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Energy Efficiency in Educational Building: A Case Study of HVAC and Lighting Retrofits

Mohammed Yahiya Naveed*, Sami M. Jaradat[+]

*Analytical Engineer, Measurement & Verification (M&V), Quantum Energy Solutions Company, Al-Khobar, Saudi Arabia.

[+]M&V Manager, Measurement & Verification (M&V), Quantum Energy Solutions Company, Al-Khobar, Saudi Arabia.

ABSTRACT:

This study provides a comprehensive assessment of an energy retrofit project carried out at a vocational institution located in the Eastern Province of Saudi Arabia. The project encompassed the replacement of conventional lighting systems with energy-efficient LED fixtures, the integration of advanced lighting controls, and the upgrading of outdated HVAC equipment to more efficient models. The performance evaluation was conducted in accordance with the International Performance Measurement and Verification Protocol (IPMVP), employing Options A and B to quantify savings with appropriate rigor. The retrofit measures achieved a notable annual energy savings of 1,179,592 kWh, corresponding to a 51.88% reduction in electricity consumption relative to the pre-retrofit baseline. Post-implementation performance was monitored over two consecutive years to verify the persistence and reliability of energy savings. The results underscore the effectiveness of M&V-driven retrofit strategies in significantly reducing energy consumption, operational costs, and environmental impact in educational facilities. These findings provide a valuable reference for energy management initiatives in similar institutional settings across the region.

Keywords: Energy Efficiency, HVAC, Retrofit, IPMVP, Measurement and Verification, LED Lighting, Educational Buildings

Introduction:

The energy consumption of public-sector educational institutions in Saudi Arabia has emerged as a pressing concern, primarily due to the country's harsh climatic conditions that necessitate year-round cooling, and the widespread use of outdated, energy-inefficient lighting and HVAC systems. As electricity demand continues to grow, particularly in buildings reliant on traditional technologies, energy conservation has become not only an environmental imperative but also a strategic economic priority. In response to these challenges, a leading governmental body overseeing vocational education in the Kingdom, initiated a large-scale energy retrofit project across several of its facilities, one of which is our focus in this paper located in the eastern region of Saudi Arabia.

Energy retrofitting involves upgrading existing building systems to enhance energy efficiency and reduce operational costs without compromising occupant comfort or performance. Typical retrofit measures include replacing conventional lighting with high-efficiency LED systems, installing advanced control technologies such as occupancy-based lighting systems, and upgrading HVAC equipment to newer, more efficient models. In this study, the retrofit intervention encompassed three major actions: the replacement of 12,124 conventional lighting fixtures with LED luminaires; the substitution of 38 aging split air conditioning units with high-efficiency models; and the installation of occupancy-based lighting controls to further minimize unnecessary energy usage.

A critical component of any energy retrofit project is the ability to accurately measure and verify the savings achieved through these interventions. Measurement and Verification (M&V) serves as a structured methodology to assess the actual performance of Energy Saving Measures (ESMs) post-implementation. It ensures transparency, validates the effectiveness of retrofitting efforts, and supports performance-based contracting models. In this project, M&V protocols were applied in accordance with the International Performance Measurement and Verification Protocol (IPMVP), a globally recognized standard for energy savings verification. Specifically, Option A (Partially Measured Retrofit Isolation) was employed to assess lighting system upgrades, while Option B (Retrofit Isolation with All Parameter Measurement) was used to evaluate the HVAC improvements. These options allowed for a robust estimation of savings by isolating and analysing the energy use of the retrofitted systems independently from the rest of the facility.

This research focuses on evaluating the outcomes of the retrofit initiative at the vocational & training college, with an emphasis on the reliability of M&V methodologies, the persistence of energy savings over a two-year period, and the broader applicability of such interventions in similar institutional settings. The findings aim to contribute practical knowledge to the field of energy management, particularly in the context of educational buildings in hot climates, where energy-intensive cooling systems dominate the load profile. Furthermore, this study highlights how M&V-driven retrofits can play a pivotal role in supporting Saudi Arabia's national goals for energy efficiency and environmental sustainability.

