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Improving Bahrain Public Schools' Energy Efficiency: Simulated Case Study

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Abstract—**Introduction: Building operations have a substantial share in worldwide energy consumption. Retrofitting existing buildings is therefore a critical climate change mitigation strategy. This study evaluates strategies for improving the energy efficiency of Bahraini public schools through simulations, aligning them with the Kingdom's energy plan. Methods: An existing Bahraini public school using a widely replicated model was researched as a case study. Its building relied on strategies like shading and thermal mass to cool the building passively; however, it ended up having high mechanical cooling and lighting loads. It was modeled to simulate its energy usage, then had adjustments made to it to see how its energy performance could be improved. Calculations to confirm the viability of using renewable energy sources, and solar power in particular, were conducted. Results: The solution was exemplified in adjusting the building envelope, improving glazing, replacing inefficient appliances, and enhancing internal conditions. Overall, a reduction of 27.3% of energy consumption was achieved, with around 130,000 kWh saved. Additionally, among the possible renewable energy sources for the school, solar power was considered the optimal choice. Calculating energy generation found that it could offset the entire building usage with surplus (affording an extra 67% for the rest of the areas in the school). Conclusion: This study highlighted the importance of simulations in retrofitting. It is recommended that the strategies discussed be applied to schools during maintenance to reap the benefits of the energy conservation. Moreover, applying the study in the real world and testing it on existing schools can help validate its results. Practice implications: Because the school uses a prevalent standard model, the energy efficiency practices presented can be applied to a multitude of buildings across the country.** **Keywords— energy efficiency, passive design, schools, simulation, renewable energy, architecture**

I. INTRODUCTION

Global initiatives to combat climate change are currently focused on energy conservation and CO_2 emissions. As building operations account for 30% of global energy consumption [1], they shape an important part of this equation. As for the Kingdom of Bahrain, its greenhouse gas (GHG) emission plan highlights energy efficiency first and renewable energy integration second as the desirable mitigation plan. Moreover, this includes strategies like applying energy efficiency building codes and managing governmental buildings' electricity [2]. To align with these goals, retrofitting existing public buildings is a strong solution for present energy use.

Retrofitting reduces energy consumption, lowers operating costs, improves internal environments, and helps attain thermal and visual comfort [3]. These qualities are worthwhile for any building, but especially schools, which are used for longs periods of time and are sensitive to indoor environmental comfort levels. Although there is research on school buildings' energy efficiency improvements, it mostly targets European or global contexts [4], with a few studies handling this region and hot-arid climates [5], but none looking specifically at Bahraini schools. Furthermore, older schools in Bahrain, which did not have energy efficiency as a strong priority, followed standard replicated models commonly found in all areas. Therefore, an energy performance improvement applicable to one such school would be a solution that fits numerous others.

This study aims to explore the viability of improving the energy performance of Bahraini public schools with cost-effective strategies, as well as looking at possible renewable energy sources for it.

II. METHODS

A standard public school was selected to be studied and simulated. First, detailed information regarding its architecture and construction was gathered. Then, it was modelled and simulated in DesignBuilder, which is used in similar research [6], to benchmark current electricity consumption. Additional modifications were applied and performance changes monitored for each. Finally, the study considered the feasibility of renewable energy generation on site and the source it would use.

A. Case Study Information

The selected case study is a public school with a site area of 14850 sqm. It was established in 1983, and it features a then-new school design model that was subsequently implemented in other schools with minor differences, becoming the most prolific model. Information was provided and a visit to the school was arranged through the Ministry of Works' Building Maintenance Directorate (BMD).

This 80s school model is an open-courtyard model, where the academic and administrative functions are placed into one building (block 1) with 2 floors and arranged around a courtyard, accessed by external outdoor corridors. It has an approximate built-up area of 3173 sqm. Then, this block is connected to a second 720 sqm block (block 2) with labs and workshops in intermediate and high schools, shaping the basic building structure. Over time, other small blocks, usually composed of 1 or 2 rooms, have been added to the site to accommodate increasing uses, such as the e-learning classroom, as seen in the site plan in Figure 1. The study mainly focuses on blocks 1 and 2, the large connected blocks, and their designs.

