Building Envelope Thermal Upgrade for School Buildings in Jordan

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Abstract. Following the educational reform in Jordan in 2003, the government decided to cease the construction of old, prototypical, and uninsulated schools in favor of thermally insulated site-specific buildings. However, more than 2917 uninsulated school buildings built before the reform have continued to function. Therefore, this research focuses on evaluating and comparing the thermal efficiency of the envelope of old, uninsulated prototypical schools with that of thermally insulated, site-specific school’s buildings in Jordan. Furthermore, it will develop envelope retrofit strategies for the remaining 2917 uninsulated schools. The proposed envelope retrofit alternatives will be analyzed in terms of potential energy saving and initial cost, based on which a holistic approach is developed by combining energy-efficient and economically feasible retrofitting alternatives. The research here uses mixed design methods to fulfill its purposes, including data collection from the literature and national archives, self-reported data, field monitoring of environmental parameters inside classrooms, and energy simulation using (Design Builder) software, in addition to economic analysis using the simple payback period analyses method. Based on analyses, a holistic approach to envelope retrofitting was developed for old governmental school models in Jordan, based on an analysis of the effects of the enhancement of envelope parameters on annual cooling and heating energy saving (walls, roof insulation, roof reflectance, windows, and shading elements). The proposed alternatives to envelope retrofitting for each envelope parameter was analyzed in terms of potential energy saving and initial cost analysis.

1. Introduction
The challenge of achieving sustainable development in construction in the 21st century can be met only if policymakers believe that retrofitting existing buildings can deliver sustainability in the resulting built environment [1]. This accurately describes the current dilemma in sustainability: with a large amount of research focused on the potential for energy saving for future construction projects, existing buildings contribute to the largest portion of worldwide energy end use, and are responsible for approximately 40% of the world’s energy consumption [2]. Power clarified this issue by stating that “new buildings add to buildings stock at most 1% a year, whereas the other 99% of existing buildings are already built, and produce 27% of all carbon emissions around the world.” Meanwhile, the current rate of retrofit for existing buildings does not exceed 1%–3% per annum [3, 4], which renders the existing building stock the key target for energy-efficient interventions.

Doglas (2006) has claimed that the definition of retrofitting is derived from that of adaptation. He defined building retrofitting as “any work to a building over and above maintenance to change its
capacity, function, or performance”—in other words, any intervention to adjust, reuse, or upgrade a building to suit new conditions or requirements [5, 6]. While retrofitting implies building enhancement, upgrade, and alterations to suit user needs, the concept has recently been strongly correlated with sustainability through “sustainable retrofitting”, which can be defined as a capital improvement with an associated cost that resets the life of the building, improves its performance in terms of energy consumption, and makes the building use more predictable for an extended period of time [7].

In Jordan, there is an urgent need to retrofit existing governmental school buildings. Jordan is a developing country located in the Middle East with an area of 89,342 km². The country is divided into 12 states, where Amman is the capital and most populous city housing 42% of the population [8]. The population of Jordan was 9.53 million in 2016, increasing at an annual rate of 2.2%, with approximately 82.3% living in urban areas [6, 8]. In addition to natural population growth, Jordan has witnessed a tremendous influx of refugees. Approximately 54% of these refugees are children below the age of 18. In 2013, of the estimated number of Syrian refugees, approximately 187,675 were school-age children, and this number continues to grow [9].

More than 75% of existing governmental school buildings in Jordan built before the educational reform are not thermally insulated [10]. Therefore, there is need for research on the potential for envelope retrofitting in them in light of Jordan’s hot arid climate. The purpose of this research is to compare and evaluate the thermal performance of the envelope in prototypical governmental schools built before 2003 with new, site-specific schools constructed with the help of donors following the reform. Furthermore, this study aims to develop an economically feasible approach to envelope retrofitting for uninsulated schools that can maximize energy efficiency within the limited budget afforded to governmental schools.