What is an Energy Retrofit?

An energy retrofit refers to the upgrading of existing systems in a building to reduce energy consumption. This typically includes installing efficient lighting, HVAC, and control systems. In this study, the retrofit project replaced:

- 12,124 old lighting fixtures with LED luminaires.
- 38 old split AC units with high-efficiency models.
- Lighting controls with occupancy-based systems.

What is the Use of M&V in Energy Retrofits?

Measurement and Verification (M&V) is the process of quantifying energy savings achieved through ESMs. In this project, M&V was essential to:

- Verify energy savings claims using standardized protocols.
- Provide transparency and accountability for stakeholders.
- Quantify actual financial returns based on real performance.

Objective:

1. To evaluate the impact of HVAC and lighting retrofits on energy consumption.
2. To validate energy savings through IPMVP-compliant M&V techniques.
3. To demonstrate the application of energy conservation in educational institutions.

Methodology:

The project was carried out at in a college in the eastern province, which consists of 11 buildings with a total built-up area of 38,080 m². The retrofitting involved replacing 12,124 lighting fixtures and 38 split HVAC units.

M&V Approach

Option A was employed for lighting systems, focusing on key parameter measurement (wattage) and estimated operation hours.

Option B was used for HVAC systems, where actual energy consumption was measured using energy meters and regression models that considered Cooling Degree Days (CDD) and academic schedules.

The M&V strategy followed the IPMVP 2014 core concepts. Option A was applied for the lighting systems where power was measured and operating hours estimated, while Option B was used for HVAC systems involving direct metering of pre- and post-retrofit consumption.

Lighting Systems (Option A):

- Wattage of fluorescent and LED fixtures measured.
- Operating hours estimated based on building usage.
- Calculated using the equation:

Energy Savings = Σ (W_old − W_new)× Operating Hours

Savings Calculation Approach

Energy and cost savings can be calculated as the reduction in power (the key parameter, kW) multiplied by the operating hours (non-key parameter). Baseline energy consumption was determined from a lighting inventory of the entire building. Powers were assigned to each existing fixture based on its data sheet. As a confirmation, a sample of measurements on the most common fixture types may be needed.

As for the savings calculations, two usage groups (Interior, exterior) corresponding to specific operating hours were defined. Operating hours were estimated as discussed above.

The baseline lighting energy use for each usage group is the sum of fixture powers multiplied by the operating hours for that usage group (UG):

$$kWh_{Baseline,UG} = \frac{(Hours_{UG})}{1{,}000} \sum_{\substack{Fixtures\ in \\ UG\ of\ type\ i}} (\#fixtures)_i (Watts/fixture)_i$$

The total baseline energy use is the sum of all usage groups.

$$kWh_{Baseline} = \sum_{UG=j} kWh_{Baseline,j}$$

This process is repeated for the proposed lamps and fixtures. Powers for the proposed lamp and fixture types were taken from manufacturer's specifications and was measured of selected samples post installation.

Energy savings are simply the baseline energy use less the proposed energy use.

$$\Delta kWh = kWh_{Baseline} - kWh_{Proposed}$$

The table below shows the details of the expected savings of the project for Option A.

Table 1: Detailed Savings

Detailed Savings Summary							
Savings Summary	**Calculated Savings**				**Guaranteed Savings**		
	kWh	**SAR**	**Baseline**	**Percentage**	**kWh**	**SAR**	**Percentage**
Interior lighting replacement with high efficiency LED	1,631,119	521,958	2,196,609	74.26%	1,127,331	360,746	51.32%
Exterior lighting replacement							
Installation of interior lighting control system							
Stadium and Street lighting replacement							
Total Consumption	**565,489**				**1,069,278**		

To follow the savings monthly for option A, a monthly table has been created to track the monthly savings.

