Sustainable Engineering Design

The SDAR* Journal September 2011

Issue 1

The journal of Applied Research in Innovative Engineering of the Built Environment

Sustainable Design & Applied Research

SDAR*

in Engineering of the Built Environment

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The SDAR Journal is a sustainable design and applied research publication written by engineers and researchers for professionals in the built environment*

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Introduction

On behalf of the Chartered Institution of Building Services Engineers (CIBSE) in Ireland, I would like to welcome you to the first edition of this exciting new publication on sustainable design and applied research.

This journal is the result of a continuing and productive collaboration between CIBSE Ireland, DIT and our members, and will provide an important repository of documented evidence in engineering design and research. We hope that it will prove to be a useful source of information and discussion to researchers, designers and all involved in the built environment.

It is important to emphasise that the building services industry needs to progress from ideologically-based sustainable or green initiatives towards proven and evidence-based technical solutions that deliver, in a cost-effective way, on a whole life-cycle basis. We feel this can only be achieved through evidence-based evaluation and applied research, and the *SDAR* Journal* is well placed to report and share these findings.

We believe that there are genuine opportunities for building services engineers, architects and academics to form alliances and strategic partnerships in the area of evidence-based research and evaluation to continuously improve the built environment based on real data and analysis. This continuous improvement cycle will not only generate much-needed activity in the market, but will deliver more sustainable buildings and communities.

This journal is made up of a strong spine of industry-based research. It comprises companies, and individuals within companies, disseminating insightful findings based on evidence gathered from live projects that drive us towards a more sustainable world. We learn from their successes but we also learn from the things that went wrong. Critical reflection is central to all of the work published here and, in that way, the quality is enhanced.

In addition, the journal also includes good-quality articles from young engineers. Indeed, with our instigation of the Irish Young Lighter in 2003, we have a proven track record in encouraging our young bright engineers of tomorrow.

I would encourage engineers, contractors and other professionals in the built environment to consider submitting articles for the next issue of this journal which is scheduled for summer 2012. I would also encourage submissions to the Irish Lighter/Young Lighter and SDAR* Awards competitions.

Regards,

Derek Mowlds
Chairman CIBSE
Republic of Ireland Region

Editor's foreword

Welcome to the first edition of what will be the most widely-read applied research journal in the engineering/built environment sector in Ireland. This journal concentrates on papers which present insightful findings to working professionals. All papers are evidence-based and are critically reviewed by engineering peers and academics to ensure good quality and authentic findings. The intention is to disseminate insightful research findings throughout the industry.

The quality of papers is judged less by the success of a project and more by the insight produced by the findings and the quality of evidence and analysis presented. There is as much to learn from the mistakes and the things that went wrong as there is from the things that went right. Insight is often borne out in research by the surprises involved.

Apart from papers by working engineers and researchers, this and all future editions will include papers from young engineers, post-graduate and undergraduate students.

The intention with this journal is to encourage applied research and disseminate interesting findings in sustainable design back into our industry. We encourage all professionals involved in the built environment to consider contributing articles to future editions.

Research is not just about people in white coats in laboratories. It is about critically evaluating your project innovations and comparing your findings with those of others. Evidence-based evaluation is applied research and every project is an individual case study waiting for analysis. Publication of that applied research allows us all to learn, increase the quality of what we do, and enhance value to the client.

Finally, I would encourage collaboration in this applied research process. This journal is a collaboration between CIBSE Ireland and DIT. Similarly, companies might join with academic institutions to produce good quality research of their own. My experience is that working professionals in companies tend to be time poor and data rich, whereas post-graduate students are time rich and data poor. This offers excellent opportunities for both parties to benefit, as well as industry generally, when the findings are disseminated.

Kevin Kelly

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Head of Department
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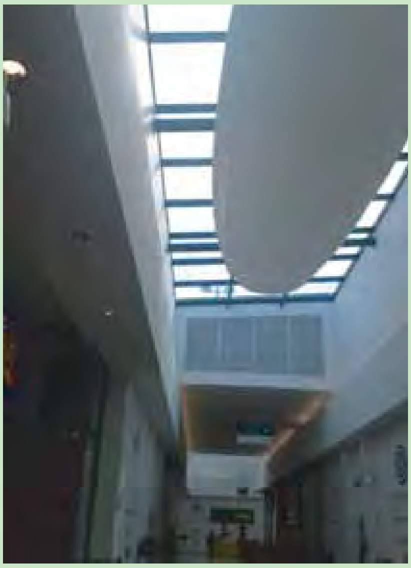
A Reader's Guide

The opening paper by **Keohane & Leonard** of PM Group was the winner of the 2011 CIBSE Ireland SDAR* Award. This is an interesting analysis and shows how a groundwater heat pump and a novel VAV underfloor mechanical ventilation system installed in the Western Gateway building of University College Cork can use lower energy consumption than traditional heating and cooling systems. This is a case study evaluation of an innovative approach to the integration of three technologies in a university building.

The second paper by **Tooth, Burke and Saul** of J V Tierney was a runner-up in the SDAR* Awards 2011. This paper examines computer-simulated energy targets against actual energy consumption for the new Criminal Courts of Justice building in Dublin. It also evaluates the benefits of engineering solutions such as twin-skin facades and heat recovery. Interestingly, the authors found that actual energy used is about 25% less than that predicted by the software. They conclude this is due to occupancy levels and fluctuations that are not predicted by the software. They considered their evaluation a sanity check and proposed that energy usage profiles be generated. Their applied research also underpinned existing knowledge of the benefit of twin-skin facades and energy recovery systems.

In his paper **Wegner** reviews the Passiv Haus concept and examines a case study application on the Tesco supermarket in Tramore, Co Waterford. This was a collaborative paper between an ME post-graduate student and the Tesco energy management division. Wenger, in a critical analysis, found that electrical consumption was 23% lower in the passive construction in Tramore than in equivalent Tesco stores, and that the results are encouraging enough to suggest that this type of construction has potential in commercial settings. However, this paper also highlights the things that can go wrong when implementing innovative solutions.

Doyle's paper was the winner of the Irish Lighter awards in 2010 and this study was published as a completed thesis by Lambert Academic Publishing in Germany. Doyle set out to evaluate the performance of lighting controls in three buildings, as a mature undergraduate student. However, when he went to the buildings to gather data, the controls had been disconnected. This led to a whole new research question that required a complete change in methodology. The research question became: *why were the controls disconnected*. Doyle used Qualitative Research (interviews) which is an unusual but growing methodology in engineering applied research. In order to analyse data he devised a conceptual framework from a literature review of previous research carried out internationally into this area. His conclusions concurred with the previous research in many respects, but also added to this previous research with interesting insights into local practices and fee structures.



The following paper by **Duff** was the Young Irish Lighter Award winner in 2010. Duff was an undergraduate student at the time of submission and now works for Arup. This is an examination of compact fluorescent lamps (CFLs) in the domestic environment. Duff concludes that potential savings in energy costs and CO2 emissions must be balanced against colour quality and other factors in a clear way. He examines 12 characteristics of the lamps. This is worth a read by anybody using CFLs in their own home but the most insightful findings from an engineering perspective are linked to the poor power factor and the harmonic distortion of the waveform when using significant numbers of CFLs. Duff used laboratory facilities in DIT to carry out his measurements.

The final paper by **Croly** of the Building Design Partnership was the SDAR* Award winner in December 2009. This is an insightful and detailed analysis of low-energy commercial kitchen design, albeit in a training kitchen in Waterford Institute of Technology. Interesting findings relate to use of displacement ventilation in kitchens, use of advanced catering equipment, use of hybrid natural ventilation, and use of complex controls in this setting.

Providing best practice advice

CIBSE is the professional body that exists to "support the science, art and practice of building services engineering, by providing our members and the public with first class information and education services and promoting the spirit of fellowship which guides our work."

CIBSE promotes the career of building services engineers by accrediting courses of study in further and higher education. It also approves work-based training programmes and provides routes to full professional registration and membership, including Chartered Engineer, Incorporated Engineer and Engineering Technician. Once you are qualified, CIBSE offers you a range of services, all focussed on maintaining and enhancing professional excellence throughout your career.

CIBSE members in Ireland are represented by an active Regional Committee who are involved in organising CPD events, technical evenings, training courses, social events and an annual conference. The committee welcomes new members, suggestions, and collaborations with other institutions in the built environment.

CIBSE
Engineering a sustainable built environment

The Chartered Institution of Building Services Engineers in Ireland

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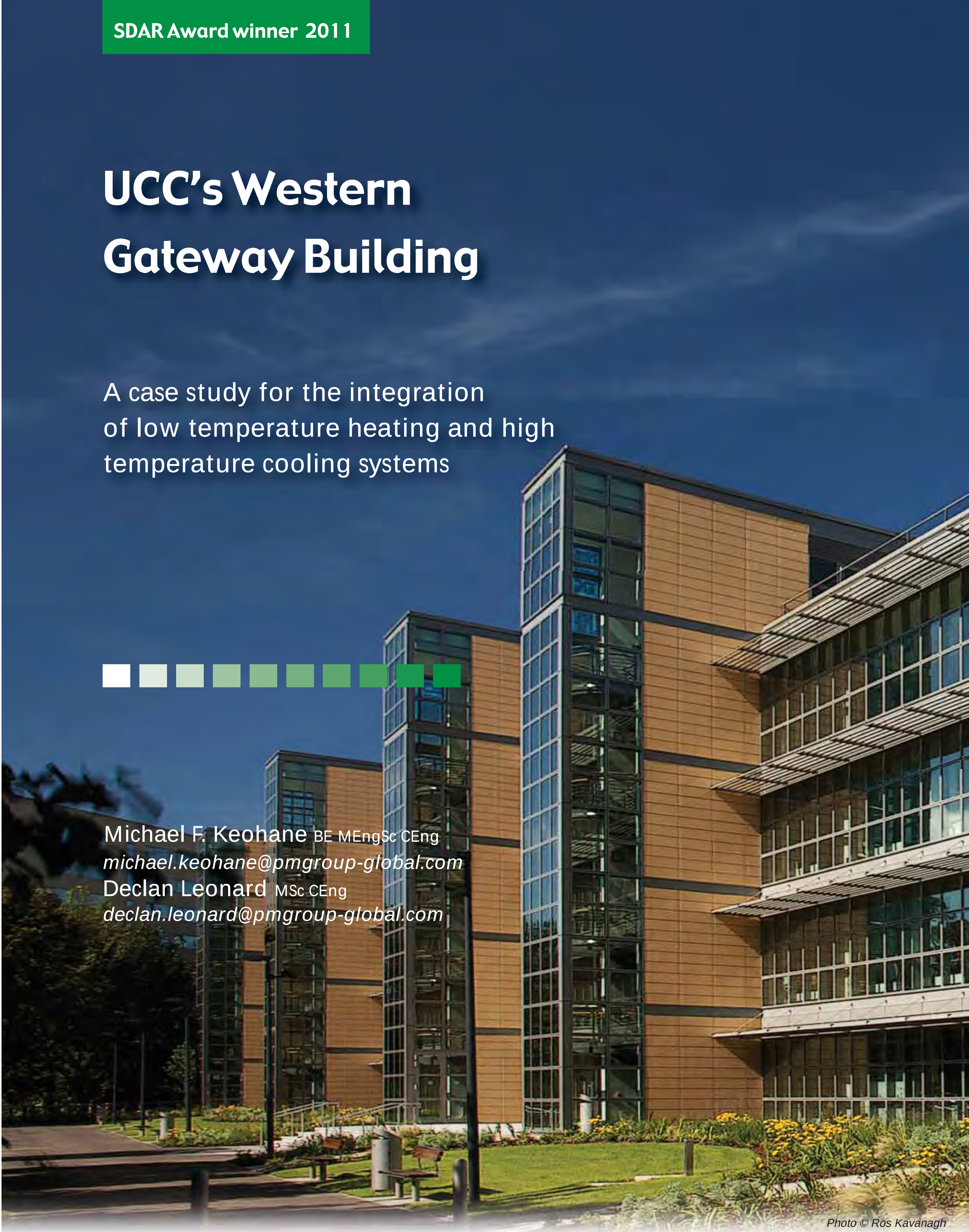

SDAR Award winner 2011

UCC's Western Gateway Building

A case study for the integration of low temperature heating and high temperature cooling systems

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Abstract

This paper deals with the installation of a 1 MW groundwater heat pump for cooling and heating, a server room heat recovery system and a novel VAV underfloor mechanical ventilation system, in a large third level university building in Cork, Ireland. After describing the building and the mechanical systems the paper presents energy usage and analysis of results for the first year in operation. Such an installation is of interest to engineers and facility managers in order to determine how all the systems complement each other, as well as the resultant energy saving potential compared to conventional systems. Large scale groundwater heat pumps with simultaneous heating and cooling capabilities can provide significant operational cost savings, as described in the paper.

Key Words:

VAV Underfloor Mechanical Ventilation, Demand Control Ventilation, Groundwater Heat Pump, Simultaneous Heating and Cooling, and Server Room Heat Recovery.

1. Introduction

In the Cork area a number of a small and medium scale groundwater heat pumps have been installed which use groundwater from the Lee Buried Ribbon Valley for space heating and cooling of buildings. Installations of the scale 1 MW have not previously been attempted.

The presence of a simultaneous heating and cooling load within a building significantly enhances the economic and environmental argument for the installation of heat pumps.

Water-cooled technology for server rooms is now becoming established for high heat gain racks (>15kW). This new development provides an opportunity for high temperature chilled water cooling and significant heat recovery potential using heat pump systems.

The use of underfloor mechanical ventilation systems has become popular in large university buildings where natural ventilation is not suitable.

This paper outlines an innovative approach to the successful integration of all three technologies in the one building. The objective of this installation was to reduce significantly the energy costs and carbon emissions associated with running large third level buildings.

1.1 Project background

University College Cork's (UCC) Western Gateway Building (WGB) is the largest building on the UCC Complex at 25,000m^2 (269,100ft^2) providing research and teaching accommodation for a range of academic departments such as Computer Science, Biochemistry, Mathematics, Pharmacology, Physiology, ICT and Cancer Research.

Master-planning for the site located on the western edge of the campus (on the old greyhound track on Western Road) by Scott Tallon Walker Architects began in 1999. After a series of delays, contract work commenced on the project in September 2006.

The first three floors (16,000m^2) of the five storey structure were completed in June 2009. Major flooding of the River Lee down stream of Inniscarra at the end of 2009 interrupted building operations until June 2010. Fit out of the shell and core top two floors commenced in early 2011.