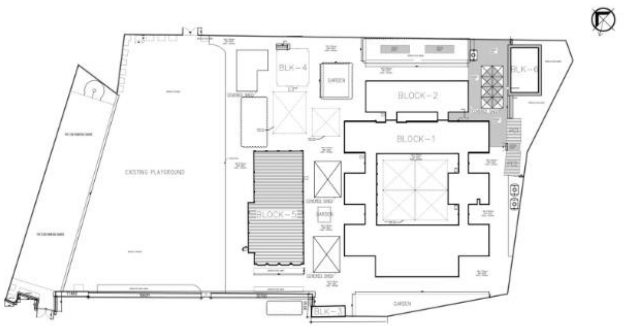

Fig. 1 Site plan of the selected case study school, provided by the BMD, Ministry of Works.

B. *Case Study Analysis*

The main energy saving measures used in the building are passive design solutions for reducing heat gain. Firstly, there are many windows used in the building. Each classroom has windows on 2 sides, one with clerestory windows facing the external corridors and receiving diffused light, and the other having the main windows. As they face the Northeast and Southwest directions, these windows have both vertical fins and metal reflector strips to reflect light away from the class. Curtains are employed when needed to control glare. Other shaded areas include the outdoor assembly area, which is completely shaded with fabric shading. Seating is partially shaded too, and there are landscaped areas, although not many of them. Additionally, all external corridors are shaded by the slabs above and naturally ventilated, and although they have lights, they are never required. Double-loaded corridors are rare, and on the one instance they are used, the roof is raised on two parts to allow for indirect roof lighting. All of these measures ensure the building receives daylighting while preventing glare.

The building is constructed completely with precast concrete systems, including floor slabs, structural columns and beams, and wall panels. All of these grant the building thermal mass to store heat and regulate indoor temperatures. For flooring, the terrazzo tiles also have a high thermal mass, in addition to having a high solar reflectance index (SRI) and durability, reducing maintenance needs and making it a sustainable choice. For walls, they are left exposed and painted with light shades only, with a mix of matt ang glossy washable finish. As for ceilings, they are left exposed to facilitate thermal massing. Unfortunately, a downside of this construction method is that when HVAC units became a must, they could not create large holes to fit in the window ACs and resorted to taking up a large portion of the windows area, and the windows ended up small. Additionally, windows used are single-paned glass (6mm), and no insulation is included. All in all, the architects and engineers played into the strengths of the construction system.

By these metrics, the simulated total energy usage per year is 474944 kWh. 63.9% of this is cooling loads, and 12.3% is lighting, for a total of 76.2% that can be adjusted with envelope design.

III. Simulation Results and Discussion

A. *Building Envelope and Insulation*

Adding insulation to the exterior envelope is the first order of business for any building and this building in particular. Starting off with the exterior wall, the use of Expanded Polystyrene (EPS) insulation was simulated, as it is well-known to have great thermal properties while being lightweight [7], and also being cost-effective and readily available in Bahrain. Combining it with an airgap produces even better results for longevity and performance (even in ducts [8]). Adding an additional 100mm to the wall, a vastly lower U-value was achieved, matching Bahrain's green building code requirement of 0.57 W/m2*K. Other research discusses insulation and cladding that is more suitable for hot climates; for instance, Abu Dabous et al (2022) [9] show that stone cladding with mineral fiber insulation works best. Stone cladding also has better longevity. To test this out, these materials were used to get the same wall thickness (300 mm). This wall did have a lower U-value (table 1), but compared to the cost and material weight, it is not well-justified. In addition to that, the airgap provides other benefits, such as sound insulation, which is useful for classrooms' acoustic insulation too. Thus, the first insulation choice is more economical, saves better energy, and has more functional value.

