Abstract

This report investigates the energy performance of a typical academic building at Dundalk Institute of Technology, in response to the growing need for energy-efficient and low-carbon buildings in the education sector. The report aims to evaluate the building's thermal and electrical energy use under current conditions and assess the impact of retrofit strategies. Key objectives include estimating heat loss and annual heating demand, calculating hot water loads and internal heat gains, assessing electricity consumption, determining summer peak indoor temperatures, analysing Heating, Ventilation, and Air Conditioning (HVAC) system energy use, and evaluating the contribution of a roof-mounted photovoltaic (PV) system. The results show that proposed improvements—such as insulation upgrades, reduced air infiltration, system efficiency enhancements, and renewable energy integration—led to a 72% reduction in thermal energy demand and a 50% reduction in electricity use. Primary energy consumption decreased from 186.65 to 41.71 kWh/m²/year, while the PV system generated 23,100 kWh/year, fully offsetting electricity use and saving approximately €5775 annually. This study demonstrates how a combination of passive design, efficient systems, and on-site renewables can significantly improve building energy performance and support national sustainability goals.

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Introduction

This report investigates the energy performance of a teaching building located at Dundalk Institute of Technology, which includes a range of spaces such as classrooms, PC lab, tutorial rooms, corridors, toilets, and a café. The building is mainly used during weekdays and operates between typical school hours. Like many similar educational buildings, it relies on conventional heating, ventilation, and electrical systems, and may experience both high winter heating demand and summer overheating in certain areas. With increasing energy costs and a growing need to reduce carbon emissions, understanding how energy is used in this building and identifying ways to improve efficiency is essential.

The aim of this study is to analyse the current energy use of the building and assess how energy-saving upgrades could improve performance. The work focuses on four key objectives: first, to calculate the heat losses and heating demand in each zone by analysing the U-values of external surfaces and estimating air infiltration; second, to evaluate the total annual consumption of thermal and electrical energy under both existing and improved conditions; third, to assess the risk of summer overheating in rooms with high internal heat gains such as the computer lab using steady-state temperature modelling; and fourth, to estimate the building's primary energy demand, energy rating, and annual energy cost, comparing results before and after modifications.

The analysis reveals that heat losses through the building envelope are significant and that high internal heat gains can lead to overheating if ventilation is limited. After proposed improvements such as better insulation, reduced air leakage, and upgraded ventilation, both thermal and electrical energy demand can be reduced, indoor comfort can be improved, and overall operational costs can be lowered.

To better understand the spatial layout and corresponding thermal zones of the building, Figure 1 illustrates the architectural floor plan used in this study. It includes detailed room labels and dimensions for key areas such as classrooms, PC labs, tutorial rooms, café, toilet facilities, corridors, and staircases. This zoning framework provides the basis for calculating heat loss, internal gains, ventilation performance, and overall energy demand on a room-by-room basis. The plan also aids in distinguishing spaces with high occupancy or equipment density, which is especially relevant when assessing overheating potential and Heating, Ventilation, and Air Conditioning (HVAC) system efficiency.

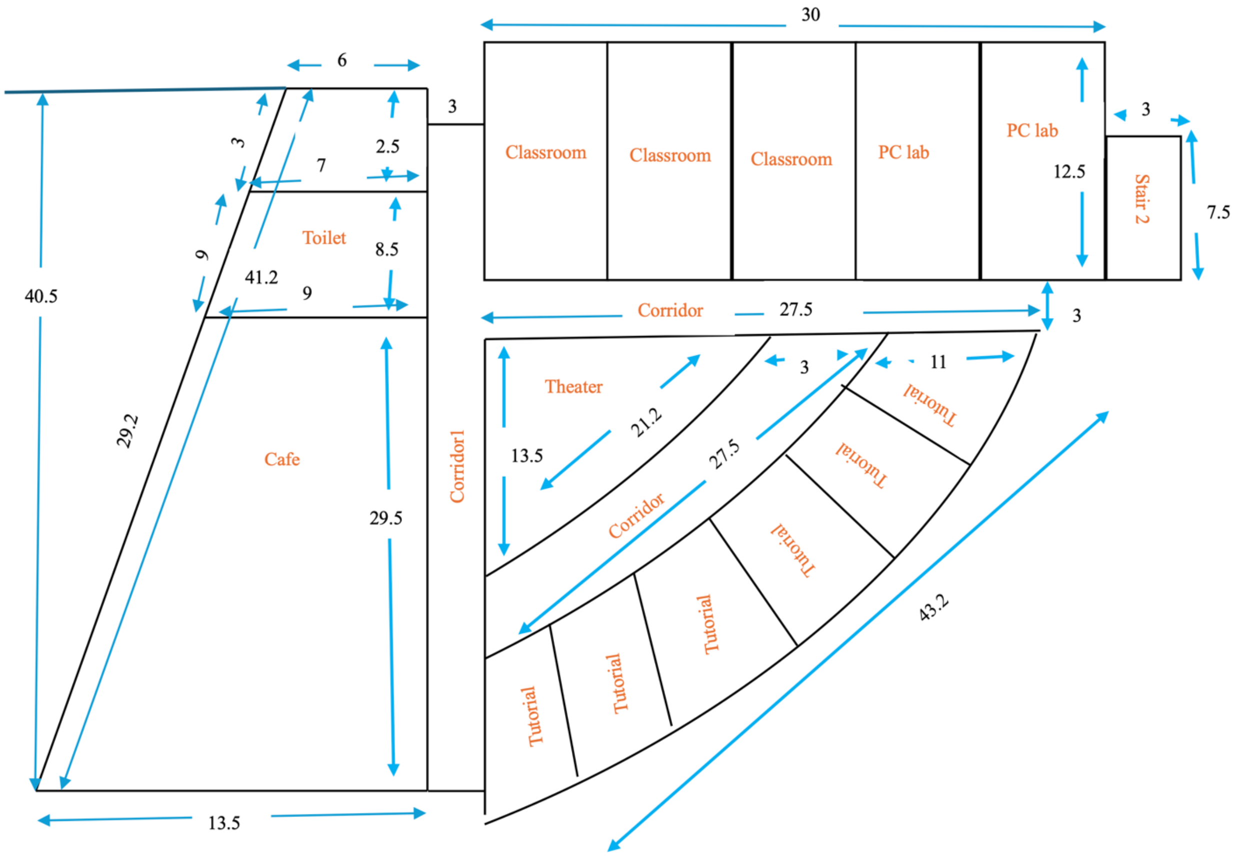

Figure 1: Zoning layout of the teaching building at Dundalk Institute of Technology