2. Building description

The 5-storey reinforced concrete above ground building (plus basement for M&E plantrooms) is situated on the banks of the River Lee and is aligned on a southwest/northeast axis. The area south of the courtyards is a 4-storey cellular/open plan office block, which provides staff accommodation and research space. Areas with high internal heat gains including the main teaching areas, computer and research labs, cafeterias and toilet blocks are located to the north of the building surrounding the main atrium which runs the

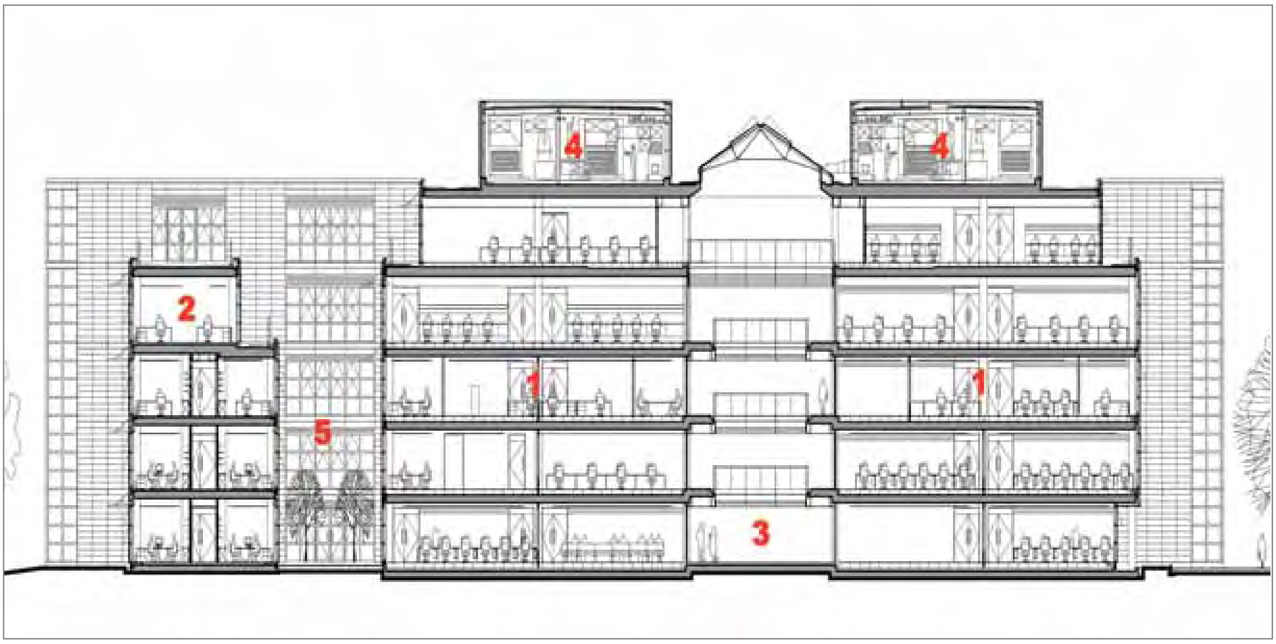

Fig. 1: Section through WGB from left to right – southern cellular and open plan offices, courtyard, classrooms and labs and main atrium

full length of the building. Full height glazing (overall U-value 1.84 W/m^{2}k, shading coefficient 0.43, light transmission 67%) dominates the southern and northern facades accounting for 60% of the exposed wall surface area. The main atrium roof light has the same specification and accounts for 9.5% of the total roof area.

Fig. 2: Photo collage of building externals and atrium

Building element U values, which were specified pre-2006 Building Regulations are 0.25 W/m^{2}k for roof and external walls with 0.16 W/m^{2}k for the ground floor.

3. Passive design features

The building is designed with a number of passive design features including:

- Building orientation is southeast facing to capture morning sunshine for solar heating and to provide shading against evening sun.
- High heat gain areas are placed to the north of the building to avoid solar gains.
- There are no occupied spaces with eastern and western facades, eliminating low angle sun issues and consequent glare.
- The atrium and courtyards are used to bring light into the core of the building.
- Air tight construction with an actual test of 4.4 m^3/hr per m^2 @ 50pa.
- Use of thermal mass in the form of exposed concrete soffits for over 90% of the ceiling area.
- Natural ventilation is utilised in areas (33% of existing floor plan) with low heat gain as per UCC policy. Night cooling occurs via automated vents.
- The naturally lit 100-metre long atrium concourse accommodates day-lighting, acts as a common return air path, and solar collector for heat recovery.
- Horizontal Brise Soleil is used on the southern facade to mitigate peak summer solar gains.
- 43m^2 of evacuated tube solar water heating panels in conjunction with gas fired condensing instantaneous stand-alone water heater for DHW.

- Localised manual light switching and PIR sensor for occupancy detection (lights off 30 minutes after last occupant).
- Photocells to allow daylight harvesting by continuous lux level dimming to preset levels (350 lux for offices, 500 lux for computer class rooms, 150 lux for the atrium).

4. Ventilaion systems

4.1 Mechanical ventilation description

The mechanical ventilation systems have the following energy efficient properties:

- Underfloor mechanical ventilation is used for areas with high internal heat gains in which spaces (classrooms, computer labs, lecture theatres, wet labs and research areas) are supplied by pressurised plenum and swirl diffusers (300mm raised access floor) with a minimum supply air temperature of 16°C (Fig 3).

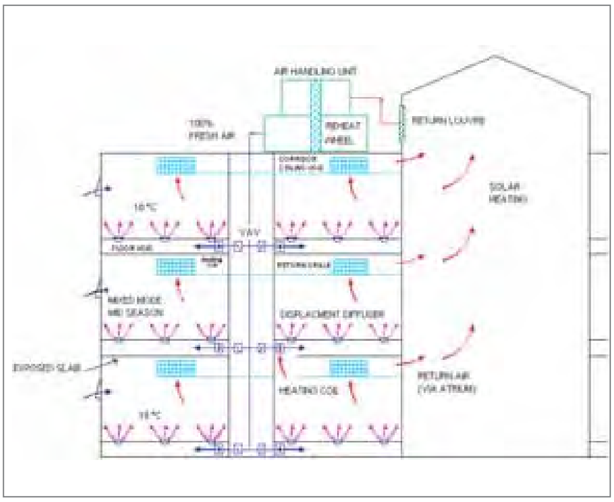

Fig. 3: Underfloor mechanical ventilation schematic for three-storey design, (Keohane 2005)

- Displacement ventilation in which auditoria spaces are supplied by pressurised plenum with a minimum supply air temperature of 18°C.
- 100% fresh air supply with pressure independent VAV system that operates on the dual maximum setpoint principle (see Fig. 4), demand based static pressure reset, and supply air temperature reset.
- Widened dead bands between cooling and heating setpoints of 2°C.
- Demand Control Ventilation (DCV) based on CO_2 sensing (1,000-ppm setpoint).
- Occupancy detection allowing VAV air supply shutoff for all rooms. If the room is within +/- 3°C of the base setpoint the VAV box closes fully. Should the room go outside these parameters the VAV box and reheat will re-activate to bring the room to within +/- 2°C of the base setpoint.
- Each air handling unit (AHU) has an Enthalpy wheel for sensible and latent heat recovery (70% efficient). There is no active humidity control in the building.

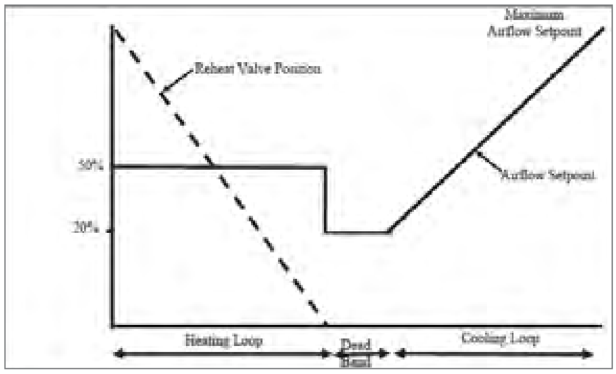

Fig. 4: Dual maximum with VAV heating – valve and airflow together (Pacific and Gas 2007)

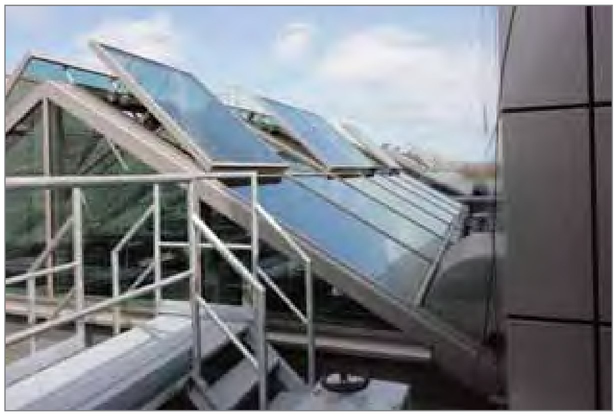

Fig. 5: If heat recovery is not required the AHU return fans are disabled, and air is exhausted through atrium rooflights

Fig. 6: Occupancy detection in green areas, no occupancy in grey areas where VAV air supply is disabled

- The majority of the spaces (14 of 18 AHUs) utilises the main atrium as a common return air path. Exhaust air is exfiltrated from the rooms at high level to the atrium or corridors, which are linked to the atrium. AHU return air is collected from the top of the atrium.
- When heat recovery is not required (Tex>17°C) the AHU return fans are disabled, and air from the spaces is exhausted through the atrium rooflight windows.
- At night the atrium rooflight and gable end windows provide night cooling to vent heat from the building.
- Typical AHUs contain direct drive centrifugal plenum fans with VSDs, an enthalpy wheel and no heating coil. The enthalpy wheel provides frost protection and reheats provide all required

heating for spaces. Cooling coils are provided for summer comfort cooling (sized for operation with 13°C chilled water (CHW).

- Postgraduate research areas have VAV fume hoods with PIR automated sash control. Undergraduate teaching areas have constant volume fume hoods.
- Mixed airflow strobic extract fans are used for fume dilution, and to create the required exhaust stack heights of 14m.
- Kitchen and restaurant, toilets (constant volume) and post-graduate research areas employ traditional VAV overhead mixed air distribution.

4.2 Data analysis

Table 1 indicates the recorded BMS data for the ventilation electrical energy. Typically two AHUs plus miscellaneous extract fans are wired through a single motor control centre (MCC) panel (with energy pulse meter). Ten such MCC panels are connected to separately energy-metered north and south plantroom power supply panels (five each).

The total commissioned ventilation power is in excess of 160 kW (10 W/m^2). Fig. 7 indicates the average annual weekly power draw-down is approximately 50 kW (3.13 W/m^2). The innovative VAV strategy, occupancy linked shutdown, and return fan disable strategies are responsible for the load factor of 31%.

The Energy Performance Indicator (EPI) value achieved for 2010 was 13.6 kWh/m^2 for the mechanically ventilated area. An ECON 19 type 3 building with similar operating hours (2,750) would expect to use 22 kWh/m^2.

In Fig. 7 there is a decline in average day loads (20 kW) during the summer as the return fans are disabled to allow rooflight exhaust. However, average weekly loads do not decrease. Due to lower undergraduate occupancy in the summer it would be expected that a reduction in fan power should be visible, and this pattern is partially indicated by a reduction in mid-May and an increase at the start of October. However, a spike occurs during the summer months. This can be explained by a large number of unoccupied computer labs (peak heat gain 35 W/m^2) where PCs were running (PCs were scheduled to start and shutdown automatically between 6.00 – 22.00 hrs), and as a result required cooling as temperatures rose outside the upper unoccupied limits. This was corrected by the end of October by programming PCs to shutdown after 15 minutes of non-use.

The classroom/lecturing/computer room areas have the lowest EPI values (5.9 – 14.4 kWh/m^2) where different occupancy and usage rates explain variations.

The highest value of 43.9 kWh/m^2 (41% of total) relates to the combined areas of the toilet core (all six floors), the kitchen-restaurant and the incubation suites. The reasons for this are:

- Constant volume toilet AHU running extended hours.
- Kitchen variable speed extract fan (25 ACH) is manually set locally to 100%, therefore supply VAV box is 100% open continuously.
- Kitchen extract fan (3 kW) running 24/7 to vent heat from refrigerators at night (40% of MCC energy).
- Servery area (VAV box @100% continuously) is overheating due to a large number of refrigerated cabinets. The cabinet condensers are currently being moved externally.

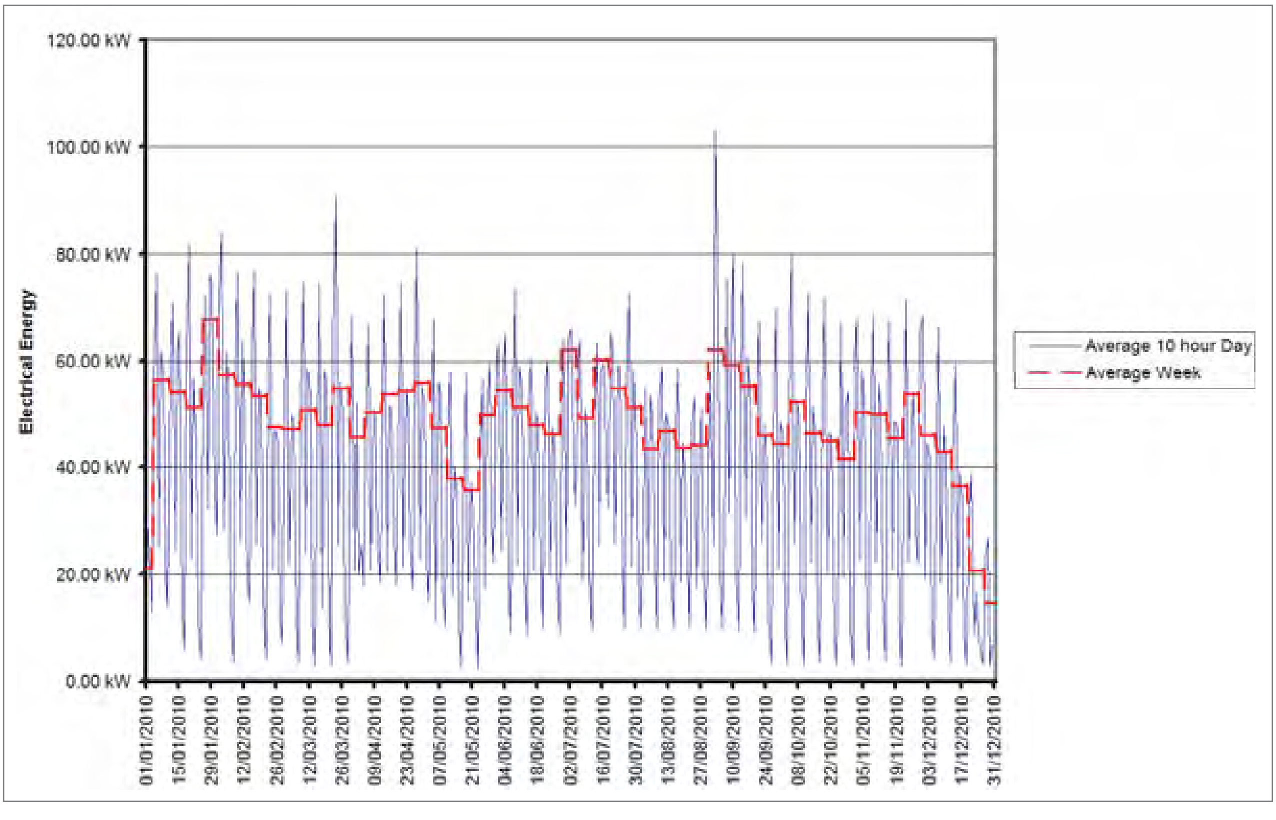

Fig. 7: Ventilation (AHU & Extract Fans, Heat Recovery Motors) Electrical Power Requirement Jan – Dec 2010

