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Energy Retrofitting of School Buildings in UAE

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Abstract: The opportunities for energy savings by retrofitting of the existing school buildings in the United Arab Emirates (UAE) are significant because of their excessive energy consumption and space cooling demand. In this research, energy modeling and simulation are utilized with the use of Design Builder software to examine the influence of various retrofitting measures of air-conditioning (A/C) system and building envelope components on the energy use. Several combined measures are implemented and assessed to achieve the main goal of this research of selecting the best course of action to reduce cooling energy consumption for existing school buildings in the UAE. The results show that the intensity of the reduction in cooling energy requirement varies from one retrofitting set of measures to another. The used electricity can be reduced by 29% to provide the required cooling demand by replacing the existing air conditioning equipment with more energy-efficient and properly sized system. A reduction of 21.5% in the annual electricity consumption to provide the required cooling demand can be obtained by adding insulation to the building roof and exterior walls. Besides, a reduction in electricity consumption of 57% can be potentially achieved to provide the required cooling load by improving the thermal resistance of the existing school walls, roof, and windows combined with high-efficiency air conditioning (A/C) system.

Keywords: Cooling demand; energy consumption; energy efficiency; retrofit; thermal insulation; existing buildings; school buildings

1 Introduction

The United Arab Emirates (UAE) has one of the fastest-growing populations and a rapidly expanding economy [1]. Due to this growth and urban development, the demand for electricity and water continues to rise to reach unprecedented levels. Current estimates indicate that the domestic electricity demand in the UAE reached nearly 131,031.000 GWh in December 2017 compared to the previous number of 127,205.000 GWh for December 2016 [2]. This high consumption places the UAE among the highest electricity consumers *per capita* in the world. The UAE's State of Energy 2016 Report states that electricity peak demand has almost doubled over the past 10 years. This can be easily noted in the primary energy consumption as several research studies indicated that the building sector in the UAE is considered the largest energy consumer and one of the largest contributors to greenhouse gases (GHG) emissions [3]. In response to these figures of rising demand for electric power, local UAE governmental

authorities have promoted new strategies and regulations that engaged different sectors and centers including health, educational, and governmental sectors. These sectors are promoted to follow sustainability approaches in buildings to minimize energy consumption and carbon emissions and to ensure better indoor air quality for users. The statistics have shown that different building sectors are responsible for most of the energy consumption and GHG emissions. In the UAE, the building sectors are responsible for more than 60% of final energy consumption and more than 80% of electricity demand; most of this energy goes for space cooling due to local extreme hot climate [4].

Existing buildings retrofitting is important to improve the energy performance, develop the indoor qualities of buildings, and reduce the emissions of GHG [5]. In UAE, existing school buildings represent a strategic sector that offers unique opportunities to conserve energy and reduce the environmental impact due to its pattern of occupancy and activities throughout the year. In this study, the school buildings sector is selected as one of the highest priorities because it affects the lives of most people in the UAE. According to the Knowledge and Human Development Authority (KHDA), more than 22.2% of the citizens are directly involved in the educational sector. Existing school buildings retrofitting is challenging because these structures have a wide variety of conditions and they cover a broad range of activities with different uses and energy services [6].

UAE extreme hot-humid climatic conditions impose a heavy reliance on air conditioning systems to achieve the comfort level in buildings due to the high air temperatures combined with high humidity levels. The air conditioning system is considered the major source of electricity consumption which is a common problem encountered in UAE that directly affects the choices of retrofitting techniques. More than 80% of the total electricity demand of buildings, in general, is used to meet the cooling demand [7]. The lighting system and plug loads (computers, copiers, etc.) are other primary energy consumers since schools are in session most of the time in the year [8]. The building envelopes also are considered among the most effective and viable measures that influence energy consumption [9]. Most existing school buildings in UAE have high glazing to wall ratio and their external walls and roof are insufficiently insulated which result in high solar gains and overheating.

The main objective of this study is to assess the energy performance of an existing school building and examine the impact of implementing several retrofitting measures and the potential of reducing the excessive electricity consumption required cooling demand considering the influence of the local climate. This study addresses specific retrofit options that focused on the building's envelope and enhancing the efficiency of the air conditioning system and its operational strategies.

It should be noted that in the real assessment of different alternatives, the cost estimates need to be considered to help identify the highest energy conservation measures. However, the focus of this study is limited to energy savings associated with different alternatives and does not include life cycle costs analysis. This research aims to identify and prioritize the retrofitting strategies of existing school buildings. Only the retrofitting measures and the results relative to potential energy savings are necessary for the purpose of this study.