Table 2: Monthly savings for option A

ESM	**Annual Savings (kWh)**	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Interior Lighting replacement with high efficiency LED	1,127,331	93,944	93,944	93,944	93,944	93,944	93,944	93,944	93,944	93,944	93,944	93,944	93,944
Exterior Lighting Replacement													
Installation of interior Lighting Control system													
Stadium and Street Lighting Replacement													

To calculate the savings potential related to the occupancy-based lighting control, lighting/occupancy sensors were deployed in the below tabulated spaces and the following savings potential was calculated as per the 'HOBO Savings Analysis Tool'.

Table 3: Occupancy Measured in Various Areas

#	Building No.	Area	Total Savings (30 Min)
1	B1	B1-GF-101	66%
2	B1	B1-3rd-402	68%
3	B8	B8-GF-CommOffice	55%
4	B1	B1-FF-206	59%
5	B8	B8-GF-Corridor	50%

The observed savings values were then analysed for the statistical average value and the associated measurement uncertainty. The results are tabulated below for reference.

Table 4: Uncertainty for HOBO

Average	0.60
Standard deviation	0.07
Count	5
Coefficient of variance	0.126
SE	0.03
Confidence Level	90%
T-value	2.13
Margin of error	0.07
Uncertainty	12.0%

Considering that the measurement uncertainty 12.0%is higher than the acceptable range of 10%, a lower-than-average value was considered for the purposes of operation hours' reduction, rather than 60% a value of 30% was considered to follow ASHRAE 90.1 Standard recommendation.

Performance Parameters

The purpose of a lighting upgrade is to provide similar illumination levels with less energy. The lux level requirement was considered following SASO standards. To confirm that lighting levels are maintained following the upgrade, ESCO should take lighting level measurements in a sample of spaces before and after the upgrade. Lighting levels are measured in a horizontal plane at either 1 meter from the floor or at desk height in roughly the centre of the space. Three to five measurements per space are taken and averaged; three spaces per major usage group are measured and averaged. This measurement should be repeated in yearly basis to ensure that the new lighting system maintains the required lux level throughout the project period.

In some cases, the lighting level measurements may be taken during the evening hours to remove the contributions from daylighting that would interfere with the measurement process.

Meter Specifications

A true-RMS power meter for fixture power measurements. To improve reading accuracy, multiple fixtures are measured on a single circuit and the power reading is divided by the number of fixtures on the circuit. Note that measuring multiple fixtures on a single circuit constitutes one measurement. Multiple measurements of common fixture types were taken so that a standard deviation of the measurement can be calculated.

The meter used has a stated accuracy of 1% of full-scale.

Expected Accuracy

The IPMVP defines acceptable accuracy of the reported savings as being twice the standard error of the measurement process. Since the operating hours were estimated and not measured, an uncertainty analysis cannot be conducted on the non-measured parameter.

HVAC Systems (Option B):

- 24 of 38 AC units metered over the cooling season.
- Energy usage correlated with Cooling Degree Days (CDD) and Class Days.
- A regression model was developed:

$$kWh = 5.52 \times CDD + 490.76 \times Class\ Days - 1166.08$$

AC Replacement IPMVP Option B

ESM Description

This ESM required replacement of the existing old and low efficiency AC units with more energy efficient ones.

The criteria followed to categorize the AC units as old is as follows:

- If EER at T1 is less than 11.0
- If the nameplate does not contain this information, the refrigerant type determines that the AC unit is old if it is R22. If the refrigerant is R410, then the unit is new Proposed Chiller Performance and Energy Use

Table 5: Savings Summary of Option B

ESMs	Annual Consumption Pre- Retrofit (kWh)	Annual Consumption After Retrofit (kWh)	Guaranteed Annual Savings (kWh)	Guaranteed Energy Cost Savings (SAR)	% Guaranteed Annual Energy Savings	M&V option
Split units Replacement	76,672	24,411	52,261	16,724	68.16%	B

Measurement Option and Boundary

Option B was selected for its simplicity and applicability to AC replacement projects. The demand and hours of operation are measured before ESM implementation The demand and consumption levels are also measured over a given period after energy savings project implementation. The measurement boundary is the air conditioning system across all the buildings, including indoor units, outdoor units, and electric panels. Power consumption, energy consumption and power factor can be simultaneously measured for all working AC units. The Option B approach taken will be consistent with guidance outlined in the International Performance Measurement & Verification Protocol Core Concepts (IPMVP, 2014) and the Energy Savings Measurement and Verification User Guide for the Kingdom of Saudi Arabia (Version #01, 2017).