Assumption

The analysis in this report is based on a series of standard assumptions to ensure consistency and practicality in the estimation of energy performance. The building is assumed to operate under steady-state conditions and is in Dundalk, Ireland (latitude 54°N). Operational hours are from 08:30 to 17:30, Monday to Friday, with building systems remaining active for an additional two hours daily to allow for cleaning and auxiliary use. Occupancy levels are taken as constant during these periods. All windows are assumed to remain closed or fixed in a particular position throughout the year, meaning natural ventilation through openings is negligible. Mechanical ventilation is assumed to be used in all classrooms, theatre, and other occupied spaces, with system type and flow rates based on typical values or surveyed data. The influence of building thermal mass is ignored to simplify thermal response calculations, and no seasonal variation in occupancy or system operation is considered. These assumptions provide a reasonable and practical basis for comparative analysis between the existing and improved building scenarios.

Heat Loss and Annual Heating Demand

1. Theory

Heat loss in buildings primarily occurs through two mechanisms: transmission heat loss and ventilation/infiltration heat loss. Transmission heat loss refers to heat escaping through the building envelope, including roofs, walls, floors, windows, and doors. Ventilation and infiltration losses arise from the exchange of indoor air with cooler outdoor air due to intentional ventilation. These combined heat losses determine the building's heating requirement under steady-state conditions. To estimate annual heating energy demand, the degree day method is commonly used. This approach combines the building's heat loss characteristics with local climatic conditions. It uses the concept of Number degree days (NDD), which quantify how often and by how much the outside air temperature is lower than the desired indoor temperature. By multiplying the total heat loss with the accumulated NDD value, an estimate of the building's total annual heating energy demand can be obtained.

2. Input Parameter

Based on the above theoretical principles**,** key parameters were assumed in order to carry out the heat loss and annual heating demand analysis. These assumptions are outlined in the Table 1 below, including construction elements, areas, U-values, air change rates, and indoor/outdoor temperatures. All values are either taken from typical

3. Formula

To support the application of these parameters, the fundamental equations used in the calculation of total heat loss and annual heating energy are summarised in the Table 2 below. These formulae reflect the relationships between thermal transmittance, ventilation, and temperature difference, which together determine the building's heating demand.

4. Results Analysis

Following the application of the theoretical equations using the assumed parameters, heat loss values were calculated for each space type in the building. The comparison between the original and improved scenarios demonstrates a clear reduction in steady-state thermal losses after the implementation of fabric upgrades and improved airtightness. For instance, the theatre, originally exhibiting the highest heat loss at 19,591.46 W, was reduced to 6,772.39 W, reflecting a 65% decrease. The café, another large space, saw its heat loss drop from 4,412.27 W to 1,645.65 W, representing a reduction of over 60%. Tutorial classrooms, which initially averaged 3,862.64 W each, were improved to approximately 1,368.88 W, while PC labs saw a decline from 3,584.29 W to 971.01 W. These reductions are illustrated in Figure 2(original) and Figure 3 (improved), and are attributed to the lowered U-values for building elements such as walls, windows, and roofs, and a reduced infiltration rate from 1 to 0.15 air changes per hour.

In addition to room-level comparisons, the overall impact is reflected in the total building heat loss and annual heating demand. As shown in Table 3, the total heat loss (Q_loss) decreased from 83277 W in the original case to 27141 W after improvements. Correspondingly, the annual heating energy demand (E_htg) dropped from 202862.4 kWh/year to 66838.4 kWh/year—a reduction of approximately 32%. These confirm that upgrading thermal insulation and reducing air leakage have a significant and measurable effect on energy performance, particularly in larger and more exposed spaces. (For this part, more calculation details shown in another excel document “Jinyan_Energy_use_house” Ht Loss_house1 and Ht Loss_house2).

Type	**Item**	**Existing Building (Before)**	**Improved Building (After)**	**Unit**	**Source**
U_Value	Walls	0.28	0.18	W/m²·K	(Conservation of Fuel and Energy, 2019)
	Windows	2.2	1.4	W/m²·K	
	Floors	0.45	0.15	W/m²·K	
	Roofs	0.45	0.15	W/m²·K	
	Doors	2.2	1.6	W/m²·K	
Air changes per hour	ACH	1	0.15	h^{-1}	n = 0.15 h^{-1} is based on the air-tightness of 3 ACH at 50 Pa, divided by 20. This is a common rule of thumb to estimate natural infiltration in buildings (n ≈ ACH@50Pa / 20 → 3 / 20 = 0.15 h^{-1})
Orientation	Orientation	West	South		Assumed
Heat loss	Q_loss	82377	27141	W	

Table 1: Assumed Parameters for Building Heat Loss

Name	**Formula**	**Parameter Explanation**	**Purpose**	**Source**
Transmission	$\sum(U \cdot A)$	U-value times area for each envelope component		

Infiltration	nV/3	n = air change rate (1/h), V = volume (m³)		
Heat Loss	Q_loss = (∑U × A + nV/3) × (Ti - To)	U: U-value (W/m²K), A: Area (m²), n: air changes/h, V: volume (m³), Ti: indoor temp (°C), To: outdoor temp (°C)	Heat loss due to transmission and air leakage (W)	(Clancy, 2024)
Annual Heating Energy	Q_htg = Q_loss × PSR	Q_loss: steady-state heat loss (W) PSR: simplified time conversion factor (1.2)	Converts heat loss to estimated annual heating energy use (kWh/year) using a simplified multiplier	
Annual Heating Energy (Degree Day Method)	E_htg = (Q_loss / (Ti - To)) × 24 × NDD / 1000	Q_loss: heat loss rate (W), Ti: indoor temp (°C), To: outdoor temp (°C), NDD: number of degree days	Calculates annual heating energy use (kWh/year) based on outdoor climate and internal setpoint	