1.1 Case Study

Star International Primary School has been selected as a case study. The school was built in 2008 and located in Dubai. The school has a central courtyard and mainly consists of two floors with a total land area of 5,225.48 m^2. The ground floor area is 5,034.57 m^2 and used for boys, while the upper floor is having the same area of the ground floor and used for girls. The school has more than 450 students with 50 classrooms and 10 labs. The total number of employees including substitutes and administrators are 85; 49 teachers and librarians, 24 teaching assistants, and 12 administrators. A total of 60 parking spaces are reserved for faculty, staff, and visitors. Fig. 1 shows the front view of the school.
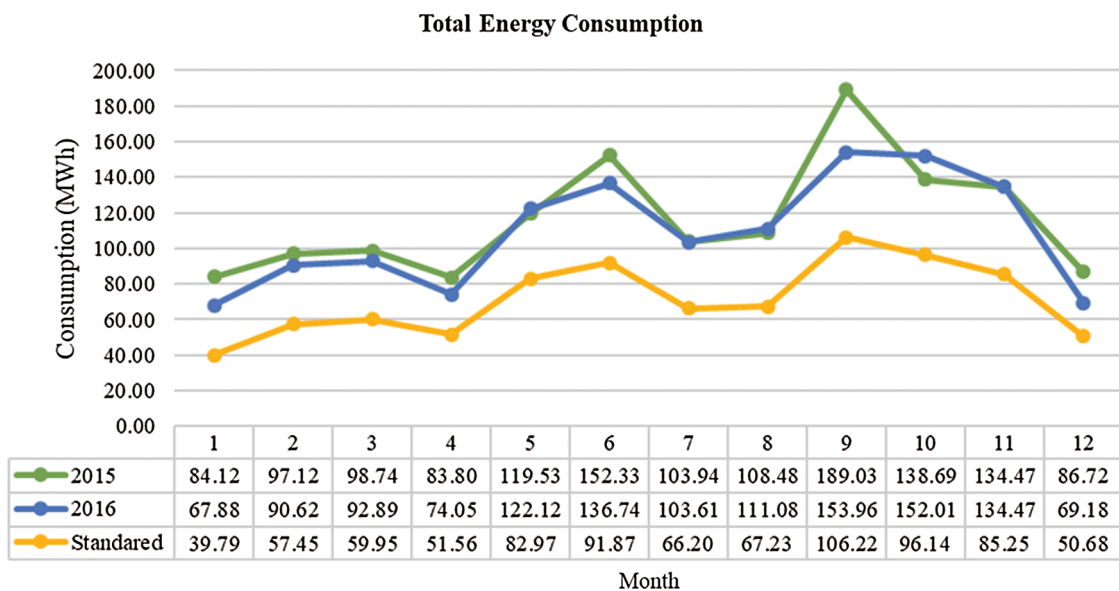
**Figure 1:** Front view of the selected case study

The school is served by 45 small single packaged rooftop units (single-zone RTUs) that are placed on the available roof area. All these units are constant air volume (CAV) serving the classroom and different services including the gym and the cafeteria. The current air conditioning units have a COP (coefficient of performance) of 2.1 which is equal to an EER (nominal energy efficiency ratio) = 7.5 (A COP of 1.0 equates to about an EER of 3.4). The building domestic hot water loop is served by electrical boilers with a rated efficiency of about 80%.

1.2 Energy Analysis of the Case Study

Evaluation of the existing school building (case study) is carried out to assess its energy efficiency, construction conditions, and equipment. The building energy consumption data for two consecutive years of 2015 and 2016 for the selected school is acquired from Dubai Electricity and Water Authority (DEWA). The energy consumption of the school for the two years was found to be higher than the recommended values by the standards set by Estidama (Pearl Building Rating System in Abu Dhabi), see Fig. 2. The energy performance of the existing school building is benchmarked to be the basis for the comparison against other generated alternatives to identify the best approaches and measures of building retrofit. The school monthly electricity consumption fluctuates throughout the year with high peak demand during the beginning of the academic year, mostly in September, October, and November as shown in Fig. 3. The high consumption is mainly due to poor envelope thermal properties, inefficient operation, and maintenance of the building's major systems and occupancy related behaviors.

Total Energy Consumption

	1	2	3	4	5	6	7	8	9	10	11	12
2015	84.12	97.12	98.74	83.80	119.53	152.33	103.94	108.48	189.03	138.69	134.47	86.72
2016	67.88	90.62	92.89	74.05	122.12	136.74	103.61	111.08	153.96	152.01	134.47	69.18
Standard	39.79	57.45	59.95	51.56	82.97	91.87	66.20	67.23	106.22	96.14	85.25	50.68

Month

Figure 2: School's energy consumption (MWh) for the years of 2015 and 2016 compared to the standards
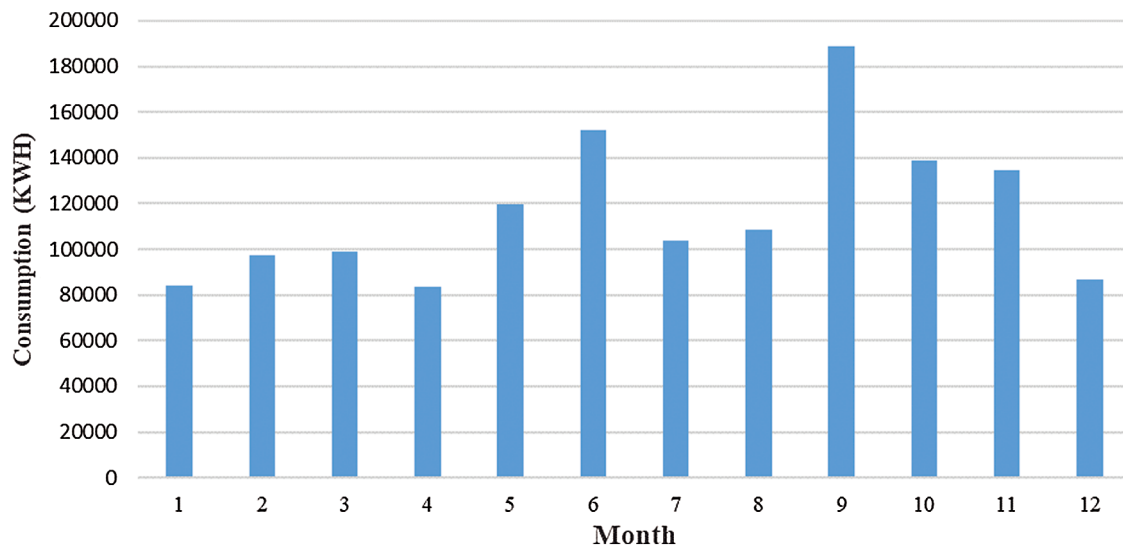
Figure 3: Average monthly energy consumption of the case study

To determine the energy usage patterns and to identify opportunities for energy improvement and implement the proper retrofit methods, different parameters including the operating characteristics of the school building were evaluated. Results showed that the high electricity demand is due to several key factors mainly space cooling and lighting. In Fig. 6, which shows the breakdown of consumption by end-use, air conditioning (A/C) is responsible for more than 80% of total electricity consumption, while lighting is accounted for 5% of consumption. This high energy consumption is expected in a region with such extreme hot-humid weather, but the percentage is higher than average electricity consumption.