Justification

Option B was selected as the preferred approach for the following reasons:

- Project scope of work is very limited to only lighting system and 38 split units. Remaining systems are out of scope. The targeted system baseline is 2,273,281 out of 6,000,000 kWh. This means that only 37% of the system is targeted and remaining 63% is out of scope.
- Option B is a retrofit isolation or system level approach. It is intended for ESMs with performance factors that can be measured at the component or system level, therefore, it provides higher accuracy levels.
- The variables being measured (kW, operation hours) are simple and inexpensive to monitor.
- Option B is appropriate for measures in which the actual energy use needs to be measured for comparison with the baseline model for calculating savings.

Estimated Savings

Savings are quantified by field measurement of the actual power draw of the AC units, and the operation hours for those units affected by this ESM retrofit, during reporting period. Baseline energy consumption was determined from an AC units' inventory of the entire building.

To calculate the energy saving resulting from replacing the old inefficient units with new efficient ones. The CDD values and the attendance of the reporting period are inserted in the regression equation that was constructed during the baseline period as it will be shown in the following sections.

To follow the savings monthly for option B, a monthly table has been created to track the monthly savings.

Table 6: Monthly Savings of Option B

ESM	Annual Savings (kWh)	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Split units Replacement	52,261	73	259	2,215	4,201	6,773	7,632	8,711	8,409	6,503	4,878	2,168	438

Baseline Development

The baseline is established by metering the energy consumption of a representative number of AC units over the entire cooling season. The demand and energy consumption along with weather data would establish the baseline energy performance.

The different types of spaces along with the capacities of AC units serving them are summarized, as shown in the following table:

Table 7: Capacities of AC units

Space	**AC Unit Capacity**
Lab	2 Ton
Office	2 Ton
Classroom	2 Ton

New and Energy efficient AC units are excluded from baseline energy consumption measurement.

It should be noted that there are many types of AC units for the same AC unit capacity. The nominal value of the AC capacity is taken to unify the AC units of different types that belong to the same capacity category.

Sampling

Since there are various AC unit capacities serving various spaces, discrete sampling method is followed to estimate the sample capacity of each AC unit capacity.A survey for all existing units was performed. The initial sample capacity for a population (AC unit capacity) is given by:

$n = Z^2 Cv^2/P^2$

Sample Capacity Equation:

where: n = initial sample capacity

Z = 1.645 for a confidence level of 90%

CV = 0.5

P = desired precision 10%

Sample size for measurement and metered quantity of units.

Table 8: Sample Size

Confidence Level	90%
Enter Population Size	38
Margin of error	10%
Estimated proportion of the population which has the attribute	50%
Number of samples calculated	24
Number of samples considered	24

Based on the sample size calculations 24 (RT 48) units are metered out of total 38 (RT 76) units which are replaced. The metered data of energy consumption is used in establishing the corelation between cooling degree days (CDD), Class Days (Occupancy) and energy consumption.

Performance Parameters

The baseline energy performance of the existing units is established with the actual cooling season consumption and local conditions for the representative sample of each subgroup.

Two Energy meters installed on 24 of split units out of 38 for the measurement and verification purposes as agreed. The split units are grouped, and a meter installed for each group. The measured consumption of the 24 units will be scaled by 1.58 which is division of the total tonnage over the measured tonnage.

The energy consumption is calculated on monthly basis. Total energy consumption is i.e., from all the units connected to different energy meters is added up on monthly basis. The monthly kWh is correlated with the Cooling Degree Days (CDD) and Class Days Occupancy for each month which was obtained from CDD Tool at base temperature of 18.5 C. and college academic year.

In the Class Days Occupancy, a value of 1 assigned to class days and a value of 0 is assigned to weekends and vacations which was obtained from the academic calendar to obtain the second independent variable. Due to low occupancy for all classrooms during the exam weeks, a value of 0 was assigned to exam days in the baseline and the performance period.

