SEI SUSTAINABLE ENERGY IRELAND

UCC Information Technology Building

Contents

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1 Introduction

University College Cork proposes to construct an IT building on the site of the old greyhound track located on the Western Road in Cork city.

The 15,871m^2 building will serve both the Department of Computer Science and the Department of Microelectronics. It will also provide space for a number of commercial operations.

The building allows for future increased space requirements for computer facilities; it is also sized to allow for future expansion of undergraduate and postgraduate student numbers in the Department of Computer Science and in the Department of Microelectronics.

The structure comprises three floors, which can be divided into two separate areas. The first floor incorporates the main atrium, teaching labs, computer labs, lecture auditoria, research facilities and office space. South of the courtyard is a three-storey cellular office block with restaurant facilities.

Architectural features include an atrium, a courtyard that runs the length of the building, and extensive glazing.

2 The Design Approach

The overall building design is light filled and elegant, portraying a strong, modern image of a progressive university.

In its design brief UCC asked that PM consider using a sustainable approach when designing the building's mechanical and electrical services. This would mean limiting the use of artificial lighting and maximizing the use of natural light in order to create bright airy spaces throughout the building. Emphasis was also to be placed on reducing both conventional heating and mechanical ventilation, and avoiding the use of air-conditioning. In addition, in order to create a 'low-energy building' it was considered important that both the form of the building and construction of the building envelope should integrate seamlessly with engineering services. In particular, consideration was to be given to the use of combined heat and power (CHP) technology and the use of ground source heating systems.

UCC was willing to consider any proposal where running costs would be minimised and where the initial capital cost could be retrieved within a period of five years. In certain circumstances a payback period that extended beyond five years would be considered.

For a building of this type (and taking its high IT loading into consideration) the target for HVAC and lighting energy consumption would be 150-200 kWh/m^2/yr. Current best practice as applied to similar buildings in the UK aims to achieve a target of 100 kWh/m^2/yr. However, it is unclear if these targets are actually being met.
In the case of the UCC building, the target adopted for HVAC and lighting energy consumption was within the range of 100-150 kWh/m^2/y.

Potential energy-saving solutions were analysed and compared using IES, a sophisticated software package; this is a thermal simulation package capable of modelling a wide range of HVAC systems in conjunction with modelling a building's thermal performance. It uses dynamic simulation techniques to trace the thermal state of the building through a series of hourly snapshots. Thus, the user is provided with a detailed picture of the way the building would perform throughout the year – in weather conditions ranging from average to extreme.

IES was used to examine:

- The suitability of the building design in terms of the use of natural/ mechanical ventilation methods
- Energy consumption sensitivity to U-values
- Energy consumption associated with mechanical systems
- The applicability of using a combined heat and power system
- Groundwater cooling analysis

3 Form and Fabric

The design team used the following passive design techniques:

- High heat gain spaces such as computer labs and auditoria are located in the northern section of the building, away from direct solar gain. Low heat gain spaces, such as offices, are located on the southern side. There are no spaces with east and west-facing glazing; thus the glare created by low-angle summer sun is avoided.
- Access to solar heating is maximised because the main glazed facades face southeast and northwest. As a result, these spaces are heated during the morning and have some degree of solar shading during the evening.
- The atrium is used as a solar collector and a thermal buffer during the winter, and as a natural stack for extracting air during the summer.
- All areas benefit from natural ventilation and direct daylight.
- The use of exposed ceiling slabs facilitates thermal mass cooling.

Thermal dynamic software was used to establish the benefits that might be derived from improving the building element U-values above those required by Irish building regulations.

The four models in Figure 3.1 were assessed in terms of likely energy consumption over a typical 12-month period.

The (R) and SI (1) models provide the best performance in terms of achieving CO_2 reductions (i.e. reductions of 7% and 10% respectively). As the graph above illustrates, it appears that from an energy consumption point of view the benefits of using high solar control glass are not as significant as might be expected. This is due to the following factors:

- Lower building occupancy rates during the summer mean that cooling requirements are nominal only. Moreover, the use of solar control glazing prevents solar heating during the winter months, thereby increasing the heating load.
- Most of the energy consumption and running costs are related to the mechanically-based system which is located on the north side of the building; the issue of solar control is not as important in an area with northern-facing glazing. On the south side of the building, where solar control glass is most effective and where the area is predominantly naturally ventilated, energy consumption is almost entirely related to heating demand.