Several research studies show that significant benefits could be gained from the improvement of the thermal characteristics of the building envelope which includes the walls, windows, doors, and roof. Minimizing heat transfer through the envelope is important for reducing the need for cooling load demand and improving indoor comfort conditions.

Consequently, the main objective of this study is to investigate the impact of improving the thermal properties of building envelope and air conditioning type and operation on reducing the electricity consumption required to satisfy the cooling demand of the school building and propose various possible retrofitting measures that potentially reduce the total cooling load in the building.

2 Methodology

Several feasible retrofit scenarios are generated based on the actual collected data of the typical school building (case study). The modeling simulation method in DesignBuilder software is used in this study to create the base case model and multiple alternatives. The main focus of this study is limited to energy savings associated with different retrofitting measures and does not include life cycle costs analysis or cost-efficiency. The aim is to define and assess the effectiveness of different retrofit scenarios and their impact on reducing energy consumption and find the optimum retrofit scheme. Several retrofit measures are investigated including:

- Measures focus on improving the thermal properties of the building envelope.
- Measures focus on reducing the building cooling load by enhancing the efficiency of the air conditioning and the air distribution systems in the building.

Verification and validation of the simulated models are essential in the research to ensure consistent and reliable results. Therefore, software validation is conducted at the start of this research. Star International School in Dubai is selected to serve as a case study building. This building is well-suited to this research for multiple reasons; firstly, the actual measured energy consumption and the energy use profile are available so this energy usage could be compared to the simulated outputs from the alternative models for verification of accuracy and model calibration process. Secondly, the selected school building is in Dubai and therefore a good representation of hot-humid weather conditions. For this purpose, a model with all thermo-physical characteristics of the existing school is developed and simulated using DesignBuilder software, see Fig. 4.
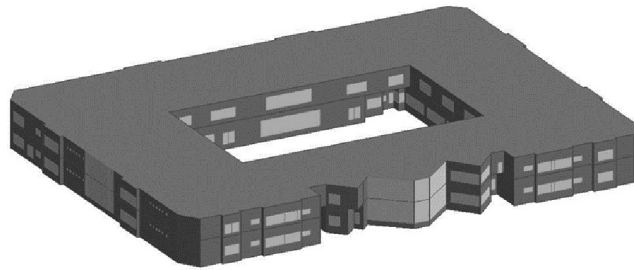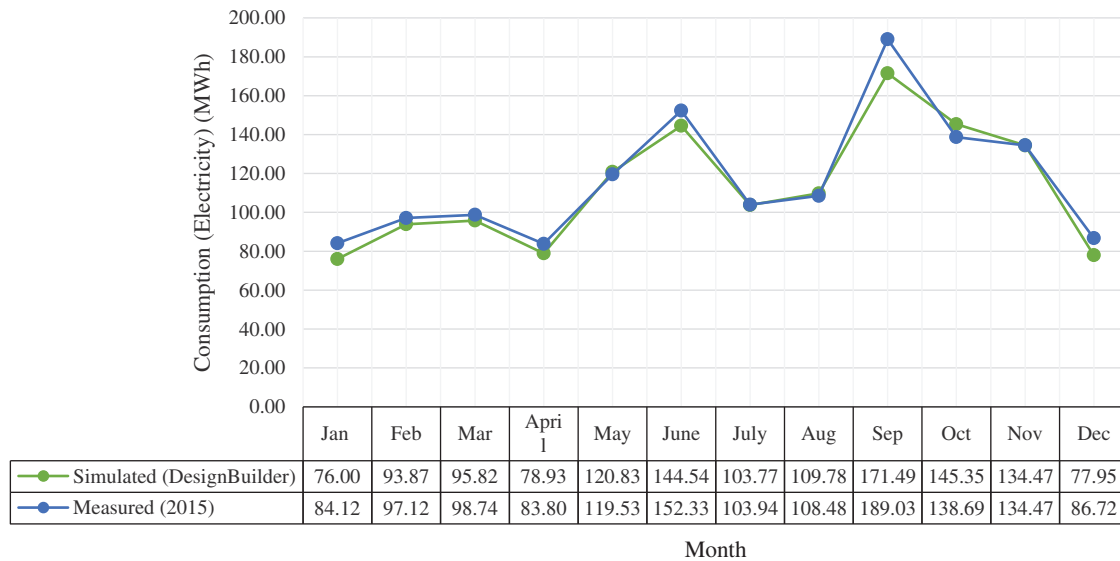

Figure 4: Base case model of the existing school in DesignBuilder

All building details such as dimensions and specifications, envelope materials, and some parameters of the HVAC system are determined accurately based on actual measurements and observations. However, some building parameters could not be determined due to the unavailability of documented data such as outside air infiltration rate, and internal electric loads. The undocumented data are estimated based on standard values and relevant information. The model is calibrated iteratively as multiple simulations runs are used to reduce the difference between actual energy consumption and model simulation results. The weather data necessary for the simulation is obtained from the Dubai weather data folder in the DesignBuilder weather data library. A schedule for the occupancy of the building has also been considered with a holiday schedule of schools in the UAE; every weekday from 8.00 to 18.00 except Friday, Saturday, and summer holiday. The schedules for the lighting and equipment are harmonized with the schedule for the occupancy. To estimate the energy savings from different proposed retrofitting measures, the building energy simulation tool has to be calibrated using actual measured energy data. The total electricity consumption of the school building is 1396.97 MWh per year. Building total cooling load including chillers, pumps, and fans is about 80% of the total electricity consumption, while lights and equipment together account for almost 8%.