North of Atrium MCC Panels[3]	Space Description	AHU Commissioned[1]	Jan – Dec 2010	Area	Annual EPI
			52,995 kWh	5,044 m²	10.5 kWh/m²
AHU 0101	Comp Labs, Lecturing, Offices	SFP 1.9 kW/m³/s, 6.6 l/s/m²	8,180 kWh	632 m²	6.4 kWh/m²
AHU 0102	Recording Studio, Lecturing, Comp Labs, Offices	SFP 1.9 kW/m³s, 6.0 l/s/m²		639 m²	
AHU 0201 6.6 l/s/m²	Comp Labs, Lecturing, Offices	SFP 1.5 kW/m³/s,	14,410 kWh	632 m²	11.3 kWh/m²
AHU 0202	Comp Labs, Lecturing, Offices	SFP 1.5 kW/m³/s, 5.1 l/s/m²		651 m²	
AHU 0801	Main 300 seat Auditorium	SFP 2.0 kW/m³/s, 11.9 l/s/m²	13,629 kWh	328 m²	14.4 kWh/m²
AHU 0802	Auditorium, Lecturing, Offices, Server Room	SFP 2.0 kW/m³/s, 6.5 l/s/m²		619 m²	
AHU 0501	Lecturing, Undergraduate Wet Labs	SFP 2.2 kW/m³/s, 7.5 l/s/m²	8,482 kWh	630 m²	6.9 kWh/m²
AHU 0502	Lecturing, Undergraduate Wet Labs, Research Lab	SFP 2.0 kW/m³/s, 7.6 l/s/m²		591 m²	
Fume hood Extract	5 Under Graduate Fume Hoods	2 X 7.5kW Extract Fans	8,295 kWh	573 m²	14.5 kWh/m²
South of Atrium MCC Panels[3]			96,380 kWh	5,905 m²	16.3 kWh/m²
AHU 0301	Comp Labs, Research Office	SFP 1.6 kW/m³/s, 5.9 l/s/m²	7,471 kWh[2]	658 m²	6.0 kWh/m²
AHU 0302	Comp Labs, Research Office	SFP 1.7 kW/m³/s, 6.5 l/s/m²		597 m²	
AHU 0303	Cancer Research and 4 Fume hoods, 2 Extract Fans[4]	SFP N/A kW/m³/s, N/A l/s/m²	4,000 kWh[2]	383 m²	10.4 kWh/m²
AHU 0401	Comp Labs, Research Office	SFP 1.7 kW/m³/s, 5.4 l/s/m²	7,471 kWh[2]	660 m²	5.9 kWh/m²
AHU 0402	Comp Labs, Research Office	SFP 1.6 kW/m³/s, 6.3 l/s/m²		600 m²	
AHU 0701	Toilet Core all 6 floors	SFP 2.6 kW/m³/s, 8.2 l/s/m²	61,602 kWh	473 m²	43.9 kWh/m²
AHU 0901	Incubation Suites	SFP 1.8 kW/m³/s, 6.0 l/s/m²		591 m²	
AHU 1101	Kitchen and Restaurant	SFP 5.4 kW/m³/s, 10.9 l/s/m²		339 m²	
AHU 0601	Comp Labs, Undergraduate Wet Labs	SFP 1.4 kW/m³/s, 6.0 l/s/m²	15,837 kWh	795 m²	12.4 kWh/m²
AHU 0602	Comp Labs, Undergraduate Wet Labs,	SFP 1.9 kW/m³/s, 7.6 l/s/m²		485 m²	
Mechanical Ventilation Total			**149,376 kWh**	**10,949 m²**	**13.6 kWh/m²**
Natural Ventilation	Open Plan Offices, Cellular Offices, Stairwells, Atrium		**0,000 kWh**	**5,051 m²**	**0 kWh/m²**
Building Total			**149,376 kWh**	**16,000m²**	**9.4 kWh/m²**

1 AHU Commissioned Figures for 100% Design flow, flow rate per m² is an average of all spaces served

2 BMS Meter not functioning, figures are estimates based on size and the overall North or South MCC reading

3 The area totals for MCC North and South include 648m² of corridor space split evenly for each panel.

4 AHU and Fume hood Extract Sized for additional floor (766 m²)

Table I: BMS ventilation energy data

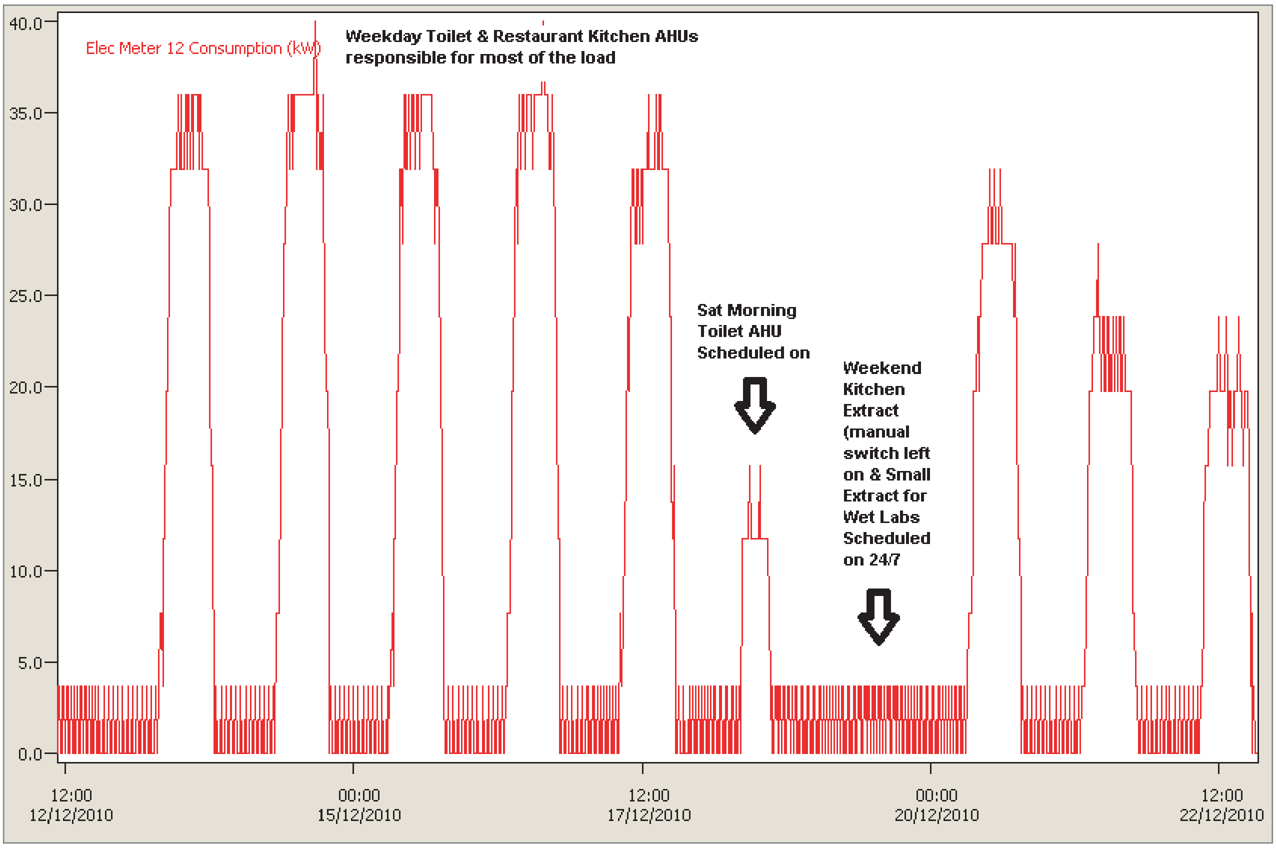

Fig. 8: BMS snapshot – South MCC combined ventilation (AHUs and extract fans, heat recovery motors) electrical power, Dec 2010

- High SPFs for the toilets and kitchen-restaurant AHU.
- Higher airflows for kitchen-restaurant AHU as a result of higher CHW temperatures designed for the underfloor AHUs.

4.3 Conclusions and lessons learned

While the overall fan power energy improves upon ECON by 38%, there are still a number of notable lessons. The commissioning of the AHUs aimed to achieve the design SFPs of 2.0 kW/m³/s or lower, however this was only achieved by 14 of the units (overall average 1.9 kW/m³/s). A number of units achieved 1.5 kW/m³/s.

The reasons for higher than expected SFPs include:

- Issues with leaking floor plenums. Only representative sample areas were tested, all floor plenums should be tested on projects using pressurised plenums. Complex detailing is required to insure integrity.
- High-pressure drop associated with acoustic transfer devices allowing air to return to the atrium.
- End of line VAV boxes on the ground floor with large flow rates required significantly higher than expected static pressure to maintain control. Duct static pressure reset to 350 Pa was required for a 100% demand, even though the rest of the system was operating at low volumes. Where possible situate rooms with large airflow requirements as near to the supply fan as possible.

Other notable lessons learned include:

- Close VAV boxes for spaces experiencing the prolonged periods of inactivity.
- The absence of a heating coil in the AHUs has resulted in supply air temperatures lower than 16°C in extreme weather (-7°C) with the consequence of draught complaints.
- Higher chilled water temperatures may not reduce energy consumption for traditional VAV overhead mixed air distribution systems as fan energy is increased.
- A significant commissioning effort was required to get the system operating as per the design intent.

The use of 100% fresh air VAV underfloor mechanical ventilation in conjunction with DCV for areas with high occupant density heat gains in this project has demonstrated the following benefits:

- Significantly lower ventilation energy consumption compared to traditional VAV mixed air distribution systems.
- Allows the use of heat recovery, which will significantly reduce thermal energy use compared to natural ventilation solutions, while achieving high indoor air quality (IAQ) with 100% fresh air supply.
- Occupancy detection combined with temperature setback and room airflow disable in large buildings with variable occupancy is a very effective measure.
- Disabling AHU return fans when heat recovery is not required is recommended, where alternative passive exhaust routes exist.
- Thermal wheels for frost protection instead of traditional frost coils are effective.
- Free-cooling is available for large portions of the year, and the system can be integrated with groundwater cooling sources.

5. Ground water heat pump and server room heat recovery

5.1 Lee Buried Valley ribbon aquifer

The Cork harbour area is characterised by a series of buried valley ribbon aquifer systems, which represents a major source of ground-water in the area. (O'Connor et al 1998, Milenic and Allen 2001). The heat island effect of urban areas raises the temperature of shallow groundwater in the aquifer by a few degrees, making it a ready usable low temperature heat sink. Groundwater from the Lee Buried Valley has more recently been employed as a source of geothermal energy for space heating/cooling buildings in Cork city.

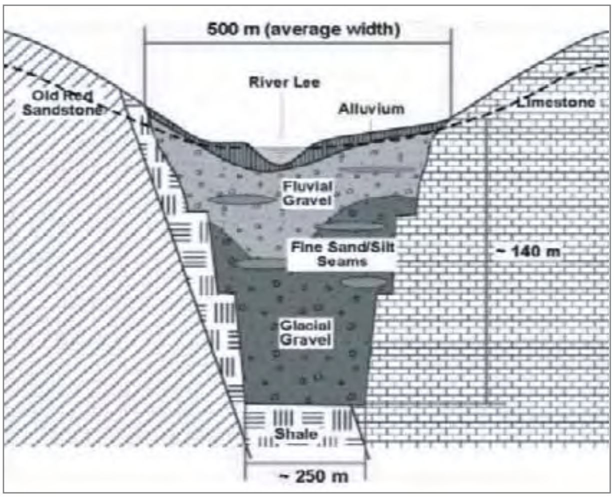

Fig. 9: Lee Buried Valley cross-section (Allen & Milenic, 2003)

Feasibility studies (Sikora 2002) and local trial borehole results (Connor 1998) indicated that the site had the potential to provide groundwater at stable temperatures of 12 to 13°C with flow rates in excess of 40 l/s. Originally for the 3-storey building it was proposed to utilise the groundwater directly for cooling purposes only.

Trial boreholes completed onsite in September 2006 indicated that flowrates of 45 l/s were achievable. Unexpectedly the ground-water temperatures recorded were in excess of 19°C. This recorded temperature was unprecedented for the Lee Buried Valley, high-lighting an extreme heat island affect onsite. The ground-water temperature swings annually (8°C - 19°C) following air temperature with a lag of three months. Consequently the original concept was superseded and a 1 MW groundwater heat pump was proposed.

5.2 Server rooms

A key factor in the decision to provide mechanical refrigeration was the proposed expansion of the server room requirements from the original design. In the future when all five floors are operational a load of 300 kW can be expected.

The server room design consists of a mixture of integrated in-row water cooling for high-density heat racks (>15kW) and CRAC units for low-density heat racks (<5kW). Both systems are designed to use elevated chilled water (CHW) temperatures (<16°C), by allowing higher than normally accepted air temperatures (22°C) to enter the server equipment (ASHRAE 2008). CRAC units contain both CHW coils and DX coils which operate only in the event of CHW failure or elevated CHW temperatures as a result of elevated groundwater temperatures. In addition there are five comms rooms for communications networks served by variable speed fan coil units (FCU). These rooms are maintained at 24°C.

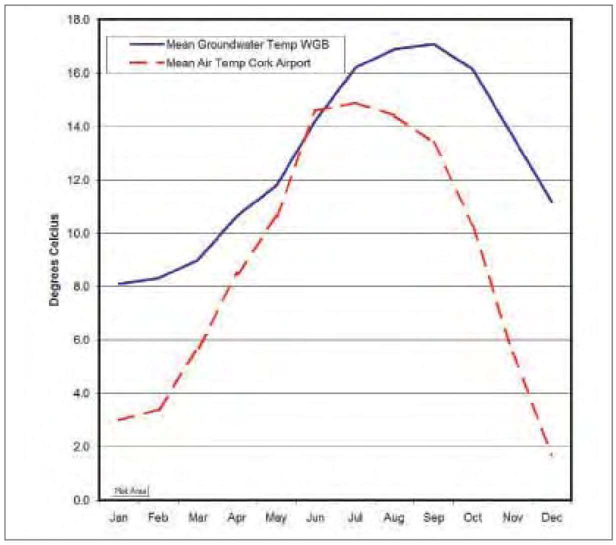

Fig. 10: Mean WGB groundwater and air temperature (Jan – Dec 2010)

5.3 Groundwater heat pump description

The system was designed from first principles and has unique hydronic configuration coupled to a complex control strategy.