The next thing to do was fix the roof insulation. As seen from the heat balance graph, a large source of heat gain was the roof structure, which was not properly insulated. To combat this, 200mm glassfiber batt insulation and a highly reflective paint coating (high SRI) were added on the roof. The sample paint had a solar reflectance of 0.95 and a solar reflectance index value (SRI) of 122. This took the roof structure to a U-value of 0.195 W/m2*K, less than 0.3, Bahrain's green building requirement.

B. *Window Adjustments*

Moving on to the windows, because the original windows were old single-paned windows, they were changed to double-paned, with each panel being 6mm thick and having an airgap of 13mm for a total of 25mm. The panels specified were also of low-e clear glass. Furthermore, the overall glazing area is also increased by removing the window AC units (discussed in the next point). Having clear glass also helps raise the illuminance levels inside.

C. *Energy Efficient Appliances*

Next, measures to increase the efficiency of electricity and energy usage were considered. One simple solution is to replace fluorescent lights with LED lights that have better energy efficiency for the same levels of lighting [10]. The next issue relates to AC units. As mentioned earlier, a part of why the windows were smaller currently is because of the window AC units (unitary AC) taking their area. In comparison, split units only need a small pipe connection through the wall to connect the outdoor compressor and indoor evaporator. This small hole can be more easily accommodated.

TABLE I. Wall Layers and Components with Their Corresponding U-Value.

Wall Type	Wall Components				U-value (W/m^2* K)
Normal	Precast concrete 200mm	---	---	---	0.704
With insulation	Precast concrete 200mm	Airgap 25mm	Expanded polystyrene 70mm	Plaster 5mm	0.277
With stone cladding	Precast concrete 200mm	Miner-al fiber 90mm	Tufa (sandstone) 10mm	---	0.253

Not only that, but split AC units are more energy efficient compared to window units. After applying the previous changes to materials, the annual energy used reached 369711 kWh, and after changing the HVAC to split units, this number dropped to 354941 kWh, saving 14770 kWh energy annually.

D. *Internal Environment*

Then, possible material changes were looked at. In the classroom, to help reflect the light deeper inside, high reflectance paint and light-colored coatings were employed here too. This is because it was not possible to further increase window areas, so the next solution would be to have the existing light penetrate deeper inside. The same paint type used on the roof is used here (with a reflectance of 0.95). This high reflectance has also improved energy usage from the aforementioned value to 344940 kWh. Also relevant is the fact that this paint (and similar ones) has an extremely low level of volatile organic compounds (VOC). Traditional paint has high VOC levels that affect the indoor air quality. Therefore, it is important to use materials with low VOC and emittance for health and sustainability.

Overall, the project was able to improve its energy usage from the initial value of 474944 kWh annually to 344940 kWh, reducing 130004 kWh, or 27.3%, of the original usage. This includes improvements to daylighting, heat gain, and cooling loads, as radiant temperatures dropped significantly. Cooling now contributes to 56.7% of total energy use, whereas lighting now accounts for 11.5%, reducing the contribution of both (values in Fig 2).

The most influential change was the window change, which reflects the extent of heat gain from them even within a small area. Therefore, it also highlights the importance of efficient treatments for it. Moreover, it can be seen that cost-effective strategies can sometimes fulfil much of the required improvements without needing to resort to high-end solutions, as tested on the wall treatment. Not only was there a diminishing return, but taking the affordable option allow these changes to be applied to a larger number of buildings around the country, causing an overall lowered energy usage. Changing the AC units to split type was especially effective as well in this context due to it taking up window space. Thus, with the previous glazing adjustment, changing them increases natural lighting and comfort in addition to reducing lighting and cooling electricity usage, achieving two goals at once.

E. *Renewable Energy*

To devise a strategy for renewable energy, possible different sources were considered first and judged on their suitability to the project and feasibility of use.

Wind is a strategy Bahrain is currently [11], but it is unsuitable for this use. First, the rooftop height in schools' 2 storey buildings does not exceed 10m, resulting in low wind speeds. Moreover, urban areas usually have increased turbulence due to the presence of buildings. Turbines also cause safety concerns and noise issue, which is undesirable for a school with children and teenagers. Regardless, wind is generally not too strong in Bahrain and produces less electricity per Megawatt (MW) than solar panels [11], and the existing site conditions exacerbate the problem.