Due to the extensive information needed on the airtightness of the building, especially the airflow rates vary from hour to hour over the year, the air infiltration is estimated based on the construction and the building lifetime. The collected data from standards and field observation of the construction conditions of the school building and the tightness of the envelope indicated high air infiltration rates which significantly impact the indoor environment and the building energy efficiency. 1.5 ACH (air changes per hour) is used as an estimation to correspond to the tightness of envelope construction.

The results from the detailed hourly simulations are compared to the available 2015 utility monthly electricity consumption records. The comparison of the simulated results shows a reasonable degree of accuracy with the measured data for all the configurations as illustrated in Fig. 5. The DesignBuilder model shows a deviation of about 5.3% from the actual performance of the existing school building. Assigning properties to all the components of the school model to match the actual conditions is highly complicated. But this difference is within an acceptable range and it could be due to:

	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Simulated (DesignBuilder)	76.00	93.87	95.82	78.93	120.83	144.54	103.77	109.78	171.49	145.35	134.47	77.95
Measured (2015)	84.12	97.12	98.74	83.80	119.53	152.33	103.94	108.48	189.03	138.69	134.47	86.72

Month

Figure 5: The school's monthly electricity consumption; measured *vs.* simulated

- The deviation between the estimated and actual building users' behavior. This makes it difficult to address the percent of the energy used by various plug loads from computers or other school equipment.

- The inaccurate quantification of air leakage through the generated school model. The unpredicted air flow passages and air exchange rate between indoors and outdoors through the building envelope would justify An additional air leakage through infiltration and exfiltration from open doors, windows, or other openings could be the reason to more electricity consumption particularly in the beginning of school year as the building utility measured electrical consumption is about 11% higher than simulated data.

The electricity consumption of the generated model of the school building is used as the baseline (benchmark) for the comparison of various retrofit options which help to determine the best combination of retrofit measures with energy-saving potentials to be implemented.

2.1 Input Data for Simulation

Different retrofit configurations of the school building are developed to assess the impact of the selected retrofit measures in terms of energy efficiency and reduction of cooling energy demand. A wide range of variables influences energy consumption in the building, but the main retrofit options that are evaluated in this research are narrowed down to:

- Improvement or replacement of the air conditioning (A/C) system such as adjusting up thermostat set-point, heat recovery systems, or economizer to provide free cooling whenever possible and retrofit of the cooling plant.

- Improving the air distribution system including the alterations and additions of the ducting system (supply and return) to the existing building to ensure an acceptable cooling airflow through properly sized ducts to conditioned spaces.

- Modification of building envelope components which includes the external walls and windows materials thermal properties. Adding a thermal insulation layer to poorly insulated envelope components and improvement of the envelope airtightness.

These options are selected according to the breakdown of school building energy end-use and the building parameters that exert the greatest influence on energy consumption. The air conditioning system and building envelop have a large role in the school building energy profile and are responsible for most of the building's total energy demand. Retrofitting these components provide the highest potential to make significant reductions in the building's total energy performance and the space cooling demand.

2.1.1 Air Conditioning

As mentioned earlier from the school energy end-use, the air-conditioning system is in less-than-adequate condition and it is responsible for a substantial portion of electricity consumption as shown in Fig. 6. It is the highest when the system is experiencing its peak with rising outdoor temperature during the summer months at beginning of the academic year.
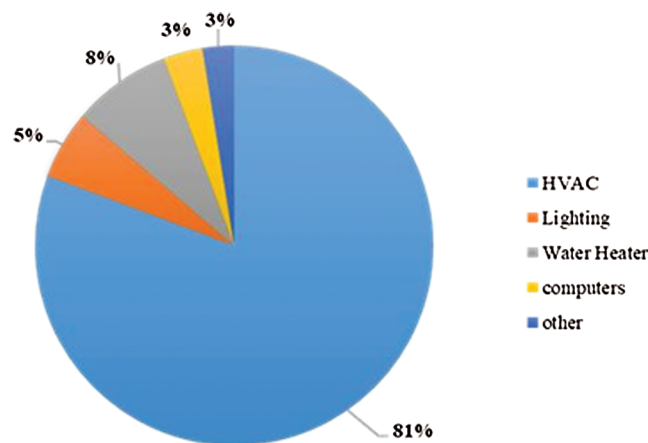
Figure 6: The breakdown of consumption by end-use of the case study

By analyzing the monthly energy usages, and load and operation profiles of the school building, it is found that the A/C system is not functioning efficiently due to a lack of appropriate measurement and monitoring energy consumption (energy management system, EMS). The system capacity losses associated with the impact of the airflow and the effects of improper setting of supply air temperature could be common reasons for reduced system performance and increased cost. It is also observed that the A/C system operates in the school building continuously, year-round without maintaining a moderate setting for the thermostat to reflect temperature changes during the unoccupied hours such as nights, weekends, and holidays, which could save significant energy.

The school is served by 45 small single packaged rooftop units to produce the required cooling demand. The monthly utility bill of energy consumption is used to calculate the existing COP factor of the cooling equipment (cooling output in watts over chiller power input in watts). The estimated average COP in all operating conditions of the existing A/C system is found to be 2.1 which is lower than expected and it doesn't meet the minimum efficiency of COP dictated by ASHRAE Standard 90.1-2004, which is 3.0. Additionally, there is a combination of problems with respect to the air distribution that has been observed within the building. Some exposed supply ducts which lack the insulation, and improper duct and diffusers installation (2 diffusers in each classroom), leakage from return plenums, specifically ceiling return plenum are possible faults for losing cooling energy and fluctuating the space temperatures within the school.