At the time of writing this report, accurate capital cost estimates were not available; therefore it was not possible to carry out a detailed lifecycle costing. However it would appear that the annual savings derived from increased elemental U-values would not provide paybacks within the suggested five-year period. In fact, they would be more likely to be in the thirty-year range.

The PM team concluded therefore that consideration should be given to using different solar control specification glazing on both the north side and the south side of the building. The south side would benefit from the increased thermal comfort of high solar control glazing while the northern mechanical section – with additional solar heating provided by a less stringent solar control specification – would benefit from a lower heating requirement and therefore lower energy consumption.

The Recommended (R) insulation model could provide the best compromise between CO_2 reduction and initial capital cost.

	Building regulations (BR)	Recommended (R)	Super-insulated 1 (SI(1))	Super-insulated 2 (SI(2))
Exposed walls	0.45 W/m²k	0.25 W/m²k	0.25 W/m²k	0.25 W/m²k
Ground floors	0.45 W/m²k	0.25 W/m²k	0.20 W/m²k	0.20 W/m²k
Roofs	0.25 W/m²k	0.25 W/m²k	0.20 W/m²k	0.20 W/m²k
Windows & doors	2.03 W/m²k	1.9 W/m²k	1.57 W/m²k	1.57 W/m²k
Roof lights	3.3 W/m²k	1.9 W/m²k	1.57 W/m²k	1.57 W/m²k
Glazing shading coefficient	58%	58%	58%	43%

Figure 3.1

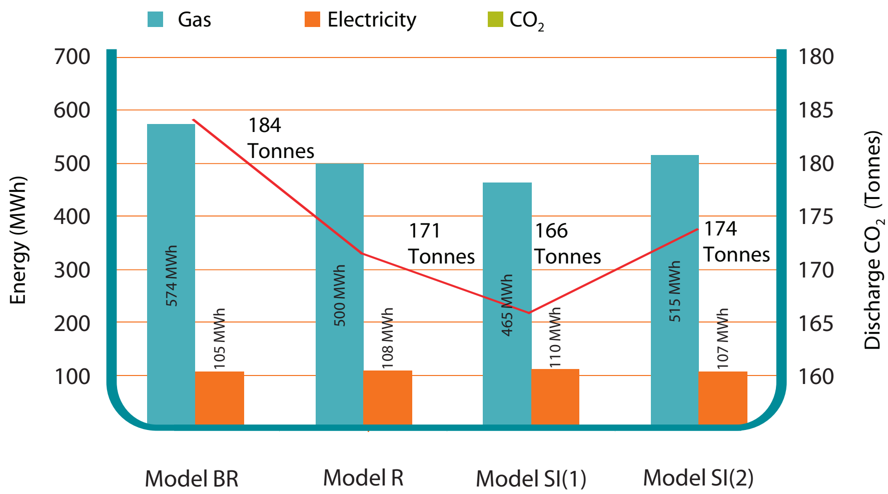


Figure 3.2 - Annual U Value, Energy Consumption and Discharge of CO_2

4 Ventilation Strategy

During the initial stages of the concept design process, PM considered opting for a naturally ventilated solution incorporating stack-driven ventilation through the atrium, with additional stacks strategically located throughout the building. The suitability of this solution was assessed using dynamic thermal analysis and computer fluid dynamics.

The results indicate that due to the depth of the building coupled with the high density of the IT equipment located throughout, it would not be possible to maintain peak temperatures within the CIBSE comfort criteria i.e. an inside dry resultant temperature of 25ºC is not exceeded for more than 5% of the annual occupied period (typically 125 hours).