Table 2: Key Equations for Heat Loss and Annual Heating Energy Calculations

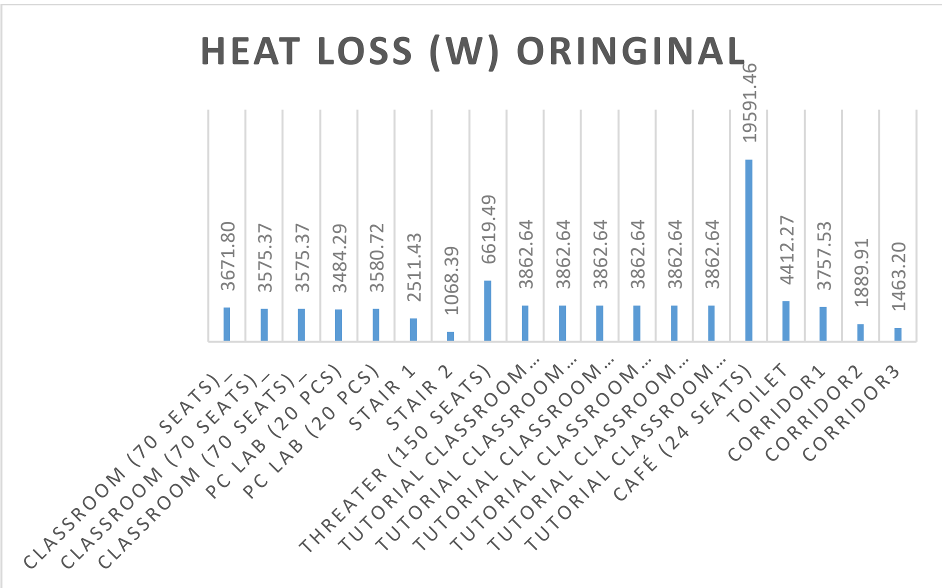

Figure 2: Heat Loss Original

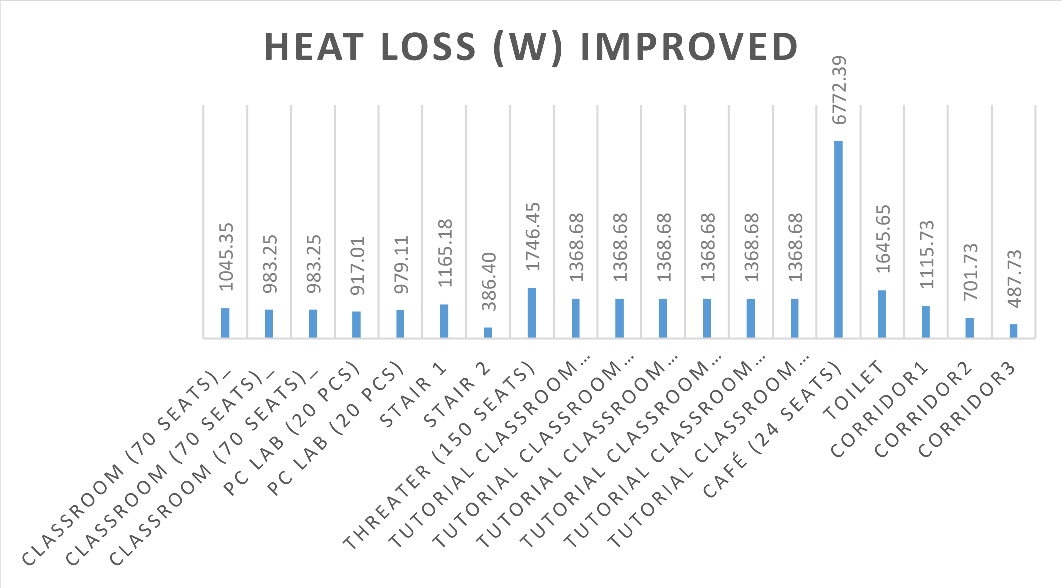

Figure 3 Heat Loss Improved

Type	Item	Existing Building (Before)	Improved Building (After)	Unit
Heat loss	Q_loss	82377	27141	W
Annual Heating Energy (Degree Day Method)	E_htg	202862.4	66838.4	kWh/year

Table 3: Heat Loss and Annual Heating Energy Comparsion

Hot Water Load

1.Theory

Domestic hot water (DHW) demand represents a portion of the total thermal energy consumption in educational buildings, particularly in areas such as cafés and sanitary facilities. Hot water load refers to the amount of energy required to heat water from its cold supply temperature to a desired usage temperature, typically for handwashing, cooking, or cleaning purposes. The DHW energy required depends on the number of users, the average hot water usage per person, the specific heat capacity of water, the desired temperature rise, and the efficiency of the water heating system. In this case, preheat times and daily usage patterns are also considered. This calculation provides a straightforward way to estimate the peak hot water heating load (in kW) as well as the annual energy demand (in kWh/year) over a specified number of usage days.

2.Input Parameter

Based on the above theoretical understanding, key assumptions were made in order to estimate both the daily and annual hot water energy demand. These include operational patterns, temperature levels, and usage rates per person, all of which are either derived from standard design guidelines (e.g. CIBSE Guide A and F) or assumed based on typical practice for educational buildings. The specific parameters used in this analysis are summarised in Table 4 below.