This study investigates three different levels of air conditioning retrofits to the existing condition of the baseline school building. Each level is individually evaluated in terms of its potential energy savings and

effectiveness compared to the existing conditions of the school. The results help the users to get a degree of flexibility in implementing the guidelines.

Alternative (1): This measure simulates the improvements, repairs, and adjusting system parameters of the existing condition of the baseline school building which includes:

- Seal leaky ducts and add duct insulation.
- Turn off the cooling equipment during off-seasons or unneeded times.
- Operation settings: set the temperature to 24 degree Celsius during the period in which the building is occupied. Increase the thermostat setback to 27 degree Celsius of the air conditioning system (A/C) during unoccupied periods.
- Adjust airflow rates in the school to meet the requirements and suspend ventilation during unoccupied periods.
- Replace or repair leaky and broken dampers.

Alternative (2): this measure simulates the correction of duct leakage and the degradation in thermal distribution efficiency in the building, the problem of less-than-perfectly insulated ducts, and are in some cases located outside the conditioned space. Two supply diffusers are added with a total of four diffusers in each classroom. Combined with all the proposals of alternative (1) that are mentioned previously, a comprehensive distribution system retrofit is proposed to correct the flow rate for conditioned spaces. Two types of supply and return ducting systems are investigated:

- Single duct system for supply and return air is conveyed entirely using architectural plenums (ceiling cavities) from the conditioned space back to the air-handling unit.
- Fully ducted—single duct system for supply and the return air is conveyed entirely in ductwork from the conditioned space back to the air-handling unit as shown in Fig. 7.

Alternative (3): this measure simulates the replacement of the air conditioning equipment with a more energy-efficient system that is common for school building design and operation practice.

- Packaged rooftop cooling units with COP = 3.0 (EER = 10.2). All new units are sized to meet the existing cooling loads at the school.
- Economizer controls: Economizer controls capable of providing free cooling using outside air. The economizer is enabled whenever outside air temperature is less than 18°C.

2.1.2 Building Envelope

The architectural characteristics, physical and thermal properties of building envelope including roof, walls, and windows have significant impacts on the building energy demand and the total energy consumption [10,11]. The existing school walls and roof are made of masonry construction, with structural steel, and external and internal plaster layers. The thermal insulating capabilities are reduced, and all exterior walls and roof are with little or no insulation. The estimated overall rate of heat transfer (U-value) for walls and roof is 3.1 W/m² K, which does not meet the minimum recommended thermal insulation values, set by local standards Estidama, of 0.83 and 0 .67 W/m² K for walls and roof, respectively. Thermal insulation is a crucial component of any envelope construction and significant improvements in thermal performance could be achieved by using thermal insulation and reflective coatings in such a hot and humid climate [12,13]. Each floor of the school building (ground and first) is composed of five thermal zones. Four of those zones are external facing a major orientation and have walls interacting with the outdoor conditions, and one thermal zone is internal as shown in Tab. 1. In this study, several scenarios of building envelope retrofit are generated, considering the most common construction practices used in the United Arab Emirates and the region.

The following is a description of the evaluated thermal properties of the building's envelope components in this research.
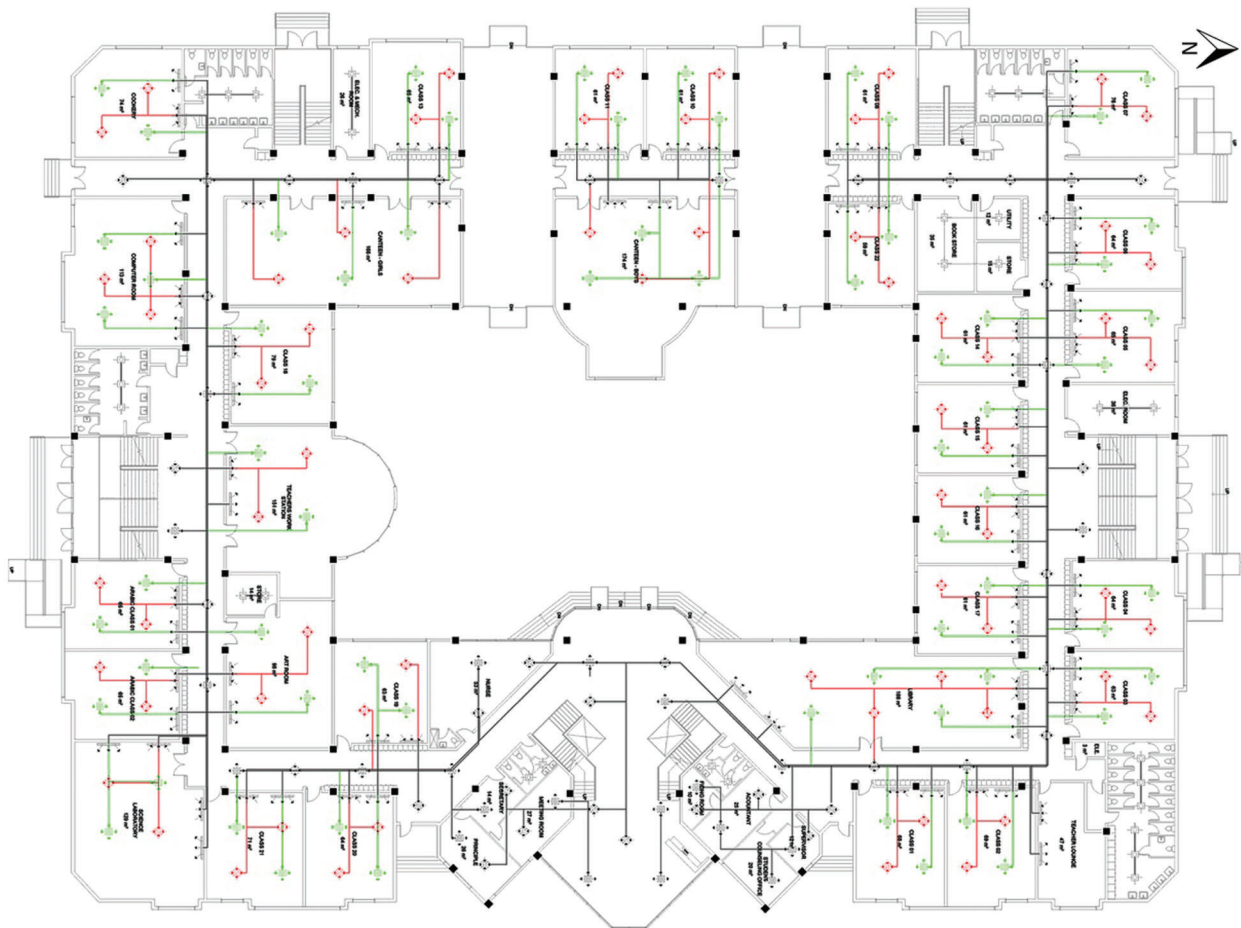
Figure 7: Proposed ground floor supply and return ducts of the case study