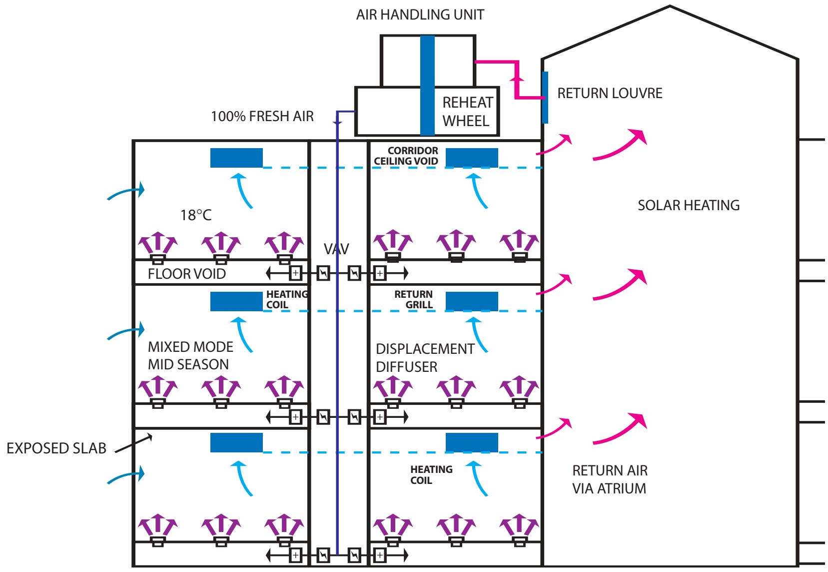
PM concluded that mechanical ventilation methods should be used in all teaching auditoria and computer lab areas and natural ventilation methods should be used in the cellular and open plan office block areas which are located on the southern side of the building.

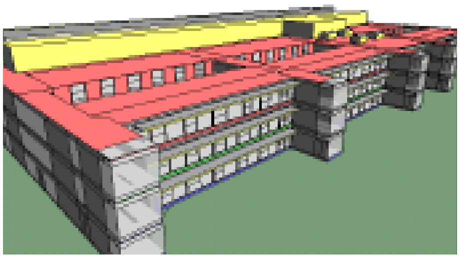
Natural ventilation

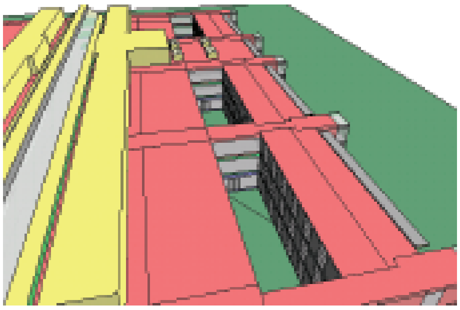
In order to verify the suitability of the natural ventilation method, IES software was used to create a thermal model for the naturally ventilated office block areas on the south side of the building. The model incorporated 1.1m horizontal brise-soleil, full-height solar control glazing (shading coefficient 0.44), and exposed ceiling to take advantage of night-time cooling.

A courtyard runs near the north of the office block thus facilitating a cross-flow ventilation arrangement.

The results indicate that when applied to the peak temperature profile, night-time cooling maintains the internal temperature in the office spaces to within 1.5ºC of the external temperature. The total average percentage of occupied hours when temperatures exceed the 25ºC CIBSE comfort criterion is 1% of the total occupied hours for the year – well below the CIBSE recommended 5% limit.







Mechanical ventilation

It was proposed to use displacement ventilation in room areas where 100% fresh air is supplied through the raised floor. In these areas the air is returned via the atrium to the plant room for heat recovery using a rotary wheel system. During the summer months, return air is extracted through the atrium roof; this is due to the stack effect.

The mechanical ventilation option facilitates the use of outside air for free cooling during a large proportion of the year; this is because the air is supplied at 18-19ºC. Displacement ventilation offers higher indoor air quality than that provided by conventional air-conditioning and other mechanical systems. Mechanical ventilation operates on a variable air volume principle in order to conserve energy, shutting down completely when the room is unoccupied.

In conclusion, the ventilation strategy comprises a mixed-mode solution which uses mechanical displacement ventilation in areas of high heat gain and natural ventilation in the south-facing office block. Thus, temperatures exceeding the 25°C level are limited to 1% of total occupied hours annually.