The 1 MW heat pump system consists of two York YCWL 425 HE water-cooled chillers (500 kW each). Each chiller is equipped with four scroll compressors (R410a), which allows the entire system to turn down to 12.5% of peak load. These non-reversible units are equipped with a heat pump function that allows control of the condenser water leaving temperature or the evaporator leaving water temperature in cooling mode. This innovative system solution allows heat recovery from the servers through the heat pump for space heating, use of ground water as heat source or heat rejection outlet, or can allow efficient free cooling through the groundwater system. Both the CHW systems and low pressure warm water (LPWW) systems are variable speed with two port control valves.

A weather-compensated (60 - 40°C) low pressure hot water (LPHW) radiator system heats naturally ventilated areas. Heating is provided by 2 X 1.1 MW gas fired condensing boilers, which also provides back up for the Heat Pump heating system.

Groundwater is delivered from two 10inch diameter wells 25m deep with submersible pumps (22kW motors) equipped with variable speed drives (VSD). Groundwater is discharged into the river Lee through a specially designed diffuser to avoid thermal plumes. Groundwater is also harvested for use in a dedicated greywater system for toilet and urinal flushing.

Heating mode

- The ground source water serves as heat source on the evaporator side of the heat pump.

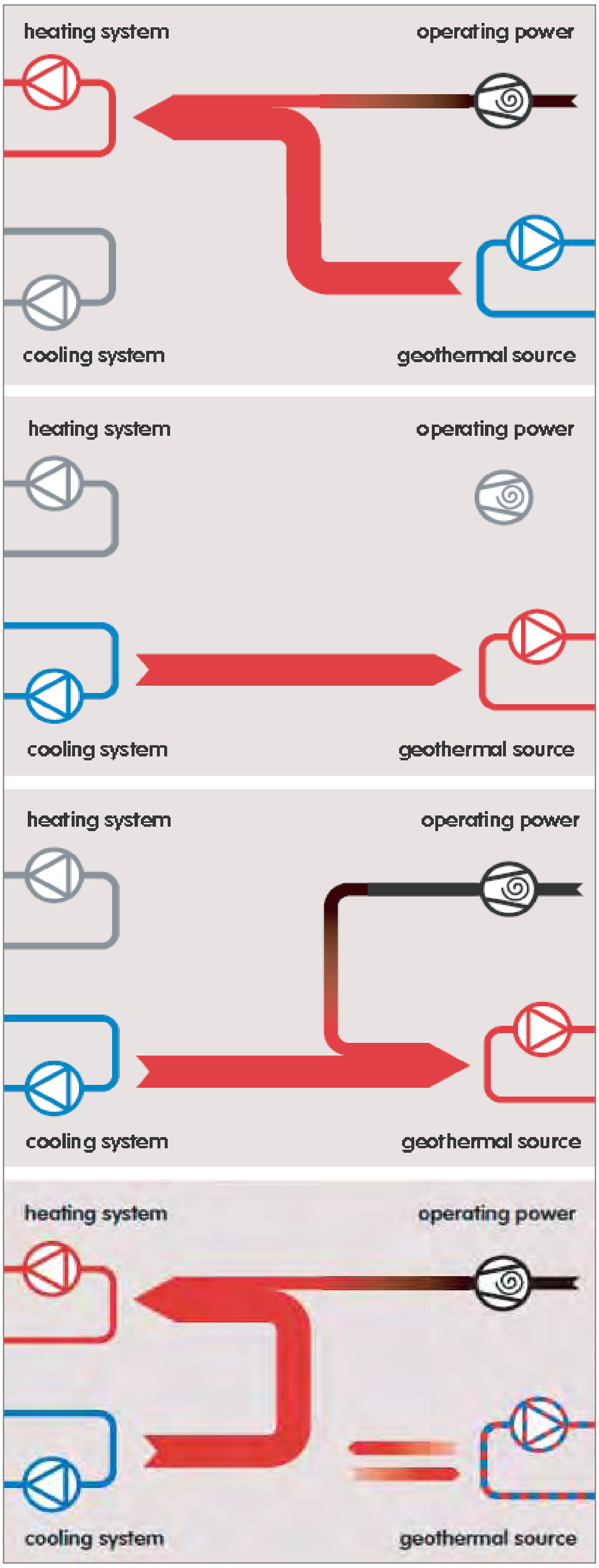

Fig. 11: Ground source heat pump modes of operation

- The heat pump raises the medium temperature groundwater (8 –19°C) heat source to a temperature level usable for the building (40 – 30°C LPWW).
- The LPWW system consists of AHU heating coils, reheat batteries, and FCU heating coils.
- The theoretical COP of the heat pump ranges between 5.1 – 7.7 in heating mode depending on LPWW supply temperatures (weather compensated) and CHW return temperatures, which are groundwater temperature dependent.

Free cooling mode

- Free cooling directly from the ground water without recourse to mechanical refrigeration is possible for large portions of the year.
- This is beneficial for server room cooling with COPs ranging between 10 - 20.
- The ground water provides chilled water in the range of 9 – 18°C depending on the time of year. During normal scheduled hours (NSH – typically 8.30 – 21.30 Mon - Fri) the CHW temperature is restricted to a maximum of 13°C for cooling of AHU coils and fan coils. Outside of NSH the CHW temperature is allowed to rise to 18°C to derive the maximum benefit of ground water cooling for the 24/7-server room load.

Cooling mode

- The ground source water serves as a cooling source by providing heat rejection on the condenser side of the heat pump.
- If no heating is required heat pump condenser inlet water temperatures are controlled in a range of 18 -22°C, depending on groundwater temperatures.
- The heat pump provides chilled water at 12°C when groundwater temperatures are too high during or outside NSH.
- The theoretical heat pump COP exceeds 7.5 in cooling mode for these conditions.

Simultaneous heating and cooling

- Can occur in heating or cooling mode.
- For dominant cooling loads the condenser water heat rejection is used by LPWW system (at required setpoint), and any excess heat is rejected to the ground water.
- For dominant heating loads, heat rejected to the CHW system by the server room and other sources provides the low temperature heat sink for the heat pump to produce upgraded heat for the LPWW system. If this is insufficient then the groundwater system will provide the required elevated CHW temperatures.
- COPs in excess of 10 are theoretically possible.

5.4 Data analysis

Due to the flood reinstatement works there are only six months (Jul – Dec 2010) operational energy data available. These figures have been extrapolated to provide estimated annual figures for 2010.

In Table 2 the MCC B9 (pumps) figures represent all primary and secondary pumps for the building, including groundwater pumps. The heat pump EPI of 7.14 kWh/m^2 is for the entire building area but distributed across only the conditioned areas served would increase to 10.4 kWh/m^2. This is the combined energy requirement for heating and cooling for areas of 10,979m^2, which illustrates the

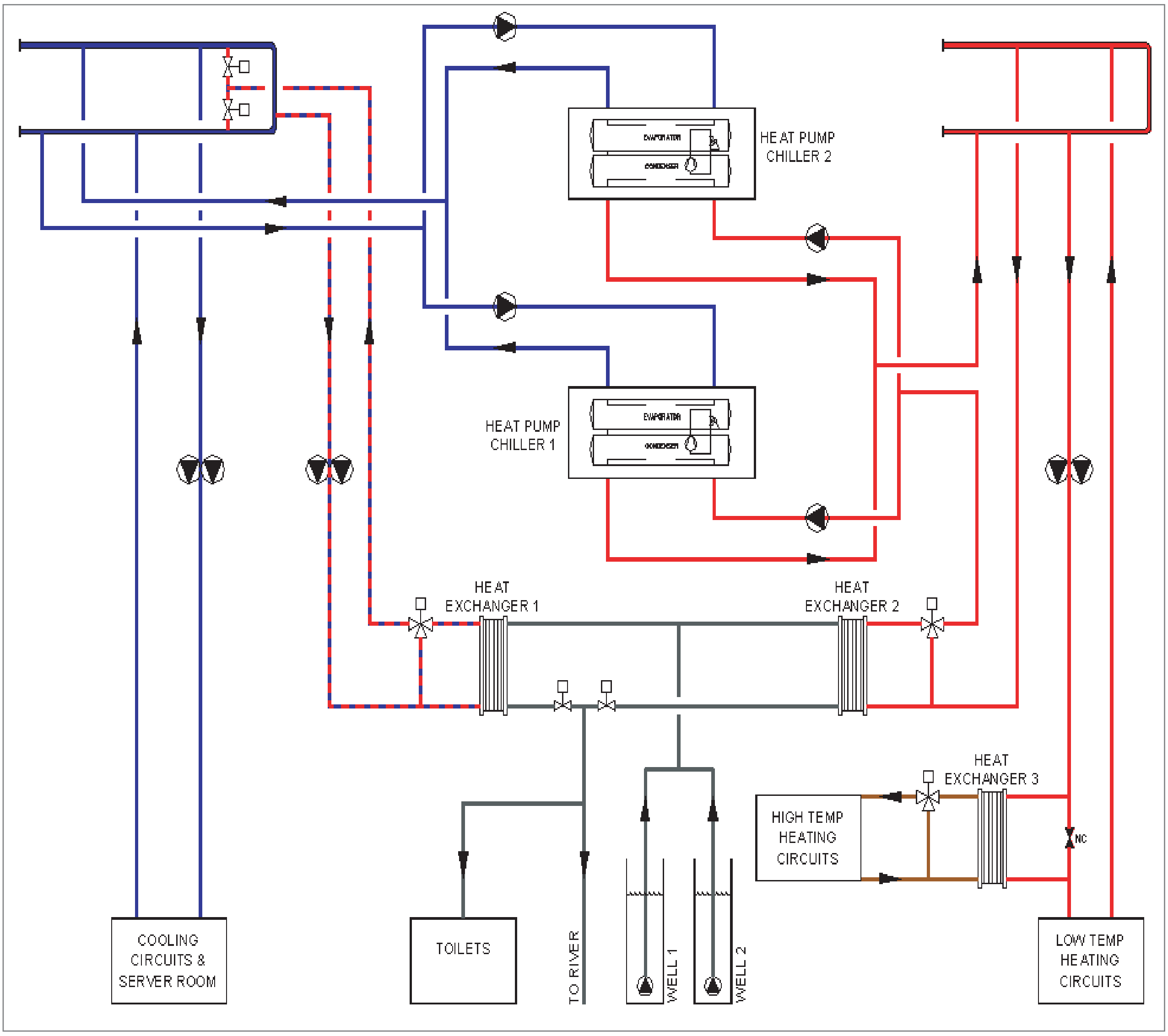

Fig. 12: Simplified ground source heat pump schematic

effectiveness of the simultaneous heating and cooling heat pump. To put the above figure in perspective, if the server room load of 60 kW were to be cooled by an air-cooled chiller with a seasonal COP of 3, the expected EPI would be 16.3 kWh/m² (area conditioned by heat pump).

	July – December Electrical Energy	Projected Annual Electrical Energy	Projected Annual EPI
MCC B9 (Pumps)	70,106 kWh	140,211 kWh	8.76 kWh/m²
Heat Pump 1	26,554 kWh	53,109 kWh	3.32 kWh/m²
Heat Pump 2	30,572 kWh	61,145 kWh	3.82 kWh/m²
Total Heat Pump	57,127 kWh	114,254 kWh	7.14 kWh/m²

Table 2: WGB heat pump heating and cooling electrical energy

	July – December Electrical Energy	Projected Annual Electrical Energy	Projected Annual EPI
Building Total	1,098,940 kWh	2,197,880 kWh	137.4 kWh/m²
Server Room	262,800 kWh	525,600 kWh	33.9 kWh/m²
Natural Gas	203,105 kWh	406,211 kWh	25.4 kWh/m²

Table 3: WGB building annual energy

Total mechanical electrical loads (including fans, pumps and heat pump) represents an EPI of 29.5 kWh/m² which accounts for 21.5% of the buildings total for the year.

In Table 3 the natural gas total includes LPHW boiler energy, lab gas usage and domestic hot water production by the stand alone gas fired heater.

A standard university building would be expected to achieve EPIs of 96.1 kWh/m² (electric) and 301.9 kWh/m² (fossil fuels) (CIBSE 2008) for similar operating hours. This represents a 59% reduction in energy use and a 30% reduction in CO_2 emissions (fig. 13). The building also compares favourably against Naturally Ventilated Office benchmarks indicated in ECON 19. Compared to the UCC average building stock for 09/10, the building represents a 47% improvement in energy usage and a 33% reduction in CO_2 emissions.

The server room constant electrical load is currently 60kW which represents 25% of the building total for the year. The server room is currently well under capacity compared to the original design, however, there are plans for significant further expansion in the next phase.

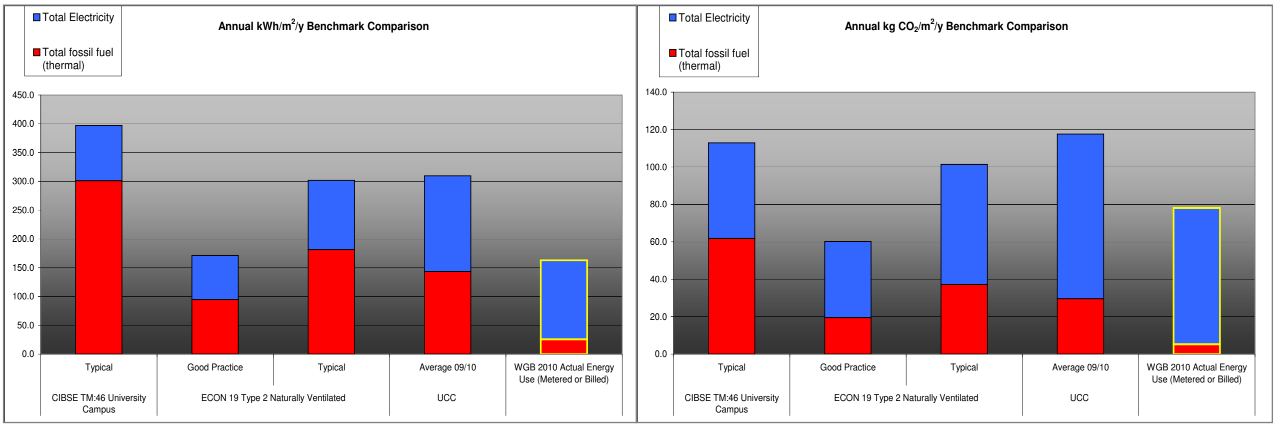

Fig. 13. CIBSE TM: 46 and ECON 19 Benchmarks adjusted for 2010 Cork Degree Heating Days (2,565) and actual building occupancy hours (5,235) according to CIBSE TM: 46 UCC 09/10 average figure (Ahern & O'Connor 2011) thermally adjusted only from 2,375 degree heating days to Cork 2010 Degree Heating Days (2,565)

In free cooling mode the submersible well VSD is currently operating at a minimum speed of 31 Hz (5.3 kW) which represents a cooling load of 300 kW (pump increases speed to maintain supply/exhaust temperature differentials). For free cooling of the server room at night the COP is currently above 10. As the cooling load increases in the future with the additional fit out, or during the summer months (largest recorded cooling currently is 330 kW), the COP of the free cooling mode will increase significantly.