4.Formula

The calculation of daily and annual hot water energy use was carried out using standard thermodynamic equations. These formulas account for the volume of water, specific heat capacity, and temperature difference between inlet and storage conditions. Table 5 presents the key equations used in this process, including parameters for daily energy demand, storage energy requirements, and system power input. Since no upgrades or efficiency improvements were made to the hot water system, the calculated hot water energy demand remains unchanged between the original and improved scenarios. As such, the results from the above formulas will be considered later in the analysis of total thermal energy use and overall building energy performance (For this part, more calculation details shown in another excel document "Jinyan_Energy_use_house" Htg_hot_water).

Name	Value	Source
Operating days/year	200 days	Assumed
Hot water per person	7 L/day	(CIBSE, 2015)
Storage temperature	60°C	Assumed
Inlet cold water temperature	10°C	Assumed
Cpwater	4187W/J/kg	Assumed
Pre-heat time (h)	2h	Assumed

Table 4: Assumptions for Hot Water Load Calculations

Name	Formula	Parameter Explanation	Purpose	Source
Hot Water Load	Q_ht = (n × V × Cp × ΔT) / (Pre-heat time × 3600 × η)	n: number of people, V: hot water per person (L), Cp: water heat capacity (4.2 kJ/kg·K), ΔT: temp rise (°C), η: system efficiency	Calculates the required heating power (kW) to meet daily hot water needs within a set time period	(Clancy, 2024)
Annual Hot Water Energy Use	E_hw = (n × V × Cp × ΔT) / (η × 3600000) × Days/year	n: number of users, V: water use per person per day (L), Cp: water heat capacity (4.2 kJ/kg·K), ΔT: temp rise (°C), η: system efficiency	Calculates annual hot water energy demand in kWh, accounting for user count, system efficiency, and operating days	

Table 5: Hot Water Energy Calculation Equation

Solar Gains and Useful Solar Contribution

1.Theory

Solar gains occur when solar radiation passes through glazing and contributes to internal heating by warming surfaces and the air within a building. These passive gains reduce the need for mechanical heating, particularly during the daytime and in colder months. The total solar gain depends on factors such as the total solar irradiation received on the building's glazing, the surface area of the glazing, and the solar transmittance (g-value) of the glass. However, not all of this gain is effectively used; therefore, a utilisation factor is applied to determine the useful portion of the gain. This results in the useful solar contribution (E_solar), which reflects the solar heat that can directly offset the building's heating demand. These values are calculated using assumed parameters based on standard guidance and solar climate data, and are included in the following analysis.

2.Input Parameter

Based on the theoretical principles above, key assumptions were adopted for the solar gain analysis, as shown in Table 6. These include the solar orientation, annual solar radiation data, and the solar transmission factor of glazing. These parameters significantly affect the calculated solar gain.

3.Formula

The calculation of total solar gains and corresponding energy contribution was conducted using standard equations, as shown in Table 7. These formulas account for glazed area, solar radiation, and transmission properties of the building envelope (For this part, more calculation details shown in another excel document "Jinyan_Energy_use_house" Ht Loss_house1 and Ht Loss_house2).

Type	**Item**	**Existing Building (Before)**	**Improved Building (After)**	**Unit**	**Source**
Orientation	Orientation	West	South		Assumed
Annual solar radiation	G (2023)	598.47	855.59	kWh/m²/year	(Met Éireann Monthly data, n.d.)
Solar transmission factor	g	0.3 (shading)	0.6 (common)		(Everest, n.d.)

Table 6: Solar Gains Parameter

Name	**Formula**	**Parameter Explanation**	**Purpose**	**Source**
Annual Solar Heat Gain	E_solar =Aglass ×G×g×F×t	Aglass : Window area (m²) G: Annual solar radiation (kWh/m²/year) g: Solar transmission factor F: Shading/reduction factor (e.g. 0.6–0.8) t: Utilisation factor (optional, often = 1)	Estimates total usable solar gain through glazed surfaces. Result is in kWh/year, to be subtracted from total heating energy use.	(Clancy, 2024)

Table 7: Equations Used for Solar Heat Gain and Annual Solar Energy Calculation

Thermal energy demand

1.Theory and Formula

Thermal energy demand refers to the total amount of heat energy required annually to maintain indoor thermal comfort in a building. It is composed of multiple elements, including heat losses through the building envelope, hot water energy demand, and solar heat gains. The total annual thermal energy requirement can therefore be expressed as the sum of the space heating demand and hot water energy, minus the useful solar gain. This relationship is represented by the following equation, which provides a clear framework for estimating overall thermal demand, formula as shown in Table 8.

2.Results Analysis

As shown in Table 9, the comparison of total annual thermal energy demand between the original and improved scenarios highlights the significant energy-saving potential achieved through building performance upgrades. The original annual heating energy (E_htg) was calculated at 202862.4 kWh, which is substantially reduced to 66838.4 kWh in the improved case — a reduction of approximately 32%**.** This reduction is attributed primarily to enhanced insulation (lower U-values) and improved airtightness, which significantly cut down transmission and infiltration losses. The domestic hot water energy (E_hw) remains constant at 50042.4 kWh, since no changes were made to occupant usage or water heating assumptions. However, the useful solar gains (E_solar) increased from 2,692.59 kWh to 7,697.22 kWh due to improved window orientation and higher solar transmission factor (from west-facing with g = 0.3 to south-facing with g = 0.6). This further reduces the net thermal load in the improved scenario. Consequently, the total annual thermal energy demand (E_total) dropped from 225973.7 kWh/year to 39877.7 kWh/year, representing a remarkable 72% improvement in thermal efficiency. This analysis confirms the effectiveness of passive design strategies — including solar optimization and envelope enhancements — in reducing energy consumption in educational buildings (For this part, more calculation details shown in another excel document "Jinyan_Energy_use_house" Th_energy1 and Th_energy2).