The slope and intercept values are used to establish the equation between the independent variable (CDD) and dependent variable (kWh). The equation is as below:

Where:

$kWh_{SG} = m\,(CDD)_{bl} + x(Class\ Days)_{xl} + b$

kWh_{SG} = Baseline Electrical Energy Consumption of a certain subgroup during metering period (The subgroups are labs, classrooms, offices, corridors, service rooms)

m	=	Regression coefficient, slope1
x	=	Regression coefficient, slope2
b	=	Regression coefficient, intercept
$(CDD)_{bl}$	=	Cooling degrees days during baseline period
$(Class\ Days)_{xl}$	=	Academic Year during baseline period

Table 9: Baseline Development Table

From	To	# days	CDD 18.5	Class Days	Source	kWh
20-Nov-21	22-Dec-21	33	76.4	15	Regression	6,617
23-Dec-21	21-Jan-22	30	3.4	5	Regression	1,306
22-Jan-22	20-Feb-22	30	12.4	19	Regression	8,227
21-Feb-22	22-Mar-22	30	87.5	15	Regression	6,679
23-Mar-22	21-Apr-22	30	224.8	22	Regression	10,872
22-Apr-22	21-May-22	30	352.2	11	Regression	6,178
22-May-22	20-Jun-22	30	496	8	Measured	4,615
21-Jun-22	20-Jul-22	30	557	0	Measured	1,994
21-Jul-22	19-Aug-22	30	563	0	Measured	2,172
20-Aug-22	20-Sep-22	32	538	18	Measured	11,431
21-Sep-22	20-Oct-22	30	361	18	Measured	8,627
21-Oct-22	19-Nov-22	30	260	14	Measured	7,954
Total		**365**	**3,532**	**145**		**76,672**

Routine Adjustment

Six months metered data is available during the baseline period. That data is used as metered data. For other four months, energy consumption is determined using the regression analysis-based slope and intercept. In the baseline table above, it shows the weeks that have been measured and the weeks we used the regression to estimate the consumption. The equation used for determination of energy consumption data based on regression is as below:

$kWh_{SG} = 5.5232 * (CDD)_{bl} + 490.755 * (Class\ Days)_{xl} - 1166.084$

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.977672791
R Square	0.955844086
Adjusted R Square	0.926406809

Standard Error	1034.559666
Observations	6

ANOVA

	df	SS	MS	F	Significance F
Regression	2	69507315.26	34753657.63	32.47053418	0.009278619
Residual	3	3210941.104	1070313.701		
Total	5	72718256.36			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-1166.084746	2606.765274	-0.447330167	0.684962329	-9461.975261	7129.805768	-9461.975261	7129.805768
CDD	5.523248931	4.597524426	1.201352819	0.315808436	-9.108125694	20.15462356	-9.108125694	20.15462356
Class Days	490.7551334	68.59498921	7.1543875	0.005623692	272.4552634	709.0550033	272.4552634	709.0550033

The following table provides the statistical values needed for the M&V protocol as per the regression analysis conducted on the baseline model.

Table 10: Statistical parameters

Multiple Coefficient of Determination	**Value**	**Recommendations**
Coefficient of determination (R^2)	0.9558	> 0.75
Standard Error of the Estimate, kWh	3,583.8	-
Coefficient of variation of the RMSE = SEE / Avg (kWh/mo.)	0.1687	< 0.2
Slope (kWh / CDD)	5.52	-
Slope (kWh / Class Days.)	490.76	
Intercept (kWh / month)	(1,166.1)	-
t-statistic (for intercept)	-0.45	ABS(t) > 2
t-statistic (for CDD)	1.20	ABS(t) > 2

The IPMVP defines acceptable accuracy of the expected savings as being twice the standard error of the baseline model. For each week, the regression model defines the baseline consumption based on the current weather conditions (CDD). The standard error (SE) of the regression models is shown in the table below. The annual standard error is then the standard error for each of the 12 weeks:

$$SE_{Annual} = \sqrt{12}\ (SE_{week})$$

The resulting uncertainty of the savings estimate is:

$$Uncertainty, \% = \frac{SE_{Annual}}{\Delta\, kWh}$$

Table 11: Uncertainty

Building	**Standard Error (SE)**	**SE Annual**	**Savings kWh/year**	**Uncertainty%**
Buildings	1,035	3,584	52,261	7%

This result demonstrates that the uncertainty in the savings is significantly less than twice the standard error and therefore meets the IPMVP criterion.