Due to technical errors the energy meters recording cooling and heating demands for the building have not been recording data until December. As a result it is not possible to comment on the seasonal efficiency of the heat pump. A number of figures (14, 15, and 16) have been prepared to indicate the behaviour of the heat pump operation. During the summer an issue with the controls was preventing free cooling of the server room at night, meaning the heat pump was in cooling mode 24/7. This was rectified in September.

5.5 Conclusions and lessons learned

The analysis of the results indicates that the system is operating extremely efficiently with an annual combined EPI for cooling and heating of 10.4 kWh/m^2. This EPI is likely to improve as the building fit out is completed over the next two years.

Currently the system is significantly oversized as the heating and cooling loads (server room) predicted for the three storey building have not materialised. However, the additional two floors will have

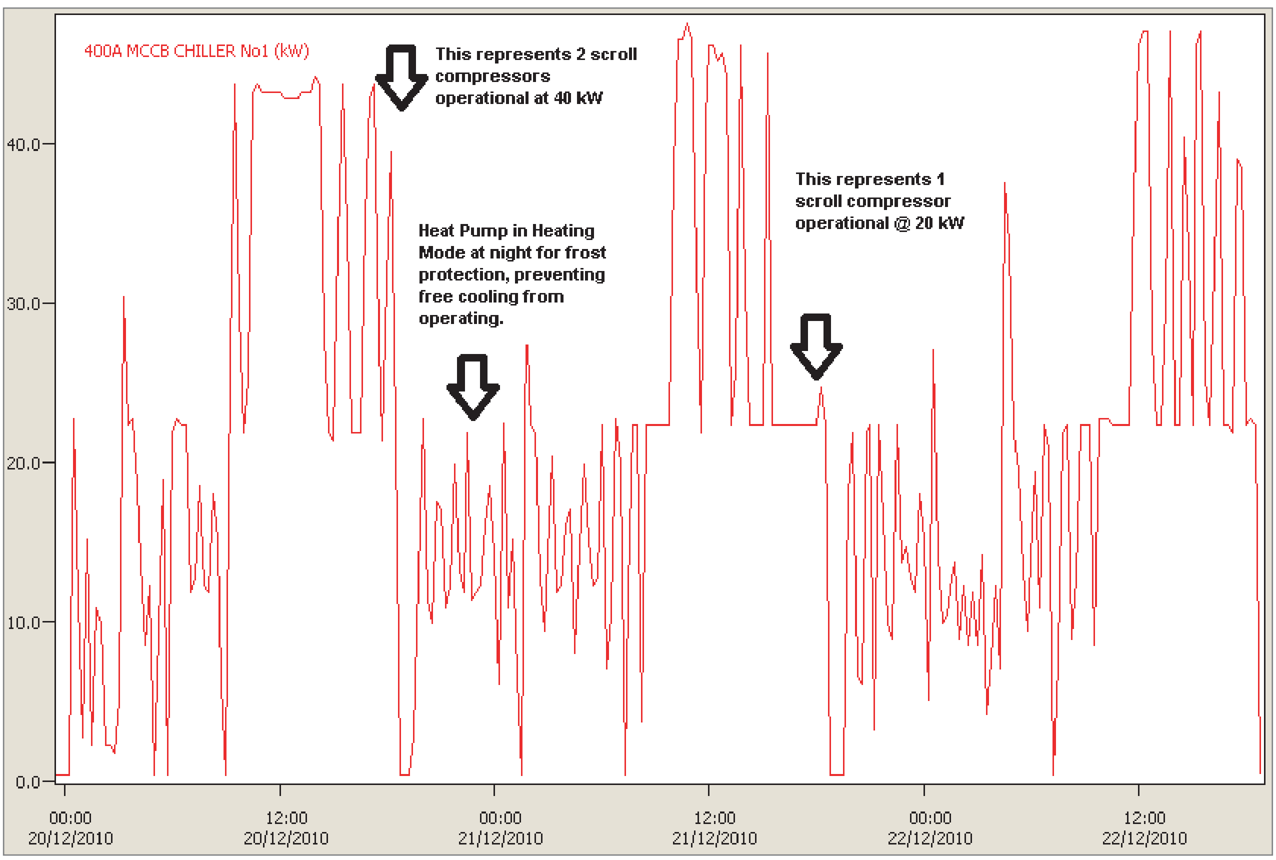

Fig. 14: WGB BMS snapshot – heat pump electrical power Dec 2010

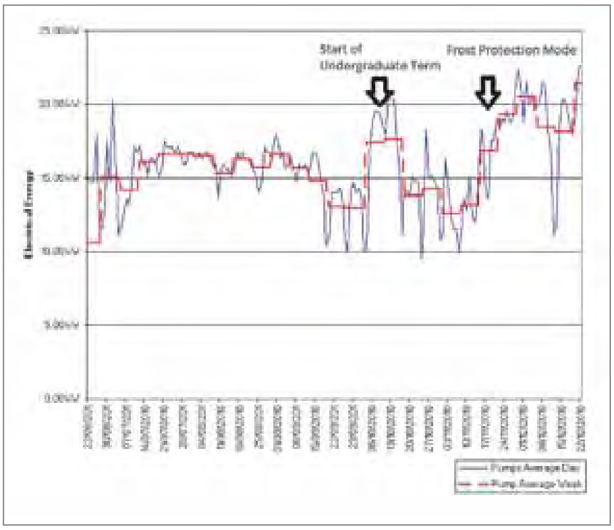

Fig. 15: WGB total pumping average energy Jul – Dec 2010

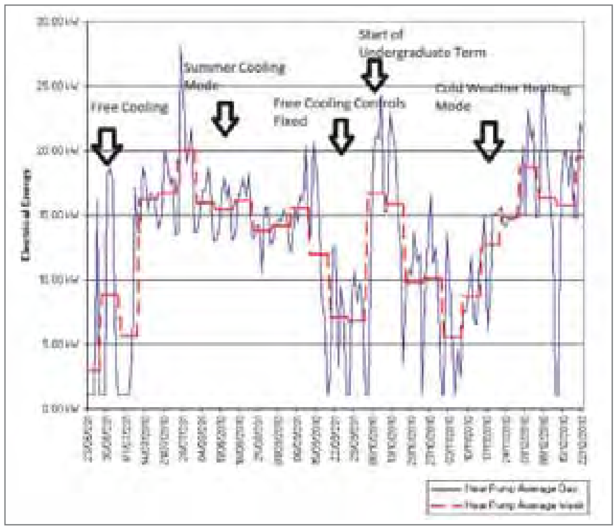

Fig. 16: WGB heat pump total average energy Jul – Dec 2010

significant heating and cooling requirements. The modular design of the system has ensured efficient operation at low part load.

Other notable lessons learned include:

- Complete trial boreholes well in advance of construction to avoid surprises.
- There is limited knowledge in the industry on how to construct and commission these systems. A detailed sequence of operations describing the complex control strategy is a prerequisite.
- Complex systems need seasonal commissioning in the first year of operation to ensure operation to the design intent.
- Avoid three-port valves on the CHW system as delta T degradation will significantly reduce heat recovery potential.

The project has demonstrated the following benefits:

- There is significantly lower energy consumption compared to traditional heating and cooling solutions. Fossil fuel heating is significantly reduced which, as the national electricity grid decarbonises, will reduce carbon emissions further.
- Successful recovery of waste heat from the server rooms (60 kW constant load with future expansion to 300 kW).
- Groundwater installations with highly variable water temperatures can be accommodated with the right control strategy and provide significant free cooling when coupled to high temperature CHW systems.
- Traditional CHW and LPHW systems can be designed to operate effectively with higher chilled water temperatures and significantly lower LPHW temperatures if carefully integrated into mechanical air systems.
- Energy usage and CO_2 emissions compares favourably with fully naturally ventilated buildings.

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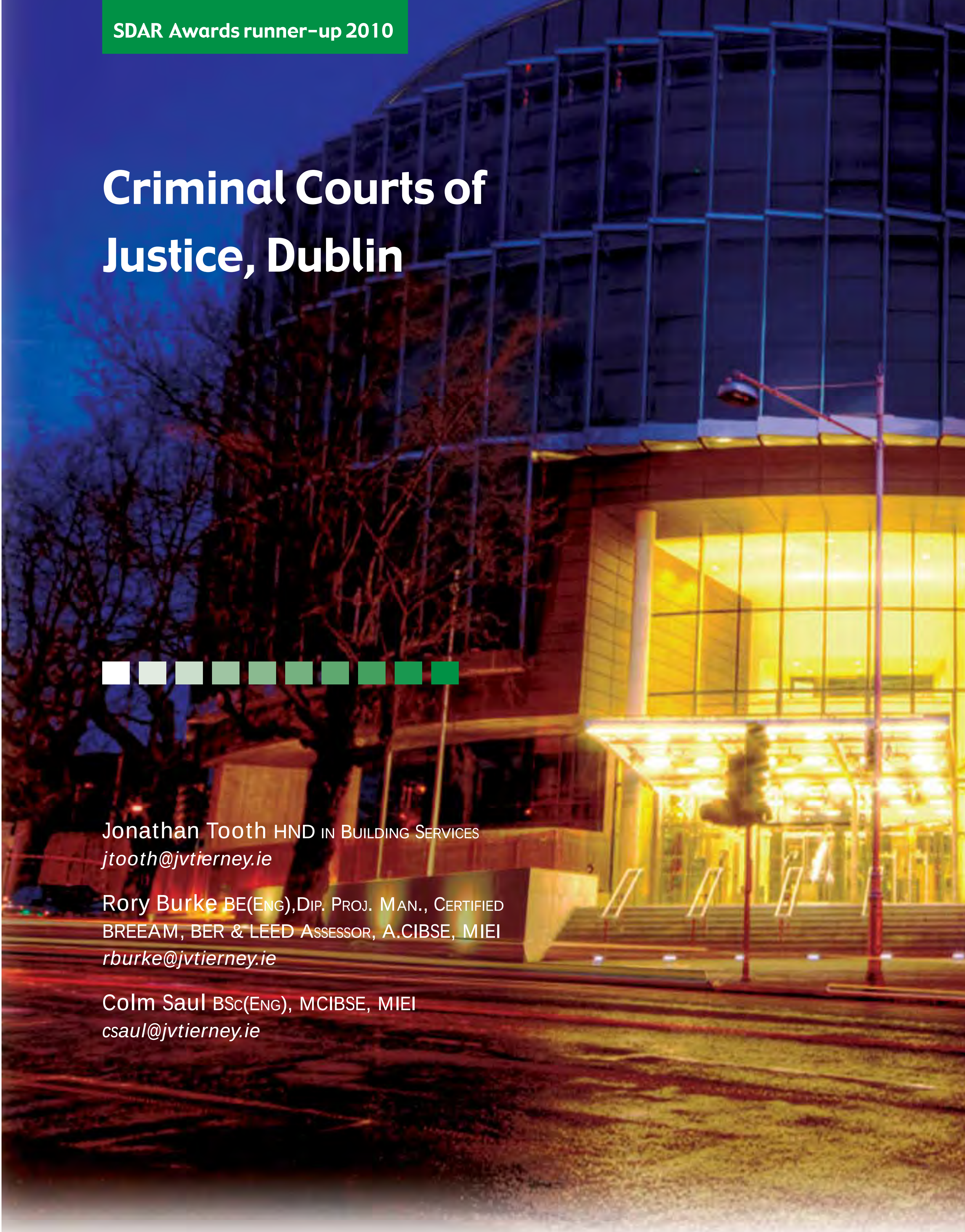

SDAR Awards runner-up 2010

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Abstract

The newly completed Criminal Courts of Justice (CCJ) at Parkgate Street in Dublin 8 is the largest courts project undertaken in the history of the Irish State. The design of the heating, ventilation and air conditioning (HVAC) systems was based on computer simulated modelling of the building to determine the optimum plant selection and operation based on the contract conditions and energy targets.

The report will analyse the computer simulated energy targets versus the actual energy consumption and assess the benefit of engineering solutions such as twin-skin facades and heat recovery based on real data. The report will draw conclusions on the real benefit of such systems within the built environment.

In addition to the energy targets, the report will discuss the commissioning processes involved in delivering the energy targets required and the importance of designing metering strategies to enable the data to be collected and analysed.

Key Words:

Facade, Natural Ventilation, Heat Recovery, Energy Usage Indices, Metering.

1. Introduction and project detail

The newly completed Criminal Courts of Justice (CCJ) at Parkgate Street in Dublin 8 is the largest courts project undertaken in the history of the Irish State. This landmark building provides a significant architectural addition to Dublin. Its architectural design, along with its construction, is befitting of a major civic building of national significance. The project was carried out under a Public Private Parnership (PPP) and has been awarded the RIAI Public Choice Award 2010 and RIAI Best Accessible Award 2010.

The design centralised criminal court activity in one serviced location. It is a major new state-of-art facility suited to the administration of justice in Ireland. The principal users will be the Courts Service, Judiciary, Jurors, Director of Public Prosecution, Legal Profession, Defendants, Gardai, Irish Prison Service, Facilities Management and the General Public. The building is circular in form with the 'Great Hall' at its core and is 11 storeys high over a naturally-ventilated basement car park with an area of 25,000m^2 and a construction value of €160m. It contains 22 courtrooms, jury retiring rooms, judicial chambers, custodial holding rooms and associated offices and services.

In addition to being a landmark building, the brief called for the building to be a low energy user with individually-controlled spaces; good daylight; acoustically-treated facilities protected from internal and external noise pollution; and highly-secure, including the segregation of the following users: defendants in custody, public, jurors and judiciary.

The design called for a challenging energy usage target of not greater than 240 kWh/m^2/year with a resultant carbon emission target of <86 KgCO$_2$/m^2/year based on the strict criteria set out in the PPP contract documents. These documents set very stringent tolerances for the internal environmental conditions and noise levels. Any deviation outside of these conditions would result in the non-availability clause being enforced.