Name	Formula	Parameter Explanation	Purpose
Total Thermal Energy	E_th = E_hw + E_htg- E_solar	E_hw: annual hot water energy (kWh), E_htg: annual space heating energy (kWh) E_solar: annual solar energy (kWh)	Calculates the total annual thermal energy demand of the building

Table 8 Thermal Energy Equation

Type	Item	Existing Building (Before)	Improved Building (After)	Unit
Annual Heating Energy	E_htg	202862.4	66838.4	kWh/year
Annual hot water energy	E_hw	50042.4	50042.4	kWh/year
Annual Solar energy	E_solar	26931.2	77003.1	kWh/year
Annual Thermal Energy	E_total	225973.7	39877.7	kWh/year

Table 9: Thermal Energy Results Comparison

Electricity Load

1.Theory

Electricity load in buildings refers to the total electrical energy consumption required to operate lighting, equipment, and building services throughout the year. This includes both fixed loads, such as lighting and plug loads, and variable loads, such as HVAC system components, pumps, fans, and electronic devices. The estimation of annual electricity demand is essential for evaluating operational energy performance and identifying opportunities for efficiency improvements. In this analysis, electricity consumption is calculated based on the power demand (W/m² or W/unit), floor area or equipment quantity, operating hours per day, number of days per year, and a diversity factor that reflects actual usage probability. Different load categories are considered according to space type (e.g., classrooms, PC labs, cafés), and values are guided by design norms such as CIBSE Guide F or SEAI benchmarks where applicable. The total electricity use is aggregated for all rooms and systems to determine the overall building demand. This method enables a detailed breakdown of how much energy each function consumes, which is critical when assessing energy-saving interventions such as LED lighting retrofits, improved equipment efficiency, or smart control systems. It also provides input for cost estimation and carbon footprint analysis.

2.Input Parameter

Based on the methodology outlined above, assumptions were made regarding the electrical load characteristics of various equipment and systems across the building. These assumptions are summarised in Table 10, comparing the existing and improved building scenarios. The key changes include reduced lighting power density by adopting LED systems, lower power demand for PCs and projectors through energy-efficient models, and a reduced diversity factor due to better control strategies and user behaviour awareness. These revised input parameters provide the basis for quantifying electricity consumption reductions under improved energy efficiency strategies. The detailed load calculations and annual electricity use results will be presented and compared in the following sections.

3.Formula

To quantify the total annual electricity consumption of various equipment and systems across the building, the following formula was applied: This expression accounts for both the rated power and operational characteristics of the devices, adjusted by realistic diversity factors. It was applied to each load item based on the assumed parameters in Table 11, such as PC usage, lighting density, and equipment ratings. The calculated results provide a comprehensive overview of electricity demand for both existing and improved scenarios and are discussed in the analysis section

4.Results Analysis

Following the application of the above calculation method and assumed parameters, the total annual electricity load was determined for both the existing and improved building scenarios. As shown in Table 12, the existing building consumes approximately 21,779 kWh/year**,** whereas the improved building consumes only 10,705 kWh/year. This represents a 50.85% reduction in electricity consumption. The substantial decrease is primarily due to efficiency enhancements such as switching to LED lighting, enabling PC sleep mode, reducing projector power ratings, and adjusting diversity factors for more realistic usage patterns. These improvements not only lower operational energy demands but also contribute to a reduced carbon footprint and enhanced energy performance across the facility (For this part, more calculation details shown in another excel document “Jinyan_Energy_use_house” Electricity Load1 and Electricity Load2).

Type	New	Existing Building (Before)	Improved Building (After)	Unit	Source
Lighting	LED Lights	10	5	W/m²	(CIBSE Guide F, n.d.)
PC	PC(enable sleep mode)	100.00	60	W	
Projector	LED Projector	200	150	W	
Diversity		0.7	0.5		
Pumps		2.00	2.00	W/m²	
Router, Switch ports		2.00	2.00	W/m²	
Controls		1.00	1.00	W/m²	
Network Switches		5.00	5.00	W/m²	
Audio system, spotlighting		1000.00	1000.00	W	
Media equipment		5.00	5.00	W/m²	
Coffee machine		1500.00	1500.00	W	
Refrigerator		300.00	300.00	W	
Microwave		1000.00	1000.00	W	
Kettle		1500.00	1500.00	W	
Router, POS		100.00	100.00	W	
Plug loads		5.00	5.00	W/m²	

Table 10: Electricity Load Input Parameter Summaries

Type	Item	Existing Building (Before)	Improved Building (After)	Unit
Annual Electricity Load	P	21778.97	10705.31	kWh/year

Table 11: Annual Electricity Load Results Comparison

Internal Heat Gains

1.Theory

Internal heat gains refer to the thermal energy generated within a building due to occupants, lighting, and electrical equipment. These gains can significantly influence indoor temperature and comfort, especially in spaces with high occupancy or electronic usage such as PC labs and classrooms. The primary sources of internal gains include metabolic heat from people (140 W/person), heat emitted by lighting systems (estimated using a power density such as W/m²), and equipment loads such as PCs, projectors, which are calculated based on their power rating, usage duration, and diversity factors. These internal heat contributions are summed to determine the total internal gain in a space, which is then used in ventilation and cooling calculations to maintain indoor comfort. Understanding and quantifying internal gains is essential for accurate HVAC sizing and thermal performance analysis.

2.Input Parameter

Based on the theoretical understanding of internal heat gains, a series of standard assumptions were applied to estimate gains from occupants, equipment, and lighting within the building. These include temperature settings, equipment loads, and ventilation characteristics. As shown in Table 12**,** the assumed parameters cover supply and room air temperatures, fan efficiency, air density, external design temperature, and pressure losses. For the improved scenario, enhancements such as better ventilation efficiency (e.g., higher fan performance), increased solar transmission control, and optimized temperature setpoints were also assumed. All values are based on CIBSE Guide F or commonly accepted engineering estimates, ensuring consistency and relevance in the building's heat gain assessment.

3.Formula

The calculation of internal heat gains was based on standard engineering equations that account for contributions from people, lighting, and equipment. These include sensible heat gain from occupants, radiant and convective components of lighting and equipment, and any additional gains introduced via ventilation airflow. The relevant equations used to estimate total heat gain are summarized in Table 13 below, which aligns with the assumptions previously outlined and follows CIBSE Guide F standards (For this part, more calculation details shown in another excel document “Jinyan_Energy_use_house” Tmax_final1 and Tmax_final2).