Excessive fan loads can be reduced by:

- The use of variable air volume to reduce air volumes when not required for cooling
- The elimination of return ducting and the use of a return plenum at the top of the atrium to reduce pressure drops
- The limiting of specific fan power to 2.0 kW per m^3/s at maximum volume per air handling unit (AHU)
- Possible use of electrostatic filters

5 Space Heating

Electrostatic filters

The use of electrostatic filters, which have much lower pressure drops i.e. (30-90 Pa), was assessed against conventional panel and bag filters (220 Pa). IES software was used to compare annual fan energy consumption for the variable air volume system.

Two options are possible:

- The first is a system where the electrostatic pads are replaced with the same frequency as that which applies to normal filters.
- The second option is a permanent filter system in the AHU. Although the filter system never needs to be replaced, it does require maintenance; it must be taken out and washed with the same frequency as that which applies to the replacement of conventional filters. This system would consume 250 W of electrical energy. It is also a capital-intensive solution. The pressure drops for both options are similar.

An analysis of the life cycle cost of both options shows a projected payback period of 4.3 years for the installation of replaceable electrostatic filters and 10.5 years for the installation of permanent electrostatic filters. If discounted paybacks at a rate of 5% per annum were to be applied, then a period of 5.0 and 15.3 years respectively would be the likely outcome.

In conclusion, the replaceable electrostatic filters are an economically viable option as they reduce fan energy emissions by 25% compared to conventional panel and bag filters. Therefore, by using this energy-saving measure it would be possible to reduce total HVAC emissions by 4.5%.

The IES model 'Recommended (R)' was used to analyse the heating loads.

The peak boiler load was estimated to be 1.35 MW for the building.

An analysis of the average seasonal efficiency of each boiler configuration was performed taking the following into account:

- Heating load profile for the year
- Standing losses
- Part-load efficiency
- Boiler supply and return temperatures

In order to optimise part-load efficiency and ensure sufficient back up, it was assumed that three boilers would be installed.

Optimising the boiler size and the use of high-efficiency and condensing boilers would deliver additional costs and emissions reductions. The table below lists the various options and shows the capital cost, running cost, CO_2 emissions reductions data and projected payback period applicable to each. An analysis of boiler loads shows that 3 X 500kW is the most efficient combination for dealing with part loads. It results in lower energy consumption than that produced by the 800 kW, 2 X 500 kW split. Moreover, it ensures that adequate back up is available should one of the boilers fail. The CCH option produces the lowest carbon emissions (11% reduction) but is the most expensive in terms of capital cost, requiring a payback period of more than five years.

Allowing for a compromise between lowest carbon emissions and highest capital cost, the best option is the CHH 3 X 500 kW option. This has a lead condensing boiler, with two high-efficiency slave boilers. When compared with the payback period required for three high-efficiency boilers, this particular option is an acceptable 3.8 years.

System	Annual gas KWh	Annual running cost	Capital cost	CO_2 reduction	Payback period
HHH 3x500	813,104	€14,433	€42,660		
CHH 3x500	768,579	€13,642	€45,629	8,816kg	3.8 yrs
CCH 3x500	755,601	€13,412	€48,598	11,386kg	5.8 yrs
HHH 800, 2x500	824,260	€14,631	€48,524		
CHH 800, 2x500	771,368	€13,692	€51,399	10,473kg	3.1 yrs

HHH = three high-efficiency boilers (full-load efficiency 84%)
CHH = one condensing lead boiler (full-load efficiency 90%); two high-efficiency boilers
CCH = one condensing lead boiler; one condensing boiler; one high-efficiency boiler

6 Combined Heat & Power

Combined heat and power (CHP) is the simultaneous generation of electricity and heat from the same plant. A synchronous generator, driven by a gas-fired engine, runs in parallel with the utility provider's electricity supply, thereby greatly reducing electrical consumption from the mains. Heat generated by the engine in the form of hot water is fed into the building's heating system. The achievement of both running cost savings and CO_2 emissions reduction is possible because electricity generated by a gas-fired CHP is produced more efficiently than that sourced from the centrally generated national grid supply. This is due to factors such as the elimination of transmission costs and losses, and the carbon-intensive nature of the national grid fuel generation mix i.e. coal, peat, oil and gas.

