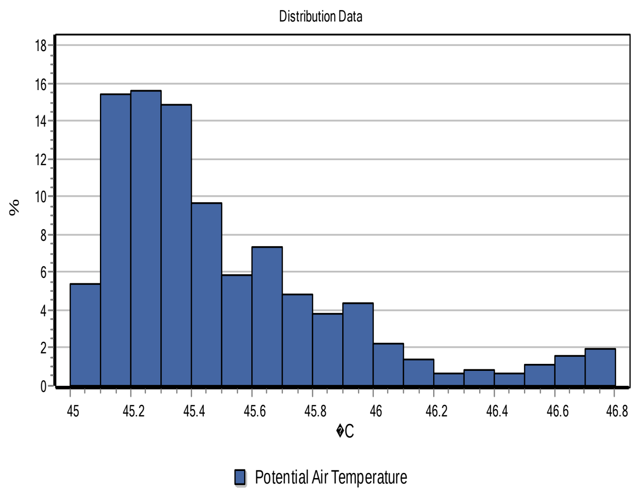


(b) proposed model (PM)

Figure 7. *PMV* (%) for kindergarten

The potential air temperature witnessed a notable decline of 67% when temperatures soared to 45 degrees Celsius or beyond. This is attributable to incorporating measures designed to alleviate thermal effects, as depicted in Figure 8. This decrease serves as a testament to the success of the implemented strategies in mitigating the consequences of heightened temperatures, highlighting a considerable enhancement in the overall thermal environment [36].



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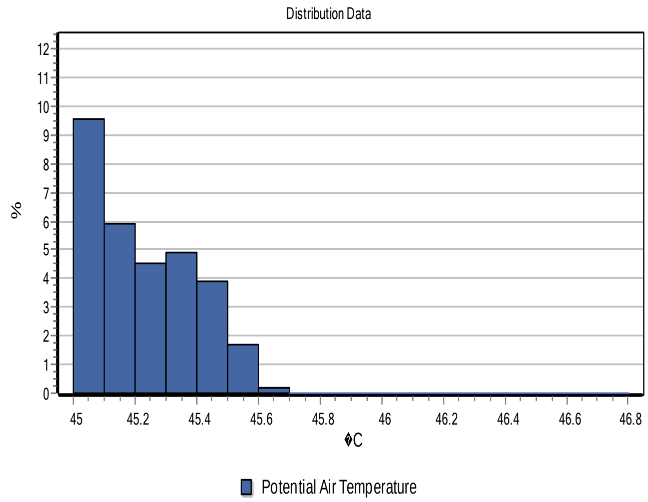


(b) proposed model (PM)

Figure 8. Potential air temperature (%) for kindergarten

Apparent variances in potential air temperature are readily apparent in Figure 9, documented at receptors ($R1$, $R2$, $R3$, $R4$) across three distinct time intervals (10:00 a.m., 12:00 p.m., and 2:00 p.m.). These data points were thoroughly assessed, drawing a comprehensive comparison between the kindergarten setting and the proposed model, which integrates solutions tailored to alleviate thermal effects. Noteworthy is the identification of the lowest temperature recorded at the receptor $R1$, it is situated beneath a steel shade, indicating a reduction within the specified range of (1.7-2.5) degrees Celsius. This specific instance underscores the tangible efficacy of the implemented interventions in effectively mitigating thermal influences, particularly in demarcated zones such as those beneath the designated steel shade [37].