2. School Buildings in Jordan

Jordan has witnessed significant reforms and changes in its educational system that has influenced the construction of governmental schools. The Ministry of education (MOE) in Jordan divides schools into three categories: governmental, private, and UNURWA (United Nations Relief and Works Agency for Palestine Refugees in the Near East). In total, there are over 6,802 school buildings in the country, 3,864 of which are governmental schools accommodating 1,295,982 students (MOE, 2015). Governmental schools in Jordan are either funded by the MOE, other Jordanian government organizations (JGO), or non-government organizations (NGOs).

As for governmental school buildings in Jordan, before 2003, all schools were constructed to follow one of the standard MOE prototypical designs, where all models had a linear classroom layout that could be arranged around a double- or a single-loaded corridor in contact with the exterior building envelope. The envelope design and building construction materials in the prototypical models were somewhat similar owing to limited financial resources, given that they did not incorporate any kind of thermal insulation on the walls or roofs [7]. However, after the Vision Forum for the Future of Education in Jordan held in September 2002, the MOE released the Education Reform for the Knowledge Economy Program (ERfKE) [10]. It set out in detail plans for overall reform within an extensive and inclusive framework. A major component of this reform concerned with school buildings was improvement in the physical learning environment, as The MOE stopped the construction of prototypical school models and started building site-specific schools with upgraded architectural specifications. Since then, the number of governmental schools in Jordan has increased from 2719 in 2005 to more than 3864 in 2015 [11]. According to the Department of Statistics, 40–70 new schools have been constructed annually from 2000 to 2012 [12].

Totally over 2917 governmental schools [11]), old schools built before the 2003 educational reform can be further divided into two sections: schools built in 1960–1970 and those built in 1970–2000 [8]:

- 1960–1970: Small-scale school buildings consisted mainly of classrooms with no insulation on the walls or roofs, built by the Ministry of Municipalities in Jordan.
- 1970–2000: The MOE adopted the construction of large-scale prototypical school buildings from the first Hai Nazal up to the seventh prototype based on school type. The final prototype used in
the construction of prototypical school buildings was the sectoral prototype in 2000. Although these schools had more functional spaces than previous ones, the envelope was a simple concrete block configuration with no insulation material in the walls or roofs.

In response to the 2003 ERfKE (Education Reform for the Knowledge Economy), the MOE in collaboration with NGOs launched the construction of new school buildings with enhanced physical characteristics. Unlike the old prototype, the layout of the new buildings did not follow any specific prototypical design. Schools were planned instead to suit the site configurations [8]. With regard to the elements and specifications of the envelopes, although the MOE worked on a guideline for school design, it was not formally published. Consequently, the materials, architectural details, and envelope configurations incorporated into the new schools followed donor guidelines and standards [8]. In light of the limited budget of the MOE, many non-government organizations (NGO) have offered initiatives supporting the construction of new schools [10].

With the construction of new site-specific insulated schools in Jordan, the cost of the construction of new schools has increased annually [10]. However, no study has been conducted to compare the thermal efficiency of the envelope in old, prototypical school buildings built before 2003 with that of the new site-specific schools built after. Furthermore, considering that the old school buildings constitute approximately 75% of governmental schools in Jordan [11], no study to date has been conducted to evaluate the energy-related and economic feasibility of envelope retrofitting in existing, uninsulated school buildings.

3. Methodology

The research problem is to develop an energy-efficient and economically feasible approach to envelope retrofitting for governmental schools in Jordan’s hot arid climate based on the analysis of thermal comfort and energy efficiency of certain old and new school buildings.

For the above purposes, relevant data was first collected by reviewing the literature related to building retrofitting, envelope retrofitting strategies, and economic theories related to the feasibility of investment in retrofitting. Furthermore, the Ministry of Education and the Ministry of Public Works and Housing (MOPWAH) provided as built drawings and architectural specifications for the selected old governmental school whereas those for the new school considered were obtained from the relevant design consultants and the MOPWAH. Additional information was obtained from on-site observations, and interviews with architects and decision makers in the school building sector.