Typically, buildings that are used for educational purposes are virtually empty during the summer and this would make the running of a CHP plant unviable.

The UCC IT building, on the other hand, has the following characteristics:

- A significant level of occupancy is likely to be maintained by staff and researchers during the summer months.
- The IT requirements of the building are such that a high, constant electrical load must be maintained throughout the year.
- One consequence of the high electrical load status is that the building is often in the process of cooling down rather than heating up. A displacement system prolongs the heating requirement during the year because supply of air at a temperature of 18-19ºC is required.

The IES model was used to produce energy and electrical consumption figures for a period of one year. A small gas-fired CHP plant producing 206 kW of electrical energy and 324 kW of heating energy was considered.

The plant is sized to meet the base heating and hot water load for the building; this is estimated to be about 300 kW with a base electrical load of 450 kW.

An analysis of the data produced indicated that absorption chilling using waste heat would not be economical for such a small CHP plant.

The CHP plant was compared against a standard gas-fired boiler system and the national grid electrical supply. Consideration was given to the placement of heat recovery rotary wheels in the AHUs. Their possible effect on CHP performance was also considered. Four options were used for the analysis process:

1. Conventional boiler system with AHU heat recovery.
2. CHP and boiler system with AHU heat recovery.
3. Conventional boiler system with no heat recovery in the AHUs.
4. CHP and boiler system with no heat recovery in the AHUs.

The maximum CHP seasonal efficiency is 77% - assuming that all heat produced is actually used.

With the 'no heat recovery' option, the CHP plant would have a seasonal efficiency of 67% in a building that uses 78% of the heat produced by the CHP. However, when the AHUs' heat recovery option is used, seasonal efficiency is reduced to 55%, with only 47% of the heat produced by the CHP actually used in the building.

The CHP and AHU heat recovery option generate the lowest CO_2 emissions i.e. 10% lower than a conventional system with AHU heat recovery and 20% lower than the conventional system. When compared with a conventional system, the CHP option provides a reduction of 13.6% in CO_2 emissions.

When compared with a conventional system, a CHP system which has an electrical output of 206 kWe and 385kW heating is both economically viable and environmentally sustainable. The introduction of a heat recovery system in the AHUs would lead to higher CO_2 reductions. However, the performance of the CHP would be compromised, with payback increasing beyond five years.

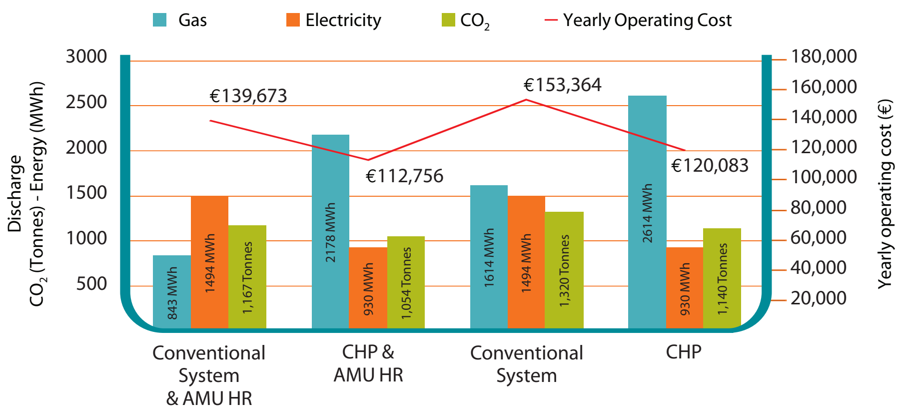


Figure 6.1 - Annual CHP Yearly Operating Costs, Energy and Discharge CO_2

	Projected payback	Discounted payback @ 5%	Projected payback with gas price increase of 30%	Payback with electricity price increase of 30%
CHP	5.2 yrs	5.9 yrs	5.7 yrs	7.3 yrs
CHP & Heat Recovery	6.3 yrs	7.7 yrs	6.8 yrs	8.4 yrs

7 Ground Source Cooling

Recent research and geological surveys carried out by UCC and others have confirmed that an underground aquifer runs parallel to the site beneath the river Lee. Data indicates that the required volumes of water, at a temperature favourable for cooling application, may almost certainly be found on the site.