Type	Item	Existing Building (Before)	Improved Building (After)	Unit	Source
Supply	Supply	15		oC	(CIBSE Guide F, n.d.)
Room	Room	22.00		oC	
Fan efficiency	Fan effi	0.70			
Air density	ρ	1.20		kg/m³	
Pressure	Pressure	500.00		pa	
Solar gain factor	g	0.30	0.6		
Specific heat of air	Cp air	1020.00		J /(kg K)	
Lights		10.00		W/m2	
Occupants		140.00		W	
Projector		200.00		W	
PC		100.00		W	

Table 12: Heat Gain Input Parameters Summaries

Name	Formula	Parameter Explanation	Purpose	Source
Solar Heat Gain (Qsolar)	Q_solar = g × I × A_glass	g: solar gain factor (0–1), I: irradiance (W/m²), A_glass: glass area (m²)	Solar radiation entering through windows (W)	(Clancy, 2024)
Surface Heat Gain (Qs)	Qs = Load (W/m²) × Area (m²)	Load: heat gain rate per square meter; Area: floor area	Calculates total heat gain from surface-based loads like lights	
Internal Load Heat Gain (Ql)	Ql = Quantity × Unit Load (W)	Quantity: number of items; Unit Load: heat gain per item (e.g., 140 W/person)	Calculates heat gain from discrete internal sources like people, PCs, projectors	
Total Heat Gain (Q_total)	Q_total = Qs + Ql+ Qsolar	Summation of all heat gain components	Total heat gain used in cooling and ventilation calculations	

Table 13: Heat Gain Equation Summaries

Summer Maximum Indoor Temperature

1.Theory

During summer, indoor thermal conditions are influenced by both internal heat gains and the building's ability to remove heat. In naturally ventilated spaces, heat accumulates from sources such as occupants, lighting, PC, and other electrical equipment. If this heat is not effectively dissipated through the building envelope or ventilation, it can lead to uncomfortable indoor temperatures, especially in spaces with high occupancy or equipment density, such as PC labs and lecture theatres. In the absence of active cooling systems, the maximum indoor temperature is primarily governed by the balance between internal gains and passive heat loss mechanisms—namely, conduction through the fabric and natural ventilation. This makes such buildings more vulnerable to overheating during hot weather.

To address this issue, HVAC systems are commonly used to provide mechanical ventilation and active cooling. These systems draw in cooler air, typically supplied at a lower temperature, and extract warmer room air, thereby reducing the indoor temperature more effectively than passive means alone. Additionally, HVAC allows for controlled airflow rates and temperature settings, which help maintain thermal comfort during peak summer conditions. In upgraded scenarios, increasing airflow or optimizing fan efficiency further enhances the building's ability to manage internal heat loads, reducing the likelihood of overheating. Therefore, integrating HVAC systems into the thermal control strategy not only improves comfort levels in summer but also ensures that internal temperatures remain within acceptable limits, even under high load conditions.

2.Input Parameter

Following the theoretical explanation of the HVAC system and indoor temperature dynamics, the specific parameters used in the calculations are presented in Table 14. These include values for external and inlet air temperatures, air change rates (ACH), air density, specific heat of air, and fan efficiency—all based on assumed data or guidance from Guide F. These parameters are essential for estimating both the summer maximum indoor temperatures and the fan energy requirement for maintaining comfort. To quantify these effects, the calculation formulae used for both summer indoor temperature estimation and HVAC fan energy use are provided in Table 15 and Table 16, respectively. These equations incorporate both thermal and ventilation-related variables and are key to understanding how indoor climate can be controlled through system operation and fabric upgrades. Following the implementation of ventilation and HVAC system improvements, significant variations were observed in both the summer maximum indoor temperatures and associated energy consumption. Table 17 illustrates that in almost all spaces, the maximum indoor temperatures (Ti max) decreased after the improvement, all the Ti max under the 30 °C or close 30 °C, because we use lower U_vaule and increase the ACH. For instance, in the PC Lab, the temperature dropped from 42.15°C to 29.96°C, and in the classroom, it fell from 48.16°C to 29.45°C, while ACH from 1-8 h^{-1}. These substantial reductions demonstrate that improved ventilation rates and supply air strategies effectively reduced overheating risks during summer periods.

Simultaneously, Table 18 shows changes in HVAC-related energy consumption. The total internal heat gain remained relatively consistent (87,598.95 W before and 87,426.14 W after), indicating stable internal loads. However, the annual fan energy increased from 924.76 kWh/year to 1,459.73 kWh/year due to enhanced airflow rates. In contrast, the combined energy for preheating and coil operation was dramatically reduced from 1,415.91 kWh/year to only 105.64 kWh/year. This highlights a key benefit of the improved system: although ventilation energy rose, better temperature control and heat recovery minimized the heating demand significantly. These outcomes confirm that while improved ventilation may slightly increase fan energy use, it greatly reduces overheating and peak indoor temperatures, leading to a more comfortable environment and significantly reduced heating loads during transitional seasons (For this part, more calculation details shown in another excel document "Jinyan_Energy_use_house" Tmax_final1 and Tmax_final2).