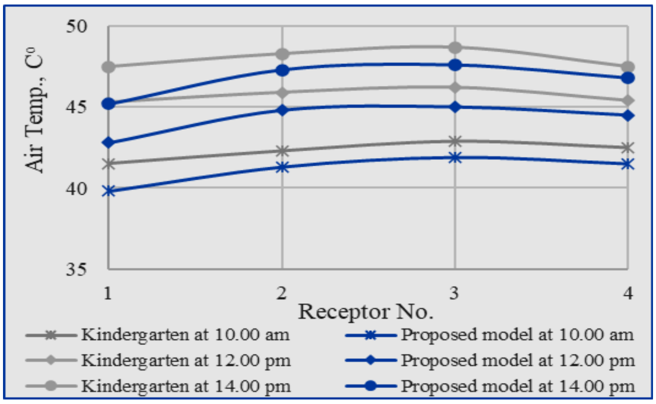
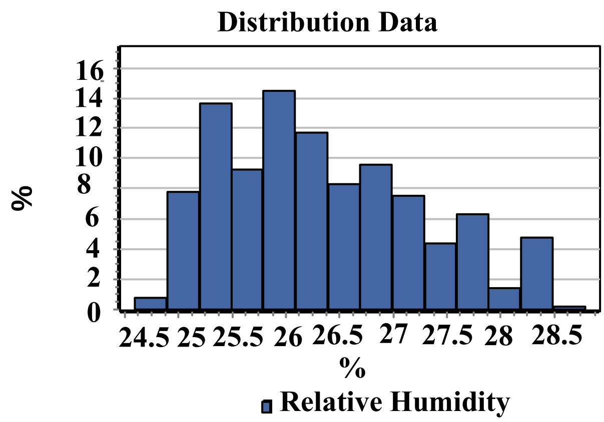


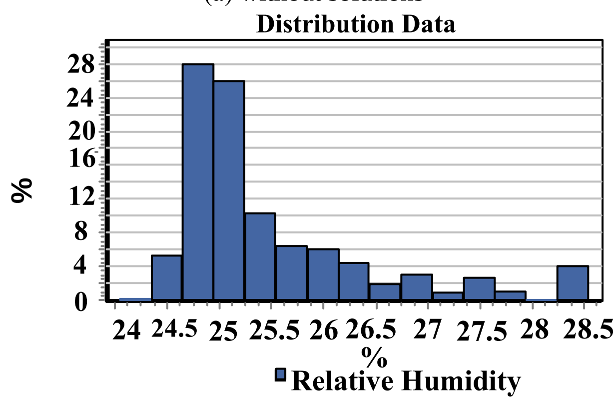
Figure 9. Simulation results of air temperature for receptors at different times

As depicted in Figure 10, the consequences of the implemented solutions in constructing the proposed kindergarten are evident, highlighting a substantial decrease of 59% in relative humidity within the range of (25.5-28%). This graphical illustration emphasizes the success of the employed strategies in regulating humidity conditions, demonstrating a marked enhancement in the overall moisture environment within the newly constructed kindergarten.

Lower humidity widens the temperatures within which individuals find the environment comfortable. In high-humidity conditions, the body's ability to cool itself through evaporation is hampered [38], and people may feel uncomfortable at lower temperatures [39]. On the contrary, individuals may find a broader range of temperatures acceptable in low-humidity conditions.



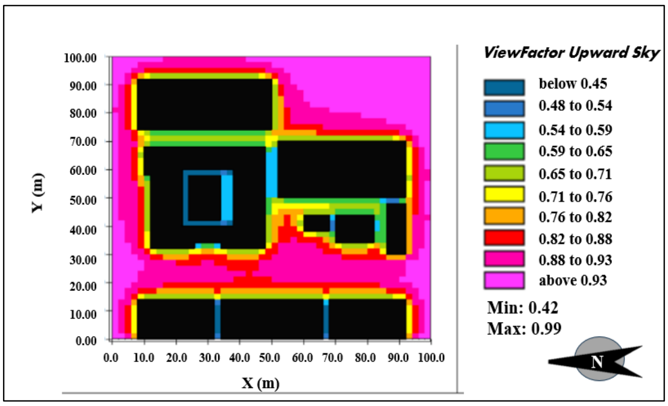
(a) without solutions



(b) proposed model (PM)

Figure 10. Relative humidity (%) for kindergarten

As depicted in Figure 11, a conspicuous observation concerns the Height-to-Width (*H/W*) aspect ratio at an elevation of 1.8 meters within the proposed kindergarten. Through the implementation of solutions geared toward improving thermal comfort in walkways, a notable decrease in the *H/W* aspect ratio is evident, falling within the range of up to 0.69, where the value of the *SVF*<1, it means that the space is obstructed [40]. This contrasts the scenario without these solutions, where the *H/W* aspect ratio extends to 1. The reduction in the sky view factor is ascribed to the strategic integration of shading elements and vegetation [41, 42], prominently exemplified by palm trees. These elements are purposefully introduced to curtail the expanses of open spaces visible to the sky, illustrating a deliberate and effective endeavor to optimize the environmental conditions in walkways [43].