Table 1: Thermal zones of the case study

Zone number	No. of wall	Wall side	No. of rooms	Wall Area (m^2)	Window/door Area (m^2)	Percentage of windows (%)	Roof Area (m^2)
1	8	N	14	489.09	140.91	29%	678.65
2	8	S	15	467.07	162.93	35%	670.02
3	19	E	16	646.55	181.48	28%	907.17
4	19	W	18	682.22	145.78	21%	970.8
5	–	Interior	40	–	–	–	1,785.87

2.1.3 External Walls and Roof

The heat transfer through walls and roof of the school building can be reduced through adding a proper thermal insulation layer coupled with a reflective coating that replaces the existing degraded insulation [14–16]. In this study, the External Insulation Finishing System (EIFS) is used because it is the most common method to retrofit an existing building. It is an exterior wall cladding that utilizes rigid insulation boards on the exterior of the wall sheathing with a plaster appearance exterior skin. Three different options of adding insulation to walls and roof are evaluated:

Alternative (1): this measure simulates utilizing Exterior Insulation and Finish System (EIFS). Expanded polystyrene (EPS) insulation is added to exterior walls. A light-colored paint with low solar absorptance is used as a final topcoat.

Alternative (2): this measure simulates adding pre-formed roof insulation (PRI) to roof only. A light-colored coating with low solar absorptance is used as a final topcoat.

Alternative (3): this measure simulates the combined effect of adding insulation to both walls and roof. A light-colored paint with low solar absorptance is used as a final topcoat. The investigated alternatives of walls and roof parameters are summarized in Tab. 2.

Table 2: Investigated school alternatives of walls and roof

Alternative	Description	R-value m^2·K/W	Solar absorptance	Thickness (mm)
1	The rigid board expanded polystyrene (EPS) insulation is added to the external wall	0.92	0.3	32
2	Rigid board pre-formed roof insulation (PRI) is added to the roof	1.22	0.3	64
3	Combination of wall and roof insulation	–	–	–

2.1.4 Windows

Windows are a major component of energy performance as they are responsible for a substantial share of energy use for both new and existing buildings. Using high-performance windows helps reduce the building cooling loads requirement and the size of the system which in turn can offset some of the cost of the efficient windows [17–19]. The case study is characterized by poorly insulated windows (glazing and frames) with an estimated U-value of 3.3 W/m^2 K. They are comprised of double pane-clear glazing and metal frames with no shading devices. As shown in Tab. 1, the window to wall ratio of the building varies by orientation with 35% glazing towards the south, followed by north and east with 29%, 28% respectively, and only 21% towards the west.

Different configurations of glazing types of double panes with low emissivity (Low-e) glass are proposed. Furthermore, Aluminum and PVC frames are proposed. Tab. 3 presents the examined alternatives in terms of windows glazing types and thermal characteristics. The proposed alternatives are based on the available materials that are widely used in the market in the UAE.

**Table 3:** Windows' glazing types and their properties

Type	U-value W/m^2 K	Description
Double pane/air filled-no coating	3.3	Existing Windows—Solar Heat Gain Coefficient (SHGC) = 0.7, and Visible Transmittance (VT) = 1
Clear window film	2.4	Clear tint with heat reflectance of 80%, Solar Heat Gain Coefficient (SHGC) = 0.5, and Visible Transmittance (VT) = 0.85
Aluminum sliding windows—6 mm clear double pane, Low-e coating/air filled	2.0	Air gap filled double glazed with Solar Heat Gain Coefficient (SHGC) = 0.37, and Visible Transmittance (VT) = 0.76
PVC sliding windows—6 mm clear double pane, Low-e coating/low SHGC-Argon filled	1.7	Argon gap filled double glazed with Solar Heat Gain Coefficient (SHGC) = 0.20, and Visible Transmittance (VT) = 0.76

3 Results and Discussion

The following discussion focuses on the most important findings by evaluating the impact of various retrofit scenarios of air conditioning characteristics and envelope thermal properties on the required cooling energy consumption. It should be noted that in the real assessment of different alternatives, the cost estimates need to be considered to help identify the highest energy conservation measures. However, the focus of this study is limited to energy savings associated with different alternatives and does not include life cycle costs analysis.