The second stage consisted of developing base case models for both schools based on the operational and physical parameters obtained in the initial stage. The base case models for both schools were thermally simulated using the Design Builder (DB) software. The thermal efficiency of the envelope in both schools was first gauged by a comparative study of their indoor thermal environments. Another method used to evaluate the thermal efficiency of the envelope in both schools was based on comparing their annual energy consumption for cooling and heating obtained from the Design Builder simulation, based on the results of this stage. Design Builder was used to assess the impact of various envelope parameters enhancements on annual cooling and heating energy saving in the old school model. Furthermore, the simple payback period analysis (SPPA) was performed to evaluate the economic feasibility of proposed envelope retrofit alternatives. Moreover, a holistic approach to envelope retrofitting was developed to attain the dual goals of energy efficiency and economic feasibility. Finally, the application of the proposed approach to envelope retrofitting was studied on old school buildings with different expected lifespans and compared with new schools construction in terms of energy saving and initial cost.

Data collection for the old and new government schools that were chosen. This can be divided into two sections, information related to the physical and operational characteristics of the selected schools, and field measurements of environmental parameters inside classrooms.

Base case models were developed for the selected schools. The physical and operational data obtained in the previous stage were used to generate base case models using the DB simulation program.
In this stage, thermal conductivity values (U-values) for the elements of the school envelope obtained through the simulation were compared with the minimum Jordanian code requirements. A comparison of annual energy consumption for cooling and heating was conducted between classrooms of the old and new schools. In the second step, a simulation was carried out to generate the annual energy consumption for cooling and heating for classroom zones (in kWh). For the purpose of comparison, the results were normalized according to the area of classroom zones (and determined in kWh/m²). The electricity used for lighting and other appliances was ignored in this study. Only the annual energy consumption in classroom zones for cooling and heating the building was calculated. Annual energy use profiles were validated based on the study [7].

4. Results and Discussion

4.1. Energy Use Assessment–Energy Consumption for Heating and Cooling
Evaluating the thermal efficiency of the envelopes of the schools involved the assessment of the annual energy used for cooling and heating in both schools. Classroom zones were considered as active energy-consuming areas only during the periods that they were occupied.

Figure 1 shows the annual energy consumption for cooling and heating, and the total energy consumption in kWh/m² for both schools in their original orientation (N–S/15º tilt).

From the above simulation results, by comparing annual energy consumption for cooling and heating in both schools, it was found that:

- Annual energy consumption for cooling in the new Abu Alanda School was 50% less than that in the old school.
- Annual heating energy consumption in the new school was 60% less than the old school.

In total, the new Abu Alanda School consumed 52% less energy for cooling and heating than the old one. Although no data were available for annual energy consumption for cooling and heating in classrooms of either school owing to the absence of active cooling and heating systems, for the old Abu Alanda School, the results of energy use were validated based on the work by Menassa [7], who used parametric simulation analysis (merging possible design parameters into all possible combinations) to run the
simulation over 108 school models. They found that a typical government school in the north–south orientation consumed 33 kWh/m² for cooling and 11 kWh/m² for heating, which was close to the annual energy consumption for cooling and heating found for the old Abu Alanda School in this research.

4.2. Effect of Schools’ Envelope on Annual Energy Consumption for Cooling and Heating

To assess the effect of the envelope only on the resultant energy saving for cooling and heating in the new school compared with the old one, the parameters of the base case model of the old school (Table 1) were assigned to those of the new one. Applying the experimental design approach and changing one parameter at a time, it was possible to estimate the impact of changing each parameter (to match the original base case model) on energy saving for cooling and heating. Table 1 summarizes the parameters of the base case model in the old and new schools as well as the effect of each parameter on energy saving for cooling and heating in the new Abu Alanda School compared with the old school.