Type	**Item**	**Existing Building (Before)**	**Improved Building (After)**	**Unit**	**Source**
External Temp.	To	20	18	oC	(CIBSE Guide F, n.d.)
Min airflow	ACH	1.00		a/c/h	
Inlet air temp	T1	0.70	150		
Preheat target temp	T2	1.20		kg/m^3	
Final supply temp	T3	500.00		pa	

Table 14: Summer Temperature and HVAC System Parameters

Name	Formula	Parameter Explanation	Purpose	Source
Pre-heater Load	Q_preheat = ṁ × Cp × (T2 - T1)	ṁ = mass flow rate of air (kg/s); Cp = specific heat capacity of air (J/kg·K); T2 = preheat target temp; T1 = inlet air temp	Calculates energy required to preheat incoming fresh air	(Clancy, 2024)
Heating Coil Load	Q_coil= ṁ × Cp × (T3 - T2)	ṁ = mass flow rate of air (kg/s); Cp = specific heat of air; T3 = final supply temp; T2 = preheated air temp	Calculates energy required by main heating coil after preheat	
Total Heating Required	Q_heat = ṁ × Cp × (T3 - T1)		Combined heat required to bring air from inlet to final temp	
Fan Load	P_fan = ΔP × V̇ / η	ΔP = pressure loss; V̇ = flow rate; η = fan efficiency	Electrical power needed by fan to overcome resistance	

Table 15: Formula for Estimating Summer Maximum Indoor Temperature

Name	Formula	Parameter Explanation	Purpose	Source
Airflow for Cooling	$\dot{m} = Q / [C_p \times (T_i - T_o)]$	Q: heat gain (W), Cp: air specific heat (J/kg·K), Ti, To: temperatures (°C)	Air mass flow rate needed to remove heat (kg/s)	(Clancy, 2024)
Volume Flow Rate	$V = \dot{m} / \rho$	ṁ: mass flow (kg/s), ρ: air density (kg/m³)	Converts mass flow into volume flow (m³/s)	
Internal Max Temperature (with full losses)	$T_i = T_o + Q_{gain} / (\Sigma UA + nV/3 + \dot{m} \times C_p)$	To: outdoor temp (°C); Qgain: total internal heat gains (W); ΣUA: fabric heat loss (W/K); nV/3: infiltration loss (W/K); ṁ: air mass flow rate (kg/s); Cp: specific heat of air (J/kg·K)	Calculates the peak indoor temperature in a room with heat gains, minimal ventilation, and envelope/infiltration losses considered	

Table 16: Formula for Calculating HVAC System Energy Consumption

	ACH (h-1)		Ti max (oC)	
Type	Existing Building (Before)	Improved Building (After)	Existing Building (Before)	Improved Building (After)
Classroom	12.42	7.00	48.16	29.45
Classroom	12.42	7.00	48.67	29.50
Classroom	12.42	6.00	48.67	31.25
PC Lab	9.43	5.00	42.15	29.96
PC Lab	9.43	5.00	41.75	29.88
Threater	15.39	8.00	56.26	30.65
Tutorial Classroom	5.04	7.00	42.20	28.06
Tutorial Classroom	11.38	7.00	42.20	28.06
Tutorial Classroom	11.38	6.00	42.20	29.51
Tutorial Classroom	11.38	6.00	42.20	29.51
Tutorial Classroom	11.38	6.00	42.20	29.51
Tutorial Classroom	11.38	6.00	42.20	29.51
Café	13.66	1.00	25.25	27.77
Toilet	0.41	1.00	23.82	24.95
Corridor	2.17	1.00	26.54	28.64

Table 17: ACH and Maximum Summer Internal Temperature

Type	**Item**	**Existing Building (Before)**	**Improved Building (After)**	Unit
Total Heat gain	Qtotal	87598.95	87426.14	W
Annual Fan Energy	E_fan	924.76	1459.73	kWh/yr
Annual preheat and coil Energy	Epreheat+Ecoil	1415.91	105.64	kWh/yr

Table 18: Annual HVAC Results Comparison

Primary Energy Demand

1.Theory

Primary energy refers to the total amount of energy required to deliver usable energy to a building, including losses from generation, transmission, and distribution. It provides a more comprehensive assessment of environmental impact than final energy consumption alone. The primary energy demand is calculated by multiplying each type of energy end-use (e.g., space heating, hot water, electricity) by its corresponding primary energy factor, which accounts for the upstream losses in the energy supply chain. In this analysis, electricity and thermal energy (used for heating and hot water) are both considered. The assumed primary energy factors are 2.0 for electricity and 1.1 for thermal energy, based on standard values from energy performance benchmarks (Clancy, 2025). These values reflect the energy losses that occur in power generation plants and heating systems before reaching the building. By applying these factors, the building's total primary energy use before and after the proposed fabric and system improvements can be estimated, serving as a key indicator for assessing energy performance and Building Energy Rating (BER).

Following the application of the primary energy factors to the calculated energy demands, a significant reduction in total primary energy use is observed after implementing the proposed improvements. As shown in Table 19, the total primary energy demand decreased from 186.65 kWh/m²/year in the existing building to just 41.71 kWh/m²/year in the improved scenario. This reduction is mainly attributed to lower electricity consumption due to energy-efficient lighting and equipment, as well as reduced heating demand through fabric upgrades and improved air-tightness. These results highlight the effectiveness of the proposed design measures in enhancing the building’s overall energy performance and contribute substantially toward achieving a better Building Energy Rating (BER) (For this part, more calculation details shown in another excel document “Jinyan_Energy_use_house” Primary_Energy1 and Primary_Energy2).

Type	Existing Building (Before)	Improved Building (After)	Unit
Primary energy (thermal)	158.82	28.03	kWh/m2/year
Primary energy (elect)	27.83	13.68	kWh/m2/year
Total Primary Energy	186.65	41.71	kWh/m2/year

Table 19: Total Primary Energy Results Comparison

Annual Energy Costs

1.Theory

The annual energy cost of a building refers to the total monetary expenditure required to meet its energy demands over the course of a year. It typically includes the cost of electricity, heating, and other energy services used to maintain comfort and functionality. Calculating this cost allows for an assessment of the building's financial performance in relation to its energy efficiency. Annual energy costs are derived by multiplying the total annual energy consumption of each system or energy type (measured in kWh/year) by the corresponding unit energy price (in €/kWh). For example, electricity used for lighting, equipment, and HVAC components such as fans or preheat coils is calculated using the electricity tariff, while gas or other fuels—if used—would apply different rates. This cost evaluation is especially important when comparing different design scenarios (e.g. existing vs. improved) to assess the economic benefit of energy-saving measures such as improved insulation, lighting upgrades, or HVAC system enhancements.