Some of the specific features that assist in meeting these energy and environmental targets are the active double skin facade, mixed mode ventilation and use of thermal mass in courtrooms, active chilled beams, low Nox boilers, night cooling, heat recovery from the Great Hall, extensive lighting management system incorporating presence detection, and daylight sensing. In the case of the double skin facade for example, it reduces winter heat losses, reduces solar gain into the spaces and provides for solar and glare control and allows for very good levels of natural daylight.

One of the early tasks undertaken by the Building Services Design Team was to provide advice to the whole project team on the building envelope. Extensive use of Dynamic Simulation Modelling in the design phase helped to optimise the double skin facade design and the control strategy. Dynamic Simulation Modelling also allowed the thermal loads and energy consumption to be assessed whilst providing analysis of the ventilation strategy of Free cooling with limited mechanical cooling in the great hall and courtrooms.

A comprehensive energy strategy was produced to demonstrate and to outline compliance with the energy and carbon emission targets and outline to the client how it would be monitored, controlled and reported on.

The active double skin facade is controlled through a Facade Management System (FMS) linked to the Building Management System (BMS). The FMS is currently finishing its extensive seasonal commissioning and 12 months into occupation has demonstrated the benefit that the double skin adds to minimising energy losses.

Based on actual data, the heat loss through the courtrooms overnight during non-operational hours was exceptionally low during the cold conditions of December 2009/January 2010 and was typically around 2 degrees Celsius, thus demonstrating the benefit of the active double skin facade and overall thermal performance of the building envelope that was studied and selected using Dynamic Simulated modelling.

The courtroom design involved the use of a displacement ventilation system with highly specified acoustic baffling to meet the stringent HVAC acoustic criteria. Each courtroom has its own dedicated air handling unit (AHU) supplying air at low level and the air is returned at high level through acoustic louvers into the 'Great Hall'. The AHU's are variable speed controlled linked to temperature and CO2 control algorithms.

The Great Hall would be regarded primarily as a large transient space with a diameter of 40m and a height of 32m and is the main connecting hub to all the courts. It is the single largest space in the building representing 35% of the all public spaces. A great deal of time was spent modeling the microclimatic conditions of the space and reviewing the most energy efficient way to meet the internal environmental conditions. The system selected was a mixed mode ventilation and underfloor heating system comprising of natural ventilation openings at low and high level with the secondary air from the 22 courtrooms assisting in the ventilation and heating of the space. There are roof mounted heat recovery units that provide pre-heating to the fresh air make-up into the courtrooms.

While not in itself a low energy feature, the use of a significant metering strategy (over 150No meters) has helped to reduce the actual energy usage within the building. This strategy is in line with the guidelines set out in CIBSE's TM39 – Building Energy Metering. According to TM39 good metering/sub-metering, is a fundamental energy monitoring and targeting tool and an essential part of energy management. Sub-metering in itself does not save energy but rather the actions taken as a result of monitoring and using the data provided. All meters are connected to a dedicated monitoring and targeting software package via the BMS.

This software allows the facilities manager to actively monitor and control a significant proportion of the energy consumers in the building. The strategy developed during design, meets and exceeds the criteria set out in TM 39 and has allowed the client to verify the energy consumption within the building with the billing information supplied by the utility companies.

The environmental brief set by the client was to achieve a "Very Good" rating under BREEAM for Courts 2006 and was comfortably achieved. Particular attention was paid during construction to the impact of site activities with a specific target to reduce, recycle and reuse construction materials where possible. In this category the constructor (PJ Hegarty's) scored the maximum of four points under the construction site impacts criteria. Additionally, all timber used during construction was responsibly sourced. In relation to the Building Regulations Part L requirements the design exceeded the carbon emissions target for the notional building by 30%.

The heat recovery system installed demonstrated that by installing the equipment at an additional capital cost of £80k, the building operation would save £10k per year giving a simple payback of eight years and was deemed to be beneficial to the overall PPP operation.

The building is designed to cater for different levels of perimeter security and is provided with an integrated security management system to allow monitoring and control of all CCTV, access control, intruder alarm and call systems from a central graphical user interface. The building is provided with two security control rooms with a dedicated control room provided for the custodial area. All fixtures in the custodial area were selected to meet Irish Prison Service anti-ligature requirements including lighting, smoke detectors, ventilation grilles and sprinkler heads.

Commissioning of the CCJ formed a significant item within the construction period, an overall allowance of 16 weeks was included in the contract programme. The HVAC, security, life safety and BMS systems were commissioned in accordance with CIBSE Commissioning Codes. However, the level of approval and sign off was more stringent due to the nature of the contract. As the CCJ was a design build finance operate and maintain contract (DBFOM), there was a four level sign off for each system (contractor, building services engineer, facility management contractor and independent commissioning engineer). When completed, this was witnessed by the client's site engineering team.

The commissioning data was fundamental to the setting up of the building management system (BMS) and subsequently the energy management and reporting. The data logs collected by the control system is used in analysing actual building operation versus simulated building operation calculated during the design process. Seasonal commissioning is being carried out to maximise system performance and optimise plant operation between seasons. Adjustments are made to set points and time schedules for winter and summer conditions, based on the historical data to further enhance the building performance and ultimately the energy usage. J.V. Tierney and Co (M&E Consultants) is assisting the FM contractor in interpreting and analysing the performance of the building and its systems during the seasonal commissioning phase.

The client, the Courts Service, was fully involved through all design stages given the nature of the PPP project. The PPP company, Amber Infrastructure Group, which managed the project from design to operation, were and are involved with the client on a continuous basis.

A collaborative approach was taken by the PPP team throughout all stages of design, construction and commissioning with PJ Hegarty's taking control of the design build element of the project. This required regular monthly project workshop meetings, fortnightly design team meetings and weekly commissioning meetings during the latter stages of the project. This approach ensured minimal changes during the process and allowed the project to be delivered three months ahead of schedule.

The FM contractor G4S contract is to operate the building for 25 years and they were involved from project bid stage through design, to selection and commissioning of equipment and are fully familiar with the design and performance criteria of the building. They have a full-time team based on site including security, maintenance technicians and cleaning staff to ensure the smooth daily running of the building complex.

The PPP company made a conscious effort to beat the building energy target by at least 15% and 12 months into operation the

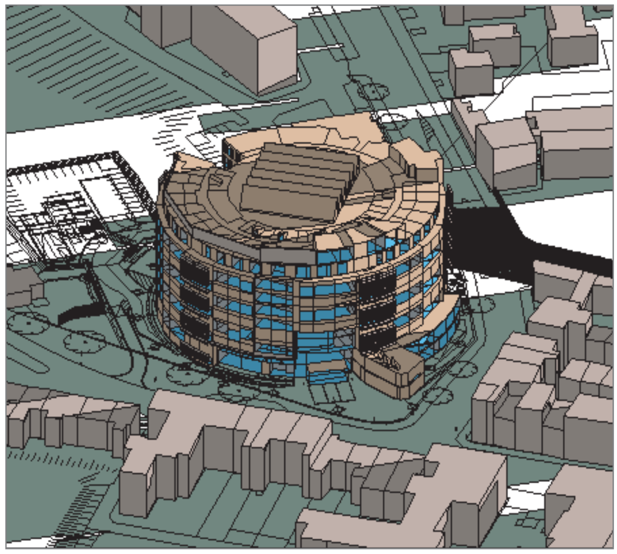

Fig. 1.1: Rendered wireframe image of the Criminal Courts of Justice

Criminal Courts Complex – energy model simulation summary data

Area Type	System Type	Plant Operational Profile	Estimated Occupancy	Occupancy Profile	Occupancy Diversity	Lighting (W/m^2)	Lighting Profile	Lighting Diversity (%)	Equipment	Equipment Profile	Equipment Diversity (%)
Courtrooms	Displacement	08.00-17.00	As per CP RDS	09.00-17.00	67%	12	09.00-17.00	80%	Court Technology	09.00-17.00	80%
Judges Chambers (B1)	FCU	07.00-19.00	6	09.00-19.00	25%	12	09.00-19.00	25%	1 PC 1 Plasma Screen 1 Small Printer	09.00-19.00	25%
Judges Ante Rooms (B2)	FCU	07.00-19.00	3	09.00-19.00	25%	12	09.00-19.00	25%	1PC	09.00-19.00	25%
Jury Retiring Rooms (C3)	FCU	07.00-19.00	12	09.00-19.00	100%	12	09.00-19.00	80%	1 Fridge	09.00-19.00	100%
Large Consultation Rooms (A9)	FCU	07.00-19.00	6	09.00-18.00	50%	12	09.00-18.00	80%	2 PCs	09.00-18.00	100%
Consultation Rooms(10)	FCU	07.00-19.00	4	09.00-18.00	50%	12	09.00-18.00	80%	2 PCs	09.00-18.00	100%
Public Restaurant (A11[1])	AA	08.00-18.00	100 people	09.00-18.00	100% 13.00-15.00 20% other	12	09.00-18.00	80%	Catering	09.00-18.00	100% 13.00-15.00 20% other
Kitchen (A11[2])	AA	08.00-18.00	6	10.00-15.00	100%	12	10.00-15.00	80%	Catering	10.00-15.00	100%
Office Block (E8[2])	CHB	08.00-18.00	24	09.00-18.00	75%	12	09.00-18.00	80%	24 PCs 4 Lge Printers	09.00-18.00	75% Pcs 100% Printers
Office Block (E8[3])	CHB	08.00-18.00	30	09.00-18.00	75%	12	09.00-18.00	80%	30 PCs 5 Lge Printers	09.00-18.00	75% Pcs 100% Printers
Bar Area (H1)	CHB	08.00-18.00	60	09.00-18.00	50%	12	09.00-18.00	80%	22 PCs 3 Lge Printers	09.00-18.00	50% Pcs 100% Printers
Bar Area (H2)	CHB	08.00-18.00	50	09.00-18.00	50%	12	09.00-18.00	80%	50 PCs 7 Lge Printers	09.00-18.00	50% Pcs 100% Printers
Bar Area (H3)	CHB	08.00-18.00	4	09.00-18.00	100%	12	09.00-18.00	80%	3 PCs 3 Lge Printers	09.00-18.00	50% Pcs 100% Printers
Bar Area (H4)	CHB	08.00-18.00	150	09.00-18.00	50%	12	09.00-18.00	50%	150 PCs 13 Lge Printers	09.00-18.00	50% Pcs 100% Printers
Custody Area (Support)	FCU	07.00-18.00	16	09.00-18.00	100%	12	09.00-18.00	80%	6 PCs	09.00-18.00	100%
Custody Area (Cells)	AA	07.00-18.00	100	09.00-18.00	100%	12	09.00-18.00	80%	–	–	–
Jury Assembly (C1)	AA	08.00-12.00	300	09.00-12.00	75%	12	09.00-12.00	80%	2 Plasma Screens	09.00-12.00	100%
Jury Assembly (A8)	AA	08.00-12.00	97	09.00-12.00	75%	12	09.00-12.00	80%	1 Plasma Screen	09.00-12.00	100%
Jury Dining (C4)	AA	12.00-16.00	192	19.00-15.00	75%	12	13.00-15.00	80%	Catering	13.00-15.00	75%
Great Hall	UFH	06.00-17.00	–	–	–	Gallery Atrium Top Decorative	09.00-18.00 09.00-18.00 15.00-18.00	60% 60% 100%			

Unless specified otherwise, occupancies are Monday to Friday excluding public holidays.

1. Some winter months have an additional 0.30 to 1.00 warmup, e.g. courtrooms, office block, bar area. 2. Above figures are based on a typical core day of 11 hours. This gives an average building operational profile of 55 hours per week.

Fig 1.2: Assumptions used for computer simulation

building is projected to have an annualised reduction of greater than 25% of this target due to the quality of the design, construction and facility management operations.

The client has commented:

"It is a tribute to the design and construction teams that the completed building fully meets the complexity of the brief and during its first four months of operations has successfully dealt with the largest single transfer of criminal court business in the history of the State."

Analysis of data

As mentioned above, a computerised thermal model was produced to ascertain the predicted energy consumption of the building prior to construction. Fig. 1.1 shows a graphic of the computer model generated with IES Virtual Environment® software. The software allows actual construction details to be created within the model – a virtual wall can be created, for example, of the designed thickness, configuration and individual build element and an actual U-value can be calculated. In other words, the computer model is a virtual replica of the building. This is a powerful tool as it can be used to simulate different scenarios or construction methods etc to optimise building performance before any real building takes place.

Various data assumptions were made during the design, based on contract room data sheets and industry best practice. These are summarised in Fig. 1.2. The simulation takes these assumptions in the form of profiles and the dynamic output is achieved,and provides information on plant operation with respect of fuel type, efficiencies, weather data, occupation and internal/ external gains.

Once the model is set up and the profiles are inputted into the model, the simulation of the building takes place. The predicted fuel consumption (gas, electricity etc) can be plotted and analysed. Fig. 1.3 shows the annual energy consumptions based on the simulated computer model.

This data is represented in kWh/m² which is the unit used for benchmarking as shown in Fig. 1.4.

Actual data collected from the BMS and energy software installed at the Criminal Courts of Justice demonstrates the Year 1 energy consumption based on the metering/recording facilities and the utility companies' energy bills. These are tabulated in Fig. 1.5.

Since energy consumption for the contract year is based on energy used 24 hours a day, it was necessary to derive a factor that assesses how much energy is used between the hours of 5am and 7pm, Monday to Friday. This factor was derived from consumption data that showed how much electricity and gas was used every 15 minutes of the day. From this analysis a "2600 hours" factor (contract factor) was developed which represented how much of the 24-hour based consumption needs to be included to derive the annual Energy Usage Indices (EUI). The "2600 factors" used in this analysis are 55% for electricity and 80% for gas.

Using the consumption analysis presented in Fig. 1.5 and a treated floor area of 23,000m², Fig. 1.6 has been prepared to compare actual Contract Year One performance with target performance, for both energy and CO2.