Table 1. Effects of parameters of the new Abu Alanda School base case model on cooling and heating energy saving (compared with the old Abu Alanda School).

| Base case parameter | Old Abu Alanda School | New Abu Alanda School | Cooling energy saving (%) | Heating energy saving (%) |
|---------------------|-----------------------|-----------------------|---------------------------|---------------------------|
| Walls               | Concrete solid blocks (no insulation; U-value, 1.38 (W/m² k)) | Concrete blocks, 5 cm polystyrene insulation; U-value, 0.46 (W/m² k) | 4.19 | 25.12 |
| Roof                | Reinforced concrete, screed, and tiles (no insulation; U-value, 1.1 (W/m² k)) | Reinforced concrete, foam concrete screed, and DPM; U-value, 0.44 (W/m² k) | 7.12 | 19.68 |
| Glass               | Single-glazed windows; U-value, 5.77 (W/m² k); SHGC, 0.81 | Double glazed windows; U-value, 2.66 (W/m² k); SHGC, 0.70 | 4.13 | 14.09 |
| Frames              | Aluminium frames      | Aluminium frame, thermal break | 1.2  | 1.9  |
| WWR                 | 30%                   | 25%                   | 2.33 | -1.99 |
| Louvers on south    | No louvers on south side | 120 mm louvers on south side | 1.03 | -0.76 |
| Louvers on north    | No louvers on north side | 60 mm louvers on north side | 9.13 | -7.16 |
| Internal windows    | No internal windows   | Single-glazed internal windows | 7.23 | -2.28 |
| Floors              | Heavy concrete slab 20 cm | Heavy concrete slab 30 cm | 0.23 | 8.45 |
| Partitions          | 10 cm brick          | 15 cm brick          | 0.34 | 1.7  |
| Infiltration        | 1 ach/h              | 0.5 ach/h            | 5.04 | 6.34 |
| Layout              | Simple rectangular building | Three masses projecting from horizontal mass | 3.15 | -1.21 |
| Occupancy           | 0.90                 | 0.75                 | 5.13 | -3.8 |
| Total energy saving (%) |                      |                      | 50% | 60%  |

Installing 12-cm louvers on the south elevation of the new Abu Alanda School made the highest contribution to energy saving for cooling, 9.1%. This is owing to the shading effect in the blocking of direct sunrays in the afternoon hours. However, installing shading louvers in the new school increased annual consumption for heating by 7.1%, which indicates that using rotating shading devices is more feasible in hot and arid climates. However, considering the low budget allocated to government schools,
a lack of maintenance, and low heating energy costs in Jordan, the increase in demand for heating can be compromised by saving on energy consumed for cooling.

The internal windows in the new Abu Alanda School had the second-highest impact on energy saving for cooling, 7.2%, with a slight increase in demand for heating, 2.2%. However, internal windows promoted cross-ventilation in the summer and contributed slightly to a rise in demand for heating during the winter. The use of double-glazed window panes in the new Abu Alanda School (U-value, 2.66 W/m²k; and solar heat gain coefficient (SHGC), 0.7) instead of single-glazed window panes in the old school (U-value, 5.77 W/m²k; SHGC, 0.81) resulted in energy saving for cooling and heating by 4% and 13%, respectively. This indicates that lowering the U-value has a significant impact on energy saving for heating. However, a reduction in the energy used for cooling depends mainly on the SHGC.

The configuration of the wall and the addition of a 5-cm thermal polystyrene insulation in the new Abu Alanda School had the highest impact on energy saving for heating, 24.1%. Moreover, it contributed 4.1% to the resulting energy consumed for cooling, which indicates the importance of exterior wall insulation for energy saving on heating during the summer months in Amman. Roof insulation in the new school had the second-highest impact on energy saving for cooling and heating – 7.1% and 18.6%, respectively. This agreed with the study by Menassa [7], that had investigated the effects of roof insulation on annual energy consumption for cooling and heating in residential buildings in Jordan. This study found that insulating the roof with a 5-cm insulation reduced annual energy loads for cooling and heating by approximately 29% in Amman and 24% in Aqaba. Consequently, roof insulation is recommended to save energy used for heating in hot and arid climates.