To determine the confidence interval at 90% confidence level, the previous result is multiplied by the corresponding Z statistic of 1.645 (two tailed).

$$Relative\ Precision_{90\%} = Z\ Uncertainty, \% = 1.645\ (Uncertainty\%)$$

$$Absolute\ Precision_{90\%} = Z\ SE_{Annual} = 1.645\ (SE_{Annual})$$

Table 12: Uncertainty on the Expected Savings

Energy	Expected accuracy on the expected savings		Confidence interval on the savings		Confidence Level
	Relative Precision 90%	**Absolute Precision 90%**	**Lower**	**Upper**	
52,261	11.28%	5,895	46,366	58,156	90%

Scaling Factor

Another adjustment is done using 'RT Scaling Factor', due to shorter number of metered unit's vis a vis number of units replaced. Following table gives the adjustment value.

Table 13: Scaling Factor

	Refrigeration Ton (RT)	Units
RT is Project Scope	76	38
RT in Measurement	48	24
RT Scaling Factor	1.5833	

RT Scaling Factor = RT of all the units replaced / RT of all the metered units.

= 76 / 48

= 1.5833

Energy consumption of all units	= 1.5833 x	Energy consumption by metered units.

The final value of summation of all the energy consumption determined using metered data, determined data using regression and scaled using scaling factor is baseline consumption.

Meter Specifications

All power and energy measurements were carried out using ACUVIM-IIR-D-5A core power logger. The ACCUENERGY Single Type with 0.5% revenue grade accuracy.

Table 14: Meter Specifications

Meter Specifications	Meter Picture
ACCUENERGY Power Logger Measures electric AC or DC power LCD Screen DC Voltage port Built in Power line communication Supports wide range of current transformers (CTs) to accommodate virtually any size load Built-in web server Fully web-configurable Built-in solid-state memory Free life-time firmware upgrades No batteries	

BACnet IP compatible	

Expected Accuracy

The IPMVP defines acceptable accuracy of the reported savings as being twice the standard error of the measurement process.

Results

The project demonstrates the significant potential for energy and cost savings in institutional buildings through basic retrofitting. By utilizing established protocols like IPMVP and focusing on measurable data, the outcomes provide a high degree of confidence in claimed savings. The lighting component proved to have the highest contribution to savings due to high operational hours and older technology. The HVAC savings, while smaller in absolute kWh, had a higher percentage reduction due to the replacement of highly inefficient units. The results of the energy retrofit project conducted were compelling evidence of the potential for substantial energy and cost savings within institutional facilities through the implementation of targeted and relatively straightforward Energy Conservation Measures (ECMs). The data-driven approach adopted in this project, utilizing the International Performance Measurement and Verification Protocol (IPMVP), ensured that savings were not only estimated but also reliably verified through standardized, transparent methodologies. The use of IPMVP Options A and B facilitated the isolation of specific systems—lighting and HVAC—allowing for accurate assessment of energy performance improvements.

Among the two primary ECMs implemented, the lighting retrofit yielded the most significant absolute energy savings. This is largely attributed to the widespread deployment of high-efficiency LED fixtures across 11 buildings and the replacement of more than 12,000 older, inefficient luminaires. Given the extensive daily operating hours typical of educational institutions and the high baseline consumption of the previous lighting systems, the lighting retrofit alone resulted in annual savings of 1,127,331 kWh, representing a 51.32% reduction in lighting energy consumption compared to baseline levels.