1.2 Conclusion

Energy usage – simulated versus actual

It can be seen based on Figs 1.2 to 1.6 that the simulation software and computer model have allowed accurate assessment of the

Criminal Courts Complex – estimated energy consumption, variation per month (excludes catering)

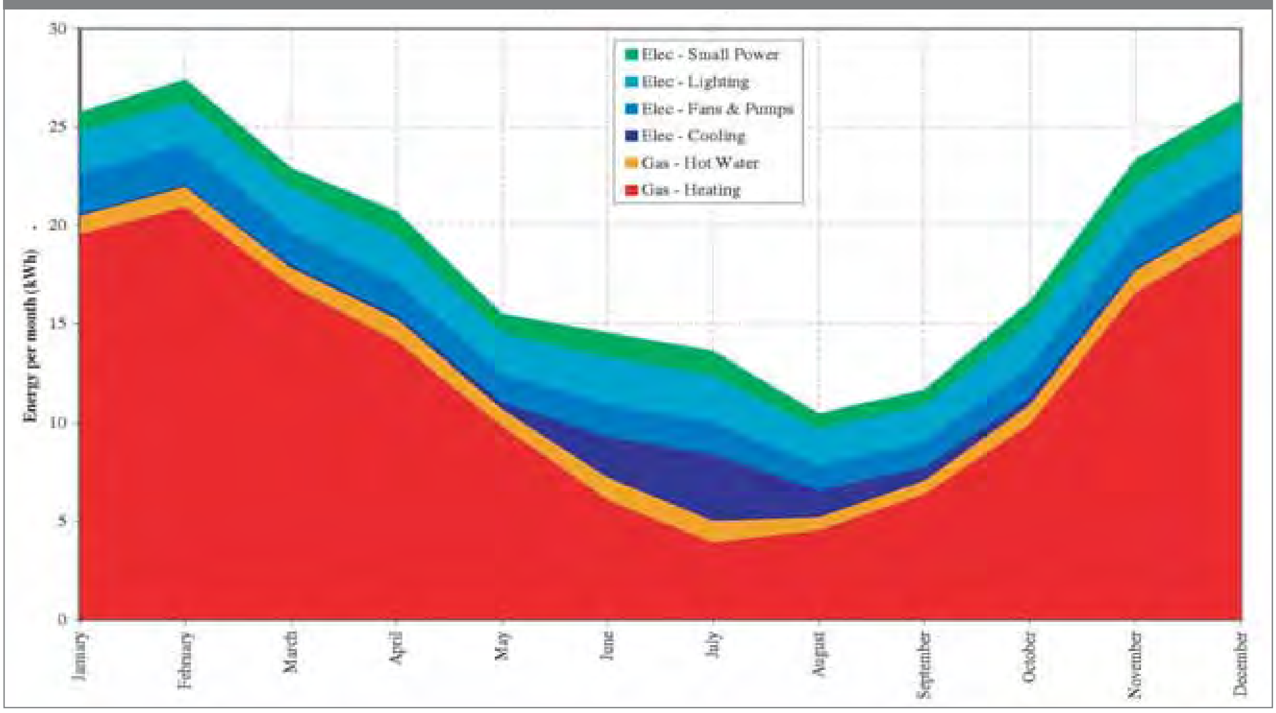

Fig. 1.3: Estimated energy consumption

Criminal Courts Complex – estimated monthly energy consumption (kW/m²)											
	Heating (kWh/m²)	Hot Water (kWh/m²)	Cooling (kWh/m²)	Fans and Pumps (kWh/m²)	Lighting (kWh/m²)	Small Power (kWh/m²)	Catering Gas (kWh/m²)	Catering Electric (kWh/m²)	Natural Gas (kWh/m²) *excluding Catering*	Electricity (kWh/m²) *excluding Catering*	Total energy (kWh/m²) *excluding Catering*
January	19.6	0.9	0.1	2.1	2.1	1.0			20.5	5.3	25.7
February	21.0	1.0	0.1	2.1	2.1	1.1			22.0	5.4	27.4
March	16.9	0.9	0.1	1.7	2.2	1.0			17.9	5.0	22.9
April	14.2	1.1	0.2	1.7	2.3	1.2			15.3	5.4	20.7
May	9.9	0.9	0.3	1.5	2.0	1.0			10.7	4.7	15.5
June	6.1	1.1	2.1	1.7	2.3	1.2			7.2	7.3	14.5
July	3.9	1.1	3.4	1.7	2.3	1.2			5.0	8.6	13.6
August	4.6	0.7	1.4	1.3	1.8	0.8			5.2	5.2	10.5
September	6.4	0.7	0.7	1.3	1.8	0.8			7.1	4.6	11.7
October	10.0	1.0	0.3	1.6	2.1	1.1			11.0	5.1	16.1
November	16.6	1.1	0.1	1.9	2.3	1.2			17.7	5.6	23.3
December	19.7	1.0	0.1	2.1	2.3	1.1			20.8	5.6	26.4
SUM	148.8	11.6	8.8	20.6	25.8	12.7	4	6	160.4	67.9	228.3
							Including Catering		164.4	73.9	238.3

Fig 1.4: Estimated energy consumption 9kWh/m²)

Notes	Invoice Month	Electricity kWh	Gas kWh	Electricity 2600hrs kWh	Gas 2600hrs kWh
From 18 Nov	Nov-09	105,354	–	57,945	–
	Dec-09	237,023	–	130,363	–
	Jan-10	254,879	–	140,183	–
	Feb-10	228,547	1,670,197	125,701	1,336,158
	Mar-10	246,592	356,631	135,626	285,305
	Apr-10	211,779	232,317	116,478	185,854
	May-10	215,477	178,585	188,512	142,868
	Jun-10	235,936	106,289	129,765	85,031
	Jul-10	247,394	131,318	136,067	105,054
	Aug-10	210,057	110,517	115,531	88,414
	Sep-10	205,921	196,955	113,257	157,564
	Oct-10	232,260	275,287	127,743	220,310
To 17 Nov	Nov-10	137,218	85,7734	75,470	68,587
	Totals	2,768,437	3,343,930	1,522,640	2,675,144

Fig 1.5: Contract year 1 energy consumption

predicted energy usage for the Criminal Courts of Justice based on continuous occupancy and internal gains used in the assumptions noted above in Fig. 1.2. In conjunction with the building services design and installation of systems that can accurately record active energy consumption, these tools provide the building user with the information to enable accurate energy prediction and management.

It can be seen that the actual energy figures are circa 25% less than predicted (Fig. 1.6). This is because the software model uses occupancy and internal gains that do not fluctuate as they do in reality. The actual energy data can be a useful 'sanity check' when

2600 hours bases EUI	Electricity	Gas	Total
Year 1 EUI kWh/m²	66	116	183
Target EUI kWh/m²	90	150	240
Vrce actual to target	**-26%**	**-22%**	**-24%**
Year 1 EUI kgsCO²/m²	41	23	64
Target EUI kgsCO²/m²	56	30	86
Vrce actual to target	**-26%**	**-22%**	**-24%**

Fig 1.6: 2600 energy usage indices

modelling buildings in the future. One thing that could be learnt from this is that the fluctuations in occupancy and internal gains could be modelled more realistically using a more complex profile, or indeed reduced from the standard figures traditionally used. In addition, installing energy meters as outlined in CIBSE TM39 has enabled the facilities manager (G4S) to monitor and control energy usage such that consumption is better than that predicted.

Historical energy data can be logged and standard energy usage profiles can be generated to allow the user to actively manage the energy consumption in a proactive, rather than reactive, way. Bench-marking energy profiles for any system can be achieved easily through data collection which can also flag issues that may occur during the building lifecycle.

Twin skin facades

The Criminal Courts of Justice was designed incorporating a twin skin facade around the majority of the building. The only exception to this is the office areas on the north facade. The computer model high-lighted the benefit on energy consumption of the twin skin during the design process and along with the installed field devices and control systems working together (building management system and facade

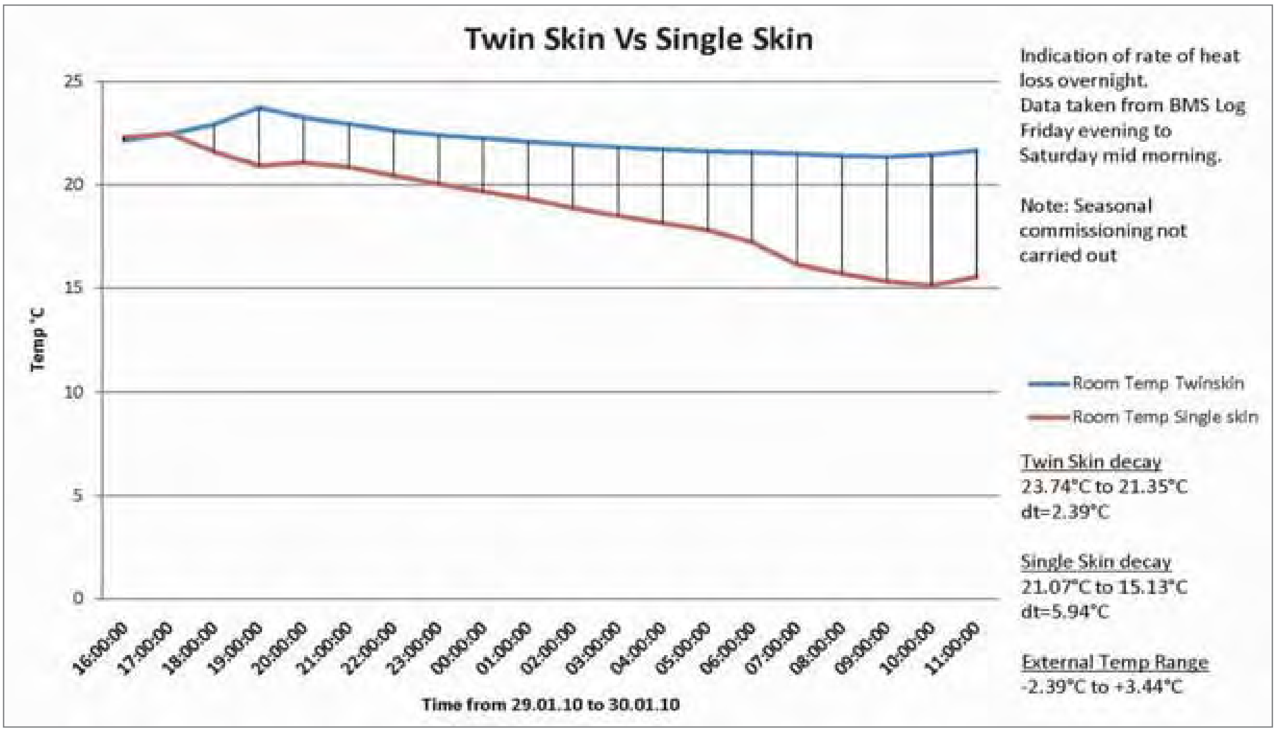

Fig. 1.7: Twin skin vs single skin. Courtroom versus office area

management system) it is possible to plot the actual benefit of the twin skin vs the single skin in terms of heat loss comparison between the two systems.

To achieve this assessment, data was collected from the room thermostats in the two areas over a weekend, when building services systems are "enabled off" on the BMS time schedule (building closed over the weekend).

As an example Fig. 1.7 shows the actual temperatures plotted in the twin skin and single skin zones showing the rate of heat loss over a non conditioned time period. The relevance of this is particularly apparent when considering heat up times when the building becomes occupied (Monday morning).

It can be seen from Fig. 1.7 that the rate of heat loss over a weekend period is notably less with the twin skin than with the single skin. This may appear to be an obvious statement but it cannot be ignored in relation to overall energy consumption, plant selection and building design. Consider the difference in energy usage indices discussed earlier if the twin skin solution was not part of the building design.

(%)	Total Energy (%)	Total Electricity (%)	Total Natural Gas (%)
Jan 01-31	-7.6%	2.8%	-9.5%
Feb 01-28	-8.5%	1.1%	-10.2%
Mar 01-31	-6.7%	1.2%	-8.1%
Apr 01-30	-6.6%	0.3%	-7.9%
May 01-31	-9.9%	-0.4%	-13.3%
Jun 01-30	-8.5%	-0.2%	-13.1%
Jul 01-31	-10.2%	-0.8%	-23.2%
Aug 01-31	-21.6%	-1.7%	-32.0%
Sep 01-30	-13.9%	-1.7%	-18.3%
Oct 01-31	-11.0%	-0.4%	-14.6%
Nov 01-30	-7.0%	0.5%	-8.6%
Dec 01-31	-7.4%	2.0%	-8.9%
Summed total	-8.7%	0.3%	-11.1%

Fig. 1.8: Heat recovery predicted energy reduction (%)

Heat recovery

The Great Hall in the Criminal Courts of Justice acts as a return air path for the court rooms and ancillary spaces (underfloor heating in the great hall). The design of this space utilises six heat recovery units (run around coil) located on the roof that are enabled based on the temperature profiles within the zone. Exhaust air from the court rooms is passively extracted into the Great Hall and, depending on the conditions, is either naturally exhausted via roof vents at high level or mechanically exhausted via the heat recovery units. The useful heat built up is introduced into the court room supply air via a pre-heat heating coil in the court room supply air handling units.

The computer model was used to predict the actual real benefit of this heat recovery system with regard to energy savings. Fig. 1.8 indicates the predicted benefit of the installation of this heat recovery system in terms of reduction in energy use and associated cost saving based on electricity cost of €0.18/kWh and gas cost of €0.04/kWh.

Acknowledgements

The authors acknowledge P.J. Hegarty & Sons Ltd, G4S and the Court Services for their assistance in the preparation of this report.

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SDAR Awards runner-up 2010

A review of the Passiv Haus Concept

and an examination of how this was applied to a supermarket in Ireland

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Abstract

The aim of this research is to garner a full understanding of low energy construction across a variety of sectors in countries throughout the world, and then investigate how the Passiv Haus concept was applied to a Supermarket in Ireland. In order to carry out this investigation, a case study was performed on the energy efficiency and performance of a Tesco store in Tramore. It was found that its electrical cosumption was 24% lower than equivalent stores which were not built to the high specification of the Passiv Haus Standard. As this supermarket is the first of its kind in the world, and with both the SEAI and the European Parliament pushing for this method of construction to be adopted,[1] this standard will most likely in some shape or form become a new building standard in Ireland. This supermarket offers a unique insight into what can be expected in building design and construction in this sector if it is undertaken.

Key Words:

Passiv Haus; Passive House; Electrical Energy Consumption in Supermarkets.

1 Introduction

In Ireland, the Passiv Haus Standard has become more widely acknowledged in recent years and accepted as a method of reducing energy consumption and the operating costs of a dwelling. However, applying this standard to a commercial building is still in relative infancy. This newer approach to using the Passiv Haus Standard was reviewed in this paper by applying an analysis of the energy consumption of a newly constructed Tesco supermarket in Tramore, Waterford, Ireland.

As this is the first supermarket in the world to be certified by the Passiv Haus Institut (PHI) it is of particular importance to demonstrate whether or not this method of construction shows any real benefits, especially in a commercial sense, as this will be one of the main driving forces behind this movement if it is to be successful.

The main aim of this study was to investigate if there were any cost savings with regards to the operational costs of the Tesco supermarket in Tramore, and if there were any improvements in efficiency in energy consumption in comparison to standard building practices.

Tesco have offsite management systems that remotely obtain all data at the point of use. Given that the store has been in operation since October 2008, there was over a year's worth of data available for this study. Field equipment was also used to independently record data for the research.