3.1 The Impact of A/C System Characteristics

By evaluating the impact of improving the A/C system (operation and characteristics) on the energy performance, the results show that the energy consumption and the cooling requirement in the current school reduced considerably after retrofit measures of each alternative, as illustrated in Fig. 8. The intensity of the reduction of energy varies with different proposed retrofit strategies and always a high reduction in energy consumption is attained when improving the characteristics of the A/C system. The first alternative which focuses on improving the performance of the existing system reduced the required electricity for cooling in the building from almost 129.96 KW h/m^2/year to almost 123.45 KW h/m^2/year. The implemented retrofit measures for this alternative reduce the loss of cooling capacity from the distribution system. The total cooling capacity of the system increases by almost 5% with a coefficient of performance (COP) = 2.3. The results also show that the second alternative which focuses on the replacement of the existing air distribution system in the school with entirely ductwork (fully ducted) of supply and return has a better performance of 14% than the benchmark. The coefficient of performance (COP) is increased to 2.7. However, using the un-ducted ceiling return plenum to convey the air from the conditioned space back to the air-handling unit, shows a lower efficiency of about 6% compared to a fully ducted distribution system. In this alternative, (plenum return system), some of the energy returned from condition spaces is wasted due to pressurizations change in response to changes in supply airflow.
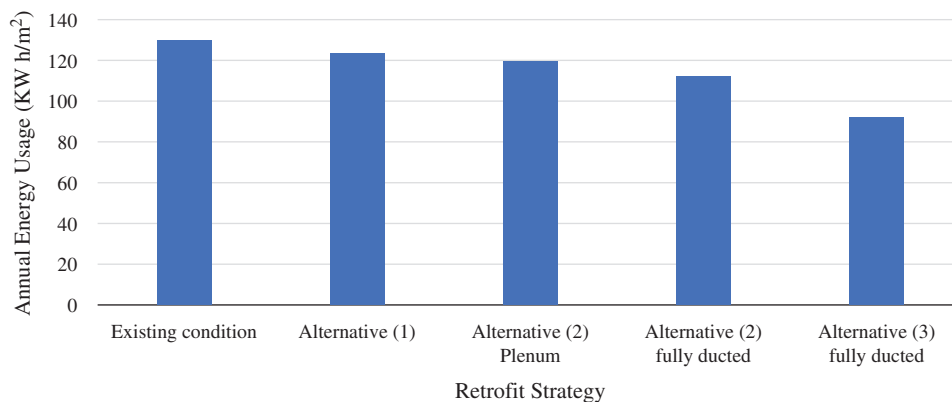
Figure 8: Comparison of annual energy usage among different proposed alternatives of A/C system

The third alternative, which focuses on the replacement of the existing air conditioning equipment with more energy-efficient and properly sized system, gives the best performance amongst all investigated alternatives. According to results, energy consumption to provide the required cooling demand in the school building reduced from almost 129.96 KW h/m^2 to almost 87 KW h/m^2. As shown in Tab. 4, it is found that the combined effect of replacing the A/C system and having a fully ducted distribution system reduces the annual cooling energy consumption by 29%. The COP of the system increases significantly to 3.2 which exceeds the recommended levels of COP set by the local building rating system standards (Estidama). Tab. 4 summarizes the results of various retrofit configurations of the A/C system.

Table 4: Energy performance according to different AC strategies

Retrofit Strategy	Cooling (Electricity) (KW h/m^2)	COP
Existence condition	129.96	2.1
Alternative (1)	123.45	2.3
Alternative (2)—Plenum	119.77	2.5
Alternative (2)—fully ducted	112.13	2.7
Alternative (3)—fully ducted	92.26	3.2

3.2 The Impact of Envelope Thermal Properties

Varying the insulation levels of the building envelope, including both the roof and walls, plays a significant role in the building's total energy consumption. Results of the walls and roof retrofitting analysis and the enhancement of the thermal properties of these components show the potential to achieve better energy performance and greater savings compared with the baseline case. The impact of altering walls and roof on energy consumption is illustrated in Fig. 9.
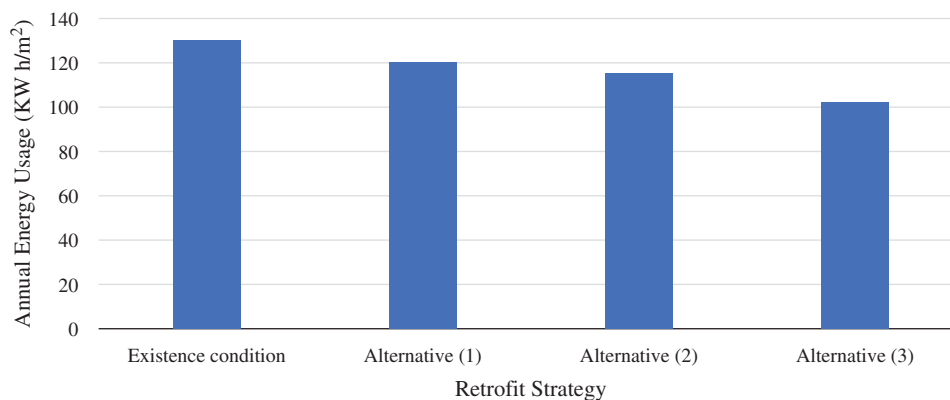
Figure 9: Comparison of annual energy usage among different proposed alternatives of walls and roof

Compared with the baseline school annual energy consumption, the wall insulation offers some significant benefits because it provides resistance to heat flow. The results have shown that improving the wall U-value from 3.1 W/m² K to 1.24 W/m²·K by adding 32 mm of expanded polystyrene insulation with an R-value of 0.92 m² ·K/W has resulted in reducing the required electricity consumption to provide space cooling by 7.5%. Moreover, the results have shown that energy savings increase with the addition of roof thermal insulation. The annual required electricity consumption to provide space cooling is reduced by 11.3% by adding 64 mm of preformed roof insulation with an R-Value of 1.22 m^2 K/W to the roof. A possible explanation for the difference in energy savings between walls and roof is due to the roof surface exposure to solar radiation at a higher angle. The effects of solar radiation are much less significant at walls, where heat transfer is mostly convective. Insulating both roof and walls is the most effective energy efficiency measure among all different proposed alternatives for the building envelope and this is illustrated in Tab. 5. The highest saving which is about 21.5% reduction in electricity consumption is obtained by combining the effects of insulating the school exterior walls and roof as a joint measure.