Ground source cooling uses pumping technology to extract low-temperature ground water (11-12ºC) from boreholes, which feed from an underground aquifer. The displacement system supplies air at 18-19ºC, compared to a conventional system, which supplies air at 13-14ºC. The ground water can be fed directly into the cooling coils of the 400 KW air handling units (AHUs), or via a heat exchanger if the water quality is not suitable. The water can then be used for toilet flushing before being released.

The aquifer cooling system comprises two 10" boreholes connected to two submersible pumps. A maximum pumping power of 22 kW gives an estimated COP of 23. A COP for a typical air-cooled chiller is 3.0-4.0.

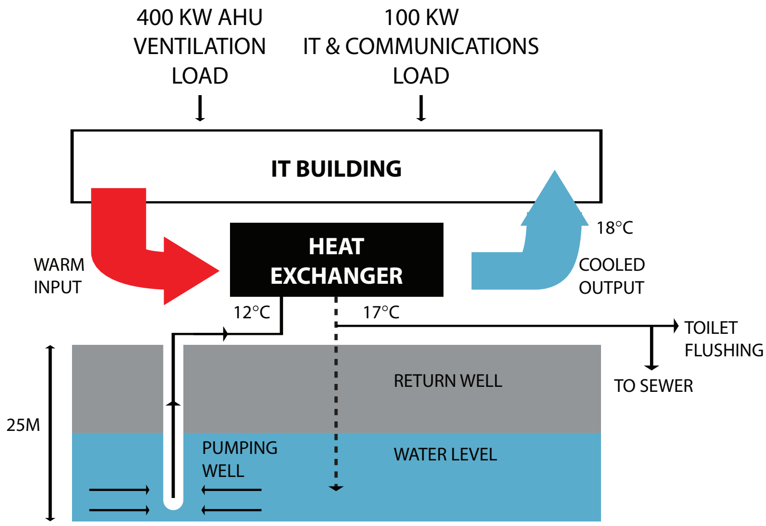
The building also has a cooling load of 100 kW for the IT and communications rooms – areas where power is required 24 hours a day throughout the year. The aquifer water rejects heat from chilled water coils in floor-standing units placed in the IT and communications rooms (COP of 7.1). The standard alternative is a refrigerant-based system placed in the floor-standing units (COP of 2.57).

The IT building's 61 toilets and 16 urinals cater for an estimated 815 people. Typically, the toilets use 13,000 litres of water per day. If well water were to be used for flushing purposes, this would reduce water consumption considerably.

The IES model 'Recommended (R)' was used to calculate energy requirements for the building for one year, allowing a comparison between conventional systems and the aquifer cooling system.

Life cycle cost analysis indicates a projected payback period of 9.2 years for the AHU cooling, 1.2 years for the IT and communications rooms cooling, and 1.4 years for toilet flushing. The combined payback period for all three elements would be 1.7 years.

An aquifer cooling system would reduce CO_2 emissions by 63%; this compares favourably with the performance of the conventional system of an air-cooled chiller and a refrigerant system for the IT and communications rooms. Ground source cooling is an environmentally and economically sustainable solution and avoids mechanical refrigeration – a criterion stipulated by UCC in its brief to the design team.



	Annual cooling demand	Conventional system	Aquifer cooling
AHU load	32 MWh	10 MWh*	1.8 MWh
IT and comms load	701 MWh	273 MWh**	102 MWh
Total energy	734 MWh	283 MWh	103 MWh
Carbon emissions	-	190 tonnes	69 tonnes

* Conventional air-cooled chiller
** Refrigerant split system

8 Overall Energy Performance

Energy performance does not take into account the various benefits delivered by a CHP plant. Its purpose is to show the building's energy consumption requirement for a particular year irrespective of how that energy was generated – and demonstrate what power-reduction measures have been put in place.