In contrast, the HVAC retrofit, which involved the replacement of 38 outdated split air conditioning units with high-efficiency models, achieved relatively lower absolute savings in terms of kilowatt-hours. However, the percentage reduction was more pronounced, as the baseline HVAC systems were exceptionally inefficient. This component of the retrofit contributed 52,261 kWh/year in savings, corresponding to a 68.16% reduction in HVAC energy usage. The sharp decrease in energy consumption for cooling demonstrates the effectiveness of modern HVAC technologies in climates characterized by high cooling loads, such as the Eastern Province of Saudi Arabia.

The total verified energy savings from both ECMs amounted to 1,179,592 kWh per year, reflecting a 51.88% overall reduction in electricity consumption relative to pre-retrofit levels. From a financial standpoint, these energy reductions translated to an estimated annual cost saving of 377,469 Saudi Riyals (SAR), offering a strong economic justification for the investment in retrofitting. In addition to the monetary benefits, the retrofit also supported environmental sustainability goals by reducing the facility's carbon footprint. Based on standard emissions factors, the total energy savings equate to an estimated 831 metric tons of CO_2 emissions avoided annually, contributing meaningfully to national and institutional objectives for greenhouse gas mitigation.

These results underscore the value of integrating rigorous M&V practices into retrofit projects and demonstrate how focused upgrades in lighting and HVAC systems can yield significant and measurable improvements in energy performance. The success of this project serves as a model for similar educational institutions across the region, where aging infrastructure and high cooling demands pose ongoing challenges to energy efficiency.

The following numbers depict the savings that were guaranteed post implementation of the ECMs:

- Lighting Savings: 1,127,331 kWh/year (51.32% reduction)

- HVAC Savings: 52,261 kWh/year (68.16% reduction)

- Total Savings: 1,179,592 kWh/year (51.88% total reduction)

- Cost Savings: 377,469 SAR/year

- CO_2 Reduction (est.): 831 metric tons/year

Performance Period Activities

Following installation and commissioning of the new lamps and fixtures, power measurements on a sample of fixtures analogous to what was done in the baseline case. The savings estimates will be updated by replacing the manufacturer's specifications with measurement results for the fixtures that were measured.

Additionally, the following annual activities that are conducted are as follows:

- Conduct annual power measurement of the same samples measured before and re-adjust the savings figures.
- Conduct annual inspections to verify that all lighting equipment is functional.
- Verify that replacement stock is the same as what is currently installed.
- Take lighting level measurements on a sample of spaces to ensure that lighting levels have not degraded to unacceptable levels.

- Following installation and commissioning of the new AC units, all measurement were taken analogous to what was done in the baseline case.

During the first two performance years the following savings were recorded as mentioned in the below tables:

Table 15: Savings Performance Year-1

From	To	No. of days	CDD	Option A Savings	Option B Savings	Total savings	Savings % w.r.t Baseline
			18.5 C	**kWh**	**kWh**	**kWh**	**%**
29-Nov-22	31-Dec-22	33	54.90	148,807.22	6,525.90	155,333.13	75.02%
1-Jan-23	31-Jan-23	31	0.90	139,788.60	9,305.22	149,093.83	75.99%
1-Feb-23	28-Feb-23	28	32.60	126,260.67	7,662.95	133,923.63	75.94%
1-Mar-23	31-Mar-23	31	138.30	139,788.60	6,427.93	146,216.54	75.17%
1-Apr-23	30-Apr-23	30	230.10	135,279.29	4,535.75	139,815.04	74.76%
1-May-23	31-May-23	31	435.30	139,788.60	4,919.13	144,707.74	72.87%
1-Jun-23	30-Jun-23	30	526.30	135,279.29	6,024.60	141,303.89	74.32%
1-Jul-23	31-Jul-23	31	597.50	139,788.60	-326.39	139,462.21	73.91%
1-Aug-23	31-Aug-23	31	591.70	139,788.60	-857.53	138,931.08	71.77%
1-Sep-23	30-Sep-23	30	484.50	135,279.29	953.85	136,233.15	71.19%
1-Oct-23	31-Oct-23	31	370.60	139,788.60	4,444.70	144,233.31	72.58%
1-Nov-23	28-Nov-23	28	159.90	126,260.67	5,182.54	131,443.22	75.28%
Total		**365**	**3,622.60**	**1,645,898.08**	**54,798.67**	**1,700,696.76**	**74.04%**