Table 5: Energy performance of different alternatives of walls and roof

Retrofit Strategy	Cooling (Electricity) (KW h/m^2)	Percentage of Energy Reduction
Existence condition	129.96	–
Alternative (1) (EPS) insulation is added to external wall	120.21	−7.5%
Alternative (2) (PRI) is added to roof	115.27	−11.3%
Alternative (3) Combination of wall and roof insulation	102.02	−21.5%

The impact of the windows on the energy consumption rate and the cooling demand of the building is obvious. The overall energy performance of windows is sensitive to glazing layers, insulating frames, and Low-e coating types, which all result in lower U-factors; the lower the U-value, the lower in cooling demand. Adding window insulation film improves window insulating properties and reduces the annual cooling energy requirements by about 5.8%. Replacing the base case windows with double-glazed windows with Low-e coating (SHGC ≤ 0.37) produces significant annual savings of about 10.4%. However, double-glazed, argon-filled windows with Low-e coating (SHGC ≤ 0.20) are the best options as they produce the most savings of 16.2%. Tab. 6 summarizes the results of various retrofit configurations of windows.

Table 6: Energy performance of different alternatives of window types

Retrofit Strategy	Cooling (Electricity) (KW h/m^2)	Percentage of Energy Reduction
Existence condition Double pane/air filled-no coating	129.96	–
Alternative (1) Clear window film	122.45	−5.8%
Alternative (2) Aluminum sliding windows—6 mm clear double pane, Low-e coating/air filled	116.50	−10.4%
Alternative (3) PVC sliding windows—6 mm clear double pane, Low-e coating/low SHGC-Argon filled	109.02	−16.2%

3.3 Combinations of Measures

The results show that individual measures maximum reduction in electricity consumption for cooling the interior of buildings (space cooling) can reach up to 29%. After analyzing a wide range of single and combined building retrofit scenarios and according to the obtained results, it is found that combining a series of building retrofitting measures is more effective in reducing the cooling energy consumption. One possible combination of measures is the effect of adding walls and roof insulation with double-glazed, argon-filled windows that offer a reduction of more than 30% in required electricity consumption for space cooling from 129.96 KW h/m^2/year to 90.85 KW h/m^2/year. However, a large energy savings of more than 57% can be achieved by combining the A/C system with a fully ducted distribution system to the previous combination of measures as shown in Fig. 10.
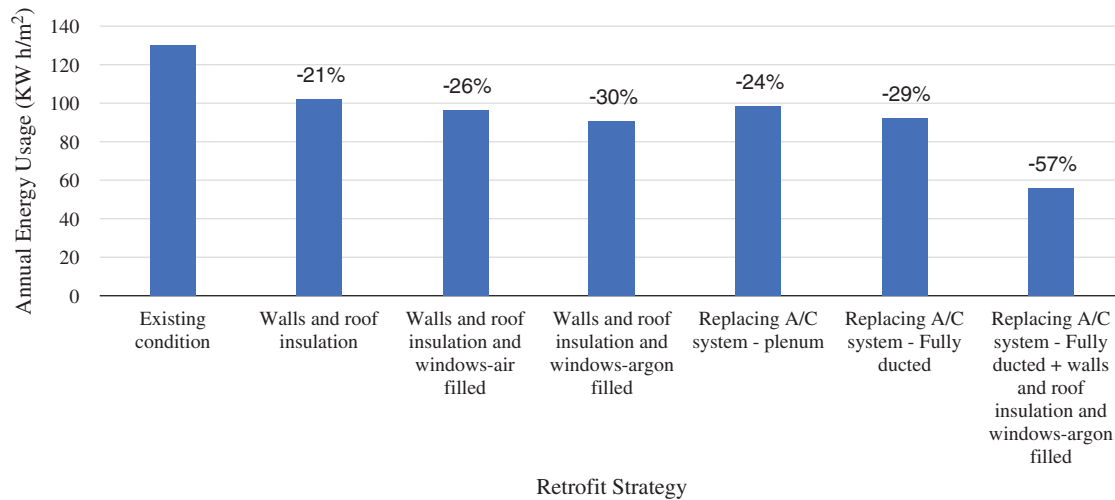
Figure 10: Comparison of annual energy usage among different combinations of measures

4 Conclusion

The results presented in this study suggest that significant reductions in electricity and cooling energy consumption can be achieved by efficient retrofitting. This study focused mainly on improving the thermal properties of the building envelope and the A/C system as components that impact the energy performance in schools in UAE. It is revealed that the reduction of cooling energy consumptions depends on the correct choice of the retrofitting measures and exhibits considerable variation based on the retrofit solution of the air condition system, roof, walls, and glazed fenestrations. The most effective energy efficiency measure when applied alone is found to be the replacement of the existing air conditioning equipment, reducing the annual requirement of electric demand for space cooling by 29% relative to the baseline condition. Next, reductions of 21.5% in the annual electricity consumption to provide the required cooling demand are observed when adding thermal insulation to the school's exterior walls and roof. Adding window insulation film is found to be the least effective energy efficiency measure when installed only with a 5.8% reduction in the annual electricity consumption.

Amongst different combinations of the investigated retrofit measures in terms of cooling load reductions is the A/C system and fully ducted distribution system with adding thermal insulation to walls and roof and double-glazed, argon-filled windows. This optimal scenario resulted in a 57% reduction in the annual electricity consumption for space cooling.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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