In conclusion, by analyzing the effect of the relevant parameters of the new school building on energy saved for cooling and heating, it was found that enhanced envelope parameters made the highest contribution to this in the new Abu Alanda School (66%), followed by the reduction in infiltration in the new school (10%). The layout of the school building and its configuration had only a 4% effect on total energy saving. Consequently, envelope retrofitting in school buildings in Jordan can have a vital impact on energy saving for cooling and heating. Furthermore, the internal windows had a 9% effect on total energy saving. Thus, enhancing cross-ventilation through internal windows can also contribute to total energy saving.

4.3. Developing Envelope Retrofit Strategies for Governmental Schools in Jordan
The second aim of this research was to develop a holistic approach to envelope retrofitting for typical government school models in Jordan with a focus on reducing annual energy consumption for cooling and heating in classrooms in an economical manner. Seven envelope retrofit strategies were investigated: thermal insulation of the walls and roof, roof absorbance, adding window films, window replacement, and adding solar heat gain control systems. The proposed retrofit alternatives for each parameter of the envelope were studied in terms of potential energy saving for cooling, heating, and initial cost. Simple payback period analysis (SPPA) was used to evaluate the economic feasibility for each of the alternatives. The following was found:

Wall retrofitting: Nine wall retrofitting alternatives with different U-values were analyzed in terms of energy saved on cooling, heating, and payback period. Although lowering the U-value of the exterior wall had a positive effect on annual energy saving on heating and cooling, it had a much higher impact on heating rather than energy saving for cooling in mixed climatic zones, such as Amman. Furthermore, based on SPPA and annual energy saving, adding 100 mm of EPS insulation boards is recommended for wall retrofitting as it can save 12% in total energy saving, and incurs a considerably short payback period of 9.1 years.

Roof retrofitting (insulation): Nine roof retrofit alternatives with different U-values were analyzed in terms of cooling, heating, total energy savings, and payback periods. As in the case of the walls, it was found that lowering the U-value of the roof has a much higher impact on heating rather than energy saving for cooling in mixed regions such as Amman. However, total energy saving for cooling from roof insulation was slightly higher than that for cooling from insulating the external walls. Furthermore, based on SPPA and annual energy saving, adding 100 mm of EPS insulation boards is recommended
for roof retrofitting in governmental schools as it saves 12.6% of energy, and has a considerably short payback period (6.5 years).

Roof retrofitting (reflectance): The impact of adding white tiles (R = 0.7) and light-coloured tiles (R = 0.6) on the Abu Alanda School model was analyzed in terms of energy saving and payback period, and both led to an increase in annual energy consumption for heating. However, this increase is justified by the resultant energy saving for cooling and low energy prices for heating in Jordan. Furthermore, white tiles are recommended for typical governmental schools as they yielded 8.6% in annual energy saving, and have a short payback period of 2.2 years.

Applying window films: Applying window films of varying SHGC values was analyzed in terms of cooling, heating, and total energy saving. It was found that increasing the SHGC has a positive impact on energy saving for cooling and a negative impact on heating. Furthermore, SPPA of the window film with an SHGC of 0.35 proved to have the shortest payback period of 3.3 years and the highest energy saving of 10%. However, it had a light transmittance of 0.6, which is not recommended for school buildings. Consequently, applying window films with an SHGC of 0.46 is recommend for school buildings as it has a considerably short payback period of 5.8 years and high energy saving of 7.7%.