Table 16: Savings Performance Year-2

From	To	No. of days	CDD	Option A Savings	Option B Savings	Total savings	Savings % w.r.t Baseline
			18.5 C	kWh	kWh	kWh	%
29-Nov-23	31-Dec-23	33	39.9	148,349.79	8,414.27	156,764.05	75.40%
1-Jan-24	31-Jan-24	31	21.2	139,358.89	6,335.93	145,694.82	75.35%
1-Feb-24	29-Feb-24	29	25.5	130,367.99	5,991.13	136,359.12	75.59%
1-Mar-24	31-Mar-24	31	93.7	139,358.89	6,972.27	146,331.16	75.15%
1-Apr-24	30-Apr-24	30	257.2	134,863.44	3,697.64	138,561.08	74.42%
1-May-24	31-May-24	31	419	139,358.89	5,039.61	144,398.51	73.11%
1-Jun-24	30-Jun-24	30	551.4	134,863.44	1,514.88	136,378.32	73.57%
1-Jul-24	31-Jul-24	31	621	139,358.89	-630.39	138,728.50	73.67%
1-Aug-24	31-Aug-24	31	583.5	139,358.89	-2,575.72	136,783.17	70.87%
1-Sep-24	30-Sep-24	30	467.4	134,863.44	-189.10	134,674.35	70.41%
1-Oct-24	31-Oct-24	31	324.5	139,358.89	3,194.02	142,552.91	72.19%
1-Nov-24	28-Nov-24	28	171.5	125,872.55	3,939.92	129,812.47	74.10%

From	To	No. of days	CDD	Option A Savings	Option B Savings	Total savings	Savings % w.r.t Baseline
			18.5 C	kWh	kWh	kWh	%
Total		**366**	**3,576**	**1,645,334**	**41,704**	**1,687,038**	**73.65%**

Conclusion

This study presents an effective implementation of energy efficiency measures in an educational facility using a structured and verifiable M&V approach. The findings support the feasibility of applying similar retrofits across other vocational institutions in Saudi Arabia. Moreover, the project offers educational value to students, supporting college's mission of integrating sustainability into technical education. This study demonstrates the practical application and long-term impact of energy retrofit strategies in a public-sector educational institution within a high-energy-demand region.

By implementing a structured and transparent Measurement and Verification (M&V) approach based on IPMVP Options A and B, the project achieved consistent and substantial energy savings across two consecutive performance years. In Performance Year 1, the retrofit achieved total energy savings of 1,700,696.76 kWh, corresponding to a 74.04% reduction compared to the pre-retrofit baseline. In Performance Year 2, a comparable savings volume of 1,687,038 kWh was recorded, representing a 73.65% reduction. These results confirm the reliability and persistence of savings, highlighting the long-term viability of retrofitting strategies when coupled with accurate M&V protocols. The most impactful savings were attributed to the LED lighting upgrade, which operated under high-use conditions, followed by the HVAC retrofits that significantly improved system efficiency. Despite variations in cooling degree days (CDD) and minor fluctuations in monthly HVAC savings, the overall performance demonstrated high consistency in energy reduction outcomes.

Beyond energy and cost savings, the project contributes meaningfully to institutional sustainability goals, including a reduction of approximately 831 metric tons of CO_2 emissions annually. Furthermore, the retrofit served as a live case study for students at the college, reinforcing the integration of sustainability concepts into vocational and technical education. This hands-on exposure to energy efficiency projects enriches the learning environment and prepares students for future roles in the energy and sustainability sectors.

The success of this initiative provides a replicable model for similar facilities across Saudi Arabia and other regions with comparable climatic conditions. It underscores the importance of targeted ECMs, rigorous M&V practices, and institutional commitment to sustainability in achieving meaningful energy and environmental benefits in the public education sector.

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List all the material used from various sources for making this project proposal

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