2.Input Parameter

Based on the calculated energy demands and the assumed unit prices for different energy types, the annual energy costs were estimated accordingly. Electricity was assumed to cost €0.25 per kWh, while heating energy (e.g., from gas or district heating) was priced at €0.10 per kWh. These rates reflect typical commercial tariffs and are used to estimate total energy expenditure before and after building improvements.

2.Formula

To support the calculation process, Table 20 presents the key formulas used to estimate HVAC-specific and total annual energy costs, along with parameter explanations and their intended analytical purposes.

3.Formula Results Analysis

The comparative analysis of annual energy costs, as summarised in Table 21, reveals a significant reduction in total expenditure following the proposed building improvements. The annual thermal energy cost dropped sharply from €22,597.37 to €3,987.77**,** reflecting the substantial reduction in heating demand due to improved insulation, air tightness, and solar gain utilisation. Similarly, the annual electricity cost decreased from €5,444.74 to €2,676.33, largely driven by upgrades to more efficient lighting and equipment, as well as optimised operational diversity. Moreover, the HVAC-related electricity cost also saw a reduction, from €711.73 in the existing building to €213.25 post-retrofit. This further highlights the positive impact of improved ventilation strategies and fan efficiency. Overall, these results confirm the economic viability of energy-efficiency upgrades, as both heating and electrical costs have been cut by over 50%, leading to substantial long-term savings (For this part, more calculation details shown in another excel document "Jinyan_Energy_use_house" Cost).

Name	Formula	Parameter Explanation	Purpose
HVAC Cost	E_fan + E_preheat+coil× Electricity price		To calculate the total HVAC-related electricity cost per year
Annual Energy Cost	Energy Consumption (kWh) × Unit Cost (€/kWh)	Energy Consumption: total energy use (heating + electricity) Unit Cost: electricity or heating energy unit price in €/kWh	To estimate the annual energy cost of the building

Table 20: Total Energy Cost Equation

Type	Item	Existing Building (Before)	Improved Building (After)	Unit
Annual Thermal Energy	Cost	22597.37	3987.77	€/kWh
Annual Electricity Load	Cost	5444.7425	2676.3275	€/kWh
HVAC	Cost	711.73	213.25	€/kWh

Table 21: Total Energy Cost Results Comparison

Renewable Energy Strategy – Integration of Roof-Mounted PV System

As part of the building improvement strategy, the integration of renewable energy systems is proposed to further reduce the building's reliance on grid-supplied electricity. Specifically, the installation of a roof-mounted photovoltaic (PV) system is considered a viable and effective approach. This strategy not only offsets part of the building's annual electricity consumption but also aligns with sustainability goals and national energy efficiency targets. By utilising available roof space for solar PV panels, the building can generate a portion of its electrical demand on-site using clean energy. The potential PV output depends on several factors, including the orientation and tilt of the roof, local solar irradiation levels, panel efficiency, and system performance ratio. Even a modest-sized PV system can make a meaningful contribution to lowering primary energy use and reducing operating costs over time.

In this analysis, the PV system is proposed as an additional measure beyond passive improvements like insulation or air tightness. It reflects a shift from purely demand reduction to also addressing supply-side decarbonisation. This holistic approach strengthens the building's long-term energy resilience, contributes to carbon neutrality objectives, and enhances the overall BER. Future extensions of the system or coupling with battery storage could further optimise energy use patterns and support peak load management.

Parameter	Value	Source / Note
Roof area available for PV	200 m²	Assumed
Annual irradiation (G)	855.59 kWh/m² /year	Based on south-facing improved case
PV panel efficiency (η)	18% (0.18)	Typical commercial panels
Performance ratio (PR)	0.75	Accounts for system losses

Table 22: Assumptions for PV System Performance

Name	Formula	Parameter Explanation
PV Output (Q_PV)	Q_PV = G × A × η × PR	G = irradiation; A = panel area; η = efficiency; PR = performance losses

Table 23: PV Output Formula

Substitute Example:

$Q\_PV = 855.59 \times 200 \times 0.18 \times 0.75 \approx 23{,}100$ kWh/year

The estimated annual energy yield from the proposed PV system is approximately 23,106 kWh/year. This output can cover a significant portion — or even all — of the building's improved annual electricity demand (e.g., 10,705 kWh/year from previous analysis), resulting in net-zero electricity consumption or even export to grid in summer months. By generating on-site renewable electricity, the building reduces its primary energy use, improves its Building Energy Rating (BER), and lowers operational carbon emissions. Moreover, this strategy provides long-term savings on energy bills and strengthens the resilience of the building to energy price fluctuations or supply interruptions.

Conclusions

This report has presented a comprehensive analysis of the energy performance of a campus building located at Dundalk Institute of Technology, with a focus on both the existing conditions and proposed energy-efficient improvements. Through detailed calculations of heat loss, hot water demand, solar heat gain, and electricity usage, the baseline energy profile of the building was established. The analysis showed that space heating and internal electrical loads represented the largest contributors to annual energy consumption. Subsequent improvements—such as upgraded insulation (lower U-values), enhanced airtightness (reduced infiltration), improved lighting and equipment efficiency, and increased mechanical ventilation rates—resulted in significant energy savings across all categories. The total thermal energy demand was reduced by more than 32%, and electricity consumption was halved. In addition, peak indoor summer temperatures in heat-intensive spaces (such as PC labs) were significantly lowered, improving thermal comfort through better HVAC operation.

To further enhance performance, a roof-mounted photovoltaic (PV) system was proposed. The system is assumed capable of generating up to 23,106 kWh/year, more than enough to meet the building's entire annual electricity demand, leading to potential annual savings of €2,676 and even surplus energy generation. When all components were considered, the primary energy use dropped from 186.65 kWh/m²/year to just 41.71 kWh/m²/year, substantially improving the building's Building Energy Rating (BER). The combination of passive design strategies, system upgrades, and renewable energy integration demonstrates a clear path toward improved energy efficiency, occupant comfort, and operational cost savings. The results validate the proposed measures as practical and impactful solutions for achieving near-zero energy performance in educational buildings.

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