Adding fixed solar heat gain control system: adding fixed shading system (horizontal overhang, 100 cm) on south elevation of the existing school was analyzed in terms of energy saving on cooling and heating, fixed shading system contributed to an increase in the demand for energy for heating, which can be justified either by the low cost of energy for heating in Jordan through SPPA, or by using adjustable shading devices, which is not recommended in school buildings. SPPA was performed, it was found that applying horizontal overhangs of 100 cm on the south elevation leads total energy saving of 12.8% with a payback period of 5.3 years. Furthermore, applying fixed shading systems on the north elevation is not economically feasible owing to its minor impact on annual energy saving.

Combination scenario: The impact of combining the proposed envelope retrofit alternatives from analyzed strategies was studied to assess the energy that can be saved on cooling and heating as well as the total energy that can be saved, to develop a holistic approach to envelope retrofitting. A combination-based scenario can save 59.2% annually for cooling and 36.4% for heating. Furthermore, applying the proposed envelope retrofitting approach to the old government school model can lead to 54% in annual energy saving, and has a relatively short payback period of 5.5 years.

Considering that the retrofitted buildings have limited expected lifespans, the study compared (A) building new classrooms of an area 800 m², with (B) retrofitting the existing classrooms of the same area in terms of total investment and total energy saving over the expected lifespans, and found:

- To retrofit the existing school classrooms with an expected lifespan of 25 years, total saved energy cost was four times higher than the initial investment in classrooms retrofitting. Consequently, retrofitting schools with expected lifespans of 25 years is recommended.
- To build new classrooms with an expected lifespan of 50 years (design/theoretical expectation), the total cost of energy saved, 194,800 JD, was still less than the initial investment for building new classrooms, 280,000. The cost of new structure will be much more expensive in terms of the cost of land, materials, and labor.

Although based on the above results, retrofitting existing school buildings with expected lifespans of 25 years is economically feasible, given that existing school buildings in Jordan were built in 1970–2000; the study investigated the economic feasibility of retrofitting classrooms of schools constructed in each of the relevant decades. The following was concluded:

- The feasibility of envelope retrofitting of government schools in Jordan depends upon expected lifespan.
- It is not economically feasible to retrofit classrooms of old government school models built before 1970 as the total investment of 24,474 would be almost twice as high as the cost of energy saved, 13,354.5, over the expected life service (three years).
Retrofitting classrooms of old government school models built after 1980 (13 years’ expected lifespan) is feasible as the cost of energy saved, 57,869.50, is more than twice the initial investment on retrofitting.

5. Conclusions and Recommendations

The proposed retrofit alternatives for each parameter of the envelope were studied in terms of potential energy saving for cooling, heating, and initial cost. Simple payback period analysis (SPPA) was used to evaluate the economic feasibility for each of the alternatives. The impact of combining the proposed envelope retrofit alternatives from analyzed strategies was studied to assess the energy that can be saved on cooling and heating as well as the total energy that can be saved, to develop a holistic approach to envelope retrofitting. A combination-based scenario can save 59.2% annually for cooling and 36.4% for heating. Furthermore, applying the proposed envelope retrofitting approach to the old government school model can lead to 54% in annual energy saving, and has a relatively short payback period of 5.5 years.

Based on the thorough analysis, it is recommended to use low U-value insulation in the external walls of the building. Thermal conductivity has a significant impact on heating energy consumption in Amman. For energy efficiency and economic feasibility, using 100 mm EPS insulation covered with concrete blocks is recommended for wall retrofitting. Using PUR insulation is not recommended because of high initial cost and long payback period. For external walls’ retrofitting, cover insulation material with concrete blocks is recommended rather than cladding stone. For roof insulation it is recommended to for energy efficiency and economic feasibility, using 100 mm EPS insulation covered with lightweight concrete finish is recommended for roof retrofitting.

It is recommended Solar heat gain control systems to Fixed solar heat gain control systems should not be applied to north elevation as they have only a minor impact on annual energy saving. Furthermore, energy prices for cooling in Jordan are much higher than those for heating. Consequently, fixed solar heat gain control systems are recommended to retrofit government schools in Jordan.

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