According to a recent survey, average energy consumption is 253 kWh/m²/y in a university building and 228 kWh/m²/y in an institute of technology building. (These are total energy consumption figures.)

The energy consumption of the various models was measured against the guidelines set out in the publication entitled Energy consumption guide 19: energy use in offices, which is produced by the UK Department of Transport, Environment and the Regions (DETR). The UCC IT building (mixed mode) could be classified according to ECON 19 as lying somewhere between a Type 2 (naturally ventilated) and Type 3 (air-conditioned) building. Typically, performances for Type 2 and Type 3 are 236 kWh/m²/y and 404 kWh/m²/y.

A notional IT building, which conforms to building regulations insulation standards but does not have any mechanical energy-saving features, is estimated to consume 220 kWh/m²/y. However, if energy efficiency measures such as AHU filters, ground source cooling, and the use of flat panel computer monitors, are implemented, a target energy performance of 188 kWh/m²/y would be appropriate for that building.

In terms of pure carbon emissions, a CHP plant would reduce the ground source cooling model from 108 to 97 kgCO_2/m². This compares to values of 87 kgCO_2/m² and 187 kgCO_2/m² for Type 2 and Type 3 buildings respectively.

HVAC and lighting loads are estimated to be 98 kWh/m²/y - i.e. well below the design target of 100-150 kWh/m²/y. This represents a reduction of 20% on a typical, naturally ventilated building and 53% on a typical air-conditioned building.

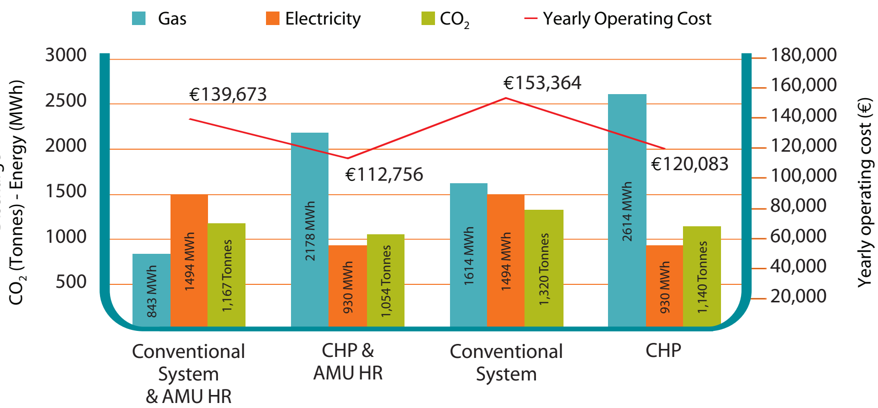


Figure 8.1 - Energy Consumption Analysis UCC IT

9 Conclusions

The report's main findings were:

- Building simulation modelling is an important tool for verifying passive and low-energy design solutions and for generating energy consumption patterns, thereby facilitating exploration of the most appropriate energy-saving solutions.

- Exposed thermal mass and shallow building depths are required in order to implement successful natural ventilation strategies for buildings with high internal heat gains.

- Increased U-values for building fabric elements reduce energy consumption but do not provide economic paybacks. For buildings with a large amount of full-height glazing and high internal gains, careful consideration should be given to the effects that solar control glazing might have on energy consumption and occupant comfort.

- An airtight building and raised floor sections are prerequisites for guaranteeing the success of the displacement system. Buildings should be pressure tested.

- Electrostatic filters are a viable and energy-efficient alternative to conventional panel and bag filter technology.

- Condensing boiler technology for the lead boiler should be considered as a standard solution. Splitting the load with smaller boilers improves part-load efficiency considerably.

- CHP is viable only if all or a large proportion of the heat generated is used. AHU heat recovery is not compatible with the economic operation of a CHP plant, but does reduce CO_2 emissions. Careful consideration and the estimation of heating and electrical loads are required in order to provide an accurate analysis.

- Active consideration should be given to the use of ground source cooling in geologically suitable areas. By using this method, buildings which have high internal heat gains can be mechanically ventilated successfully without recourse to refrigerant-based air-conditioning.

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NATIONAL DEVELOPMENT PLAN

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