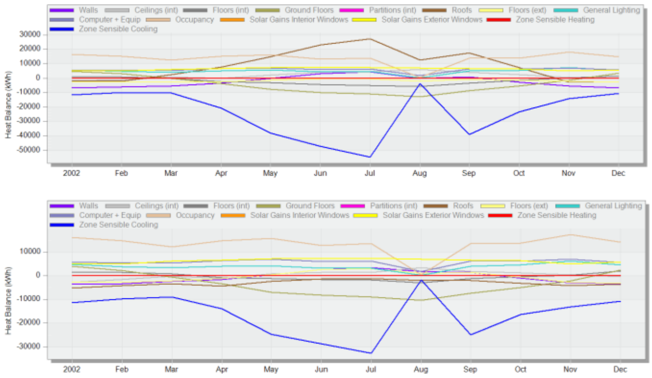

Fig. 2 Heat balance graph before (top) and after (bottom) modification, with reduced heat energy entering and resulting reduced cooling loads.

Thus, the final and optimal choice was solar power. Solar power is best because the sun exposure is high in Bahrain and the site area is unobstructed. Usually, schools are built in areas with low building heights (such as residential buildings), so no buildings nearby shade it. The rooftop is mostly not used except for one small area with water tanks and two small raised lighting areas for the double loaded corridor. Overall, the area has good potential for solar panels. Another benefit is that this could be integrated in the curriculum too, as students visit it to learn directly about energy, while providing good energy gains and bill savings at same time. Cleaner staff employed already can be trained to clean dust from panels at scheduled times. Not to mention, school use time coincides with peak solar gain, so energy can be used immediately and not stored. If there is excess, it can be sold to the grid.

F. *Solar Energy Calculation*

Considering the empty rooftop area of 2084 sqm with 15% circulation, an area of 1667 sqm can be used for solar panels. For the selected high efficiency PV panel from SolarOne (a local company), the area is 2.2 sqm per unit, and the efficiency is 20.37%. Notably, while the maximum monthly consumption of electricity can be accommodated with 249 panels, the actual number that can be fitted on the roof is 757 panels, far exceeding the requirements (as seen in table 2 below). This results in covering all costs and energy usage (100%) in addition to generating a surplus to be sold or stored, confirming that solar panels are the best choice for this site.

IV. Conclusion

This study analysed an existing school model in depth and simulated energy conservation methods for it. Although the 80s building model present in the case study included thermal mass and shading, its limitations were its lack of insulation and fully precast construction technique, limiting the choices for affordable changes (such as having larger windows). The end solutions were able to mitigate 27.3% (130004 kWh) of energy consumption, providing significant energy savings. This reflects the effectiveness of simulations to test retrofitting strategies. The study recommends the following:

- Performing simulations to justify possible adjustments applied in retrofitting, especially in challenging cases,
- Implementing the solutions presented in the study whenever possible in routine maintenance to increase energy efficiency and reduce costs in the long-term,
- Incorporating applied solutions in the educational curriculum to increase awareness in children,

TABLE II. SOLAR PANEL OUTPUT AND SUITABILITY CALCULATION.

Calculated item	Value
Total annual electricity consumption	344940 kWh
Number of solar panels for the available area	757 panels
Total cost of installation	75700 BHD
Total production per year for all solar panels	1262998 kWh
Surplus Production	918058 kWh
Yearly income from selling surplus production	26624 BHD

- Ensuring new buildings meet green building standards before being built,
- Testing the solutions' effects on an actual school building to validate the study.

LIMITATIONS

To the best of our knowledge, this is the first study that simulates retrofitting strategies for public schools in Bahrain. It shows promising results that could be applied on larger scales and different typologies in the future. Nevertheless, there are limitations. The study explores one building only with a simulated energy usage, as the author did not have access to actual usage data, which might impair generalization of the results to other buildings.

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