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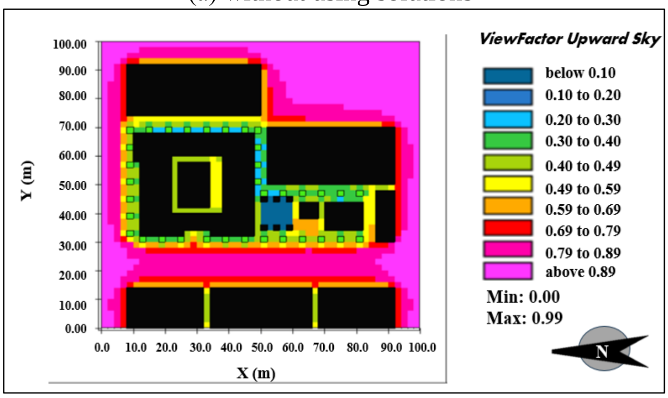

(b) proposed model (PM)

Figure 11. Sky View Factor distribution simulated by ENVI-met at an elevation of 1.8 m

At receptor *R*1, the proposed model has a 40% decline in wind speed within a shaded area compared to a hypothetical scenario where the model is constructed without implementing solutions to enhance thermal effects, as illustrated in Figure 12. This reduction is a consequence of the deliberate introduction of obstacles, represented explicitly by the planned construction of shading structures [44]. These structures impede the wind flow, leading to decreased wind speed at the receptor *R*1. This deliberate adjustment of wind patterns is a crucial aspect of the design approach, considering and dealing with the effects on wind velocity while improving thermal conditions in the specific area [45].

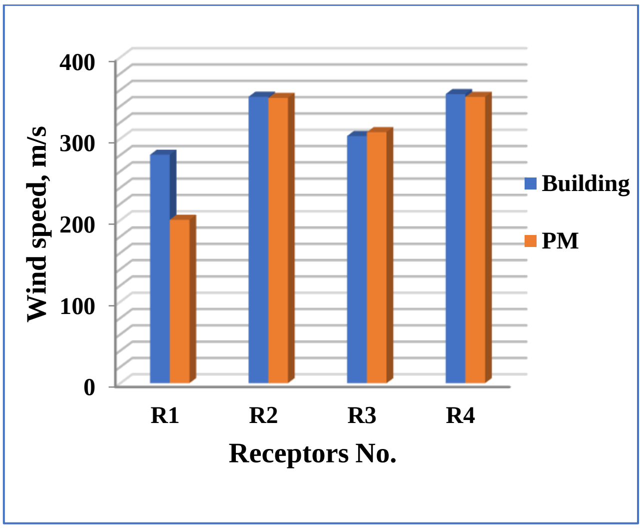

Figure 12. Comparison of results for wind speed at 12.00 p.m. and elevation of 1.8 m

5. CONCLUSIONS

This study highlights the benefits of adopting sustainable construction designs, especially when building kindergartens. By prioritizing eco-friendly practices, we create healthier spaces for our kids to learn and ensure a more sustainable and robust future.

After analyzing the data, it is evident that incorporating vegetation and shading elements during the day dramatically influences the thermal environment. These elements significantly decrease crucial factors like *Tmrt*, air temperature, wind speed, relative humidity, sky view factor, and Predicted Mean Vote (*PMV*). The implications of these findings are clear and undeniable.

The findings demonstrate a significant drop in the mentioned factors for the new model on a typical day. This highlights how specific design features, such as light-colored pavement, aluminum cladding, and the incorporation of plants and shade structures, significantly improve the comfort level in the kindergarten. By systematically using these eco-friendly techniques, we are improving the learning environment and moving towards a more environmentally friendly future for future generations.

The Ministry of Education adopts the results of this study in all its departments as specifications and recommendations during the construction of schools and kindergartens to enhance environmental parameters. The Ministry of Education in Iraq presented valuable assistance by designing and implementing the findings of this study into their proposed kindergarten model.

6. RECOMMENDATIONS

For future studies, schools with more extensive areas containing wide play yards are suggested for analysis in order to assess the increased thermal comfort for older students, in addition, to studying the effects of more ways to improve thermal comfort, such as fountains, green walls, etc.

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