2 Governmental influence

On the 8th January 2008 following the work done in the inter-governmental European CEPHEUS research programme, the European Parliament published a document entitled "An Action Plan for Energy Efficiency: Realising the Potential". Within this document, which covered a range of aspects, particular mention was made of the Passiv Haus:

> *"…29. Calls on the Commission to propose a binding requirement that all new buildings needing to be heated and/or cooled be constructed to passive house or equivalent non-residential standards from 2011, and a requirement to use passive heating and cooling solutions from 2008…[3]"*

3 Technical criteria for Passiv Haus

Specific Space Heating Demand	Max 15 kWh/(m^{2}a)
Specific Space Heating Load	Max. 10 W/m^2
Pressurisation Test Result n_{50}	Max. 0.6 h-1
Specific Space Cooling Demand	Max. 15 kWh/(m^{2}a)
Total Specific Primary Energy Demand	Max. 120 kWh/(m^{2}a)*

Table 1: Criteria for non-residential buildings for Passiv Haus certifiacation[2]
*Over runs of this amount is allowable at the discretion of the Passiv Haus Institut

As the case study performed in this research was performed on a non-residential building, it is important to note at this stage the criteria set out by the PHI, for Non-Residential Passive House Buildings (Table 1).

4 Case study: Tesco Tramore, Waterford

A recent study commissioned by the SEAI estimates that the commercial sector could save up to 25% of its energy use through investment in economically viable energy efficiency opportunities.[4]

In October 2009 Tesco unveiled a new energy efficient supermarket that took on some of the more cutting edge design techniques and technologies that are available today for low energy construction, and to test in a real-world, commercial environment the viability of these technologies. They had sought to create the world's first Passiv Haus supermarket.

A. The supermarket: analysis

1) Physical structure

The structure of the supermarket is broken out into its separate constituents below, and explained in brief detail.[5]

Roof Panel: The roof was 200 [mm] insulated Kingspan Ks 1150 panel, sitting on timber purlins with insulated pads to achieve the overall U-Value of 0.12w/sqm K

Roof lights: 15 degree pitch triple glazed glass and insulated to the same specification as the roof panels.

Roof penetrations: Fully packed and sealed with insulation to 0.035 thermal conductivity.

Triple Glazing: Curtain wall to design value of 0.8 W/m^2 K.

Air sealing: Air seal tested by BSRIA. Result was 1.64 M^3/h/M^2 @50Pa. Standard building regulations looks for 10 air changes. 1.64 equates to an air change rate of 0.3.

Floor slab insulated: The floor slab was completely insulated, and most importantly and unusually, right up on the vertical side of the slab also. This was to prevent any cold bridging between the outside and the inside of the building.

Structural Timber Beams: These timber beams are also called Glue Lam Beams, and are selected for their reduction in embedded carbon being introduced into the construction of the building.

Rain water harvesting: The car park areas are cobbled intentionally to allow rain water to be gathered into a rain water harvesting tank.

2) Building services

Though the PHI do not typically dictate what type of building services are used within the construction of a building, the energy consumption was going to over run the 120 kWh/(m^{2}a) allowable within the criteria. This means that the PHI needed to also approve the Building Services design.

Combined Heat and Power (CHP): CHP on a small scale as is installed in Tesco Tramore can be very beneficial, assuming that a heat load is required all year round.

Tri-Generation: It was also decided to add an absorption chiller, which operates by using heat and a chemical process to create low temperatures, and as such can be used during the summer months to keep the thermal load high and as such keep the CHP running 12 months of the year. This tri-generation plant was not installed during this study.

Hot Water Air Curtains and Heaters: Instead of using electric door curtain and water heaters, the design of the building was to try and incorporate as much of the heat load into the heating system, which was the gas fired CHP.

Chilled Beams (instead of split A/C): Chilled beams were installed in all areas that required cooling: the office areas in particular. Again the reason for using the chilled beams was to make use of the CHP tri-generation facility once it is installed on site.

CO2 Refrigeration: A centralised refrigeration unit was used in the Tesco store for the fridge cabinets. This refrigeration unit operated on CO2 gas. Its efficiency is almost 15% more than that of the typical refrigerant (R404a) that is used, and is substantially more beneficial to the environment.

Intelligent Lighting: A DALI (Digital Addressable Lighting Interface) lighting system is installed within the supermarket. This system enables Tesco to control lighting within the store to take advantage of the large areas of windows by positioning photo cell sensors in the vicinity of these windows. The lighting will dim in these areas when the sun is shining, and thus save on energy.

LED Lighting: All fridges and chilled storage cabinets have LED light installed

Solar PV: Tesco's solar electricity system consists of forty 210 Wp Sanyo HIT modules, giving a total of 8.4 kWp (kilowatt peak).

B. The Supermarket: The Energy Consumption Analysis

The electrical consumption of the building has been broken down into different parts and each section of consumption will be analysed in as much detail as the data allows.

CHP:

The output of the CHP was shown to drop dramatically over the summer months due to there being no requirement for a thermal load (Figure 1).

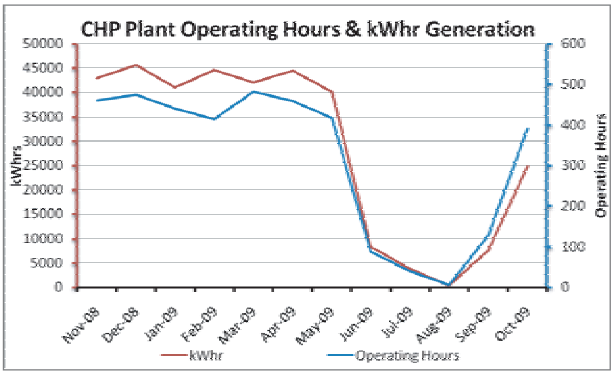

Fig.1: This chart shows the performance of the CHP plant and its generated kWhrs over its operation. The large dip is due to the thermal requirement dictating its usage and as such during spells of warmer weather the unit switched off.

To overcome this lack of usage period, the use of an absorption chiller unit was designed to be installed in the Tesco store. Unfortunately when this research was carried out it was not installed, and as such no results for the performance of such a piece of equipment could be analysed.

Solar PV

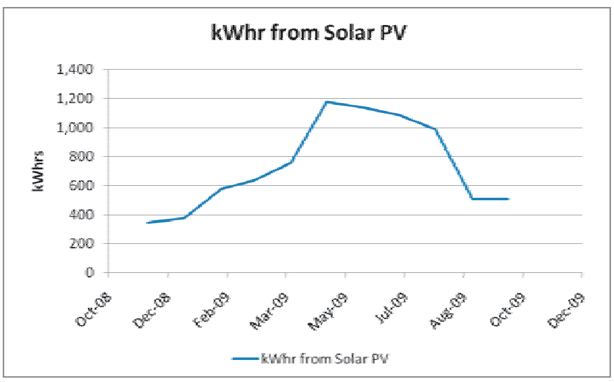

Fig. 2: This chart shows the performance of the Solar PV. This particular installation behaved exactly as it would be expected. However the sudden dip in August is due to an obstruction placed in its way.

It can be seen from Figure 2 that the Solar PV output is at its maximum output from the months of April to August. Conveniently this coincides with the poor output from the CHP at this period, and upon brief inspection one may think that they complement each other very well.

However, the sheer low energy output from this Solar PV array in comparison to the energy consumed is very large. If the maximum cost of electrical units were applied to the cost savings in electrical consumption that this solar array delivered, it would be no more than €1000 over the course of a year.

The large drop off in performance for the month of August is a situation worth investigating. The supplier of this very system to Tesco monitors the data from this installation and noticed the drop off also.

Fig. 3: Picture of the obstruction blocking the Solar PV array

Upon inspection it was seen that a large duct was placed directly in front of the installation (Figure 3). This duct would have had a large effect on the performance of the array due to its proximity and large size blocking sunlight.

CHP, Solar PV and the grid supply:

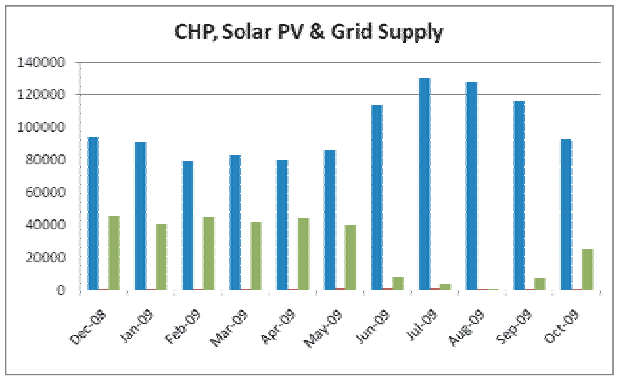

Fig. 4: Chart comparing the performances of the CHP plant, Solar PV and the consumed grid supply. It can be seen that the solar PV barely makes an impact on the overall consumption of a store this size.

Figure 4 shows the clear picture of the output of the different electrical sources over the period of almost one year. This picture shows the general low output of the Solar PV, when it is compared with the other sources, such as that from the CHP and from the grid.

Electrical running costs and comparisons

Bettystown and Letterkenny and the Tesco Tramore installation had their electrical costs and different systems compared in detail (Figure 5). However, Tesco Tramore is the only one of all three with a CHP installation.

Electrical costs are on average 37.73% less expensive than that of the other comparison stores (Figure 6). However, these measurements and costs are taken directly from the bills, and though they show the actual consumption of electricity of the Tesco stores, the results do not take into account the consumption/generation of the CHP plant. When the offset of the CHP are taken into account, the actual energy consumption of the building increases and the energy savings become 24.17%.

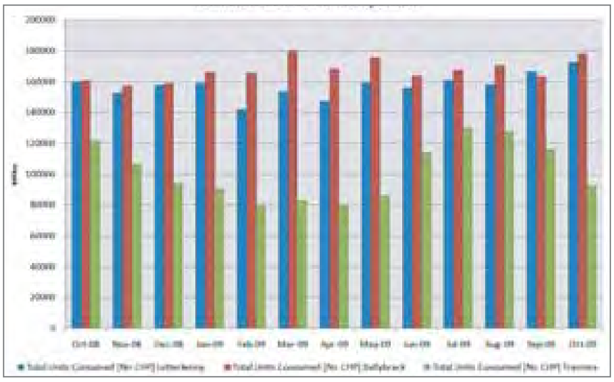

Fig. 5: Comparison of Tesco stores – CHP output has not been added to the overall consumption of Tesco Tramore

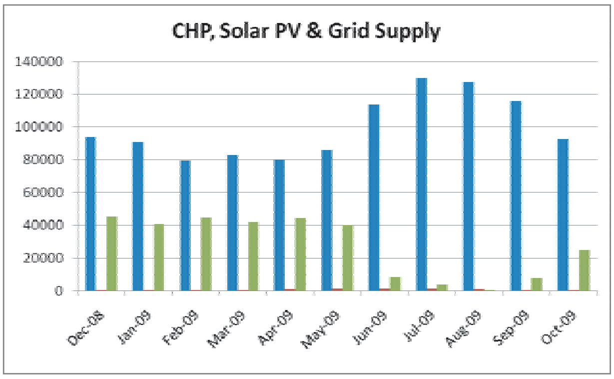

Fig. 6: Percentage less expensive between Tramore and the average costs of the two other Tesco stores

Internal environment

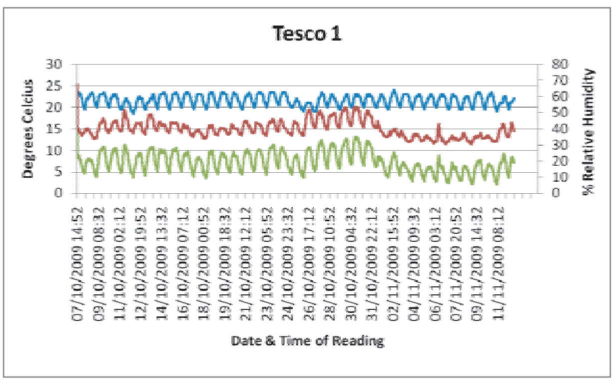

Fig. 7: During the cold October/November 2009 period, the main sales floor area was kept at a constant 20-23ºC with the RH rarely going over 50%

Even over the cold October/November 2009 period, the main sales floor area was kept at a constant 20-23ºC with the RH rarely going over 50% (Figure 7). The internal environment is within agreeable parameters for any store of this nature. The good control of the internal environment leads to better control over other systems. The low humidity levels prevent condensation from fogging up the fridge cabinets and thus the "de-fogging" heating elements from turning on. This all serves to add to the efficiency of the overall building, especially when so much of the shop floor is taken up with fridge cabinets.

General electrical and lighting readings

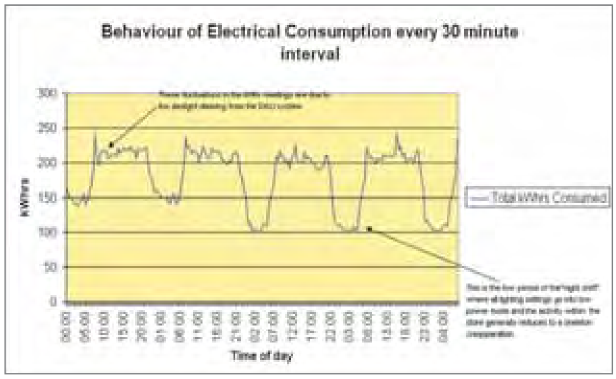

Fig. 8: Behaviour of electrical consumption every 30 minute interval

The source of data that was used to put together the analysis of electrical readings on site, as seen in Figure 8, was from the individual metering in order to help Tesco individually monitor different aspects of the installation. As can be seen the fluctuations during the course of the day are due to electrical requirements of an occupied building moving up and down. This would be due to perhaps ovens being turned on at the bakery and other items, though more importantly in the sense of the electrical efficiency the lighting dimming when it receives daylight to its lighting sensor at the shop floor. The large dips also indicate the night shift operation of the store, and show a very large decrease in activity and the lighting lowering its intensity into night time mode.

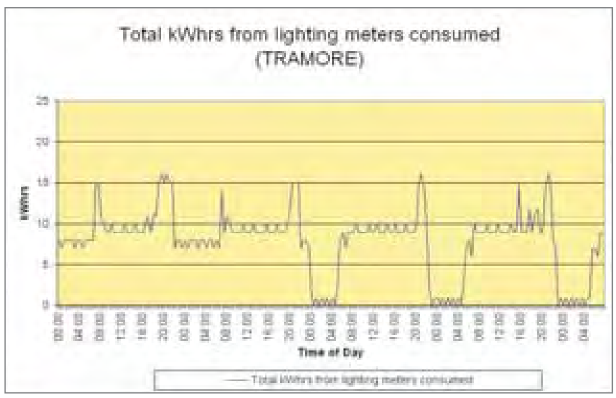

Fig. 9: Total kWhrs from lighting meters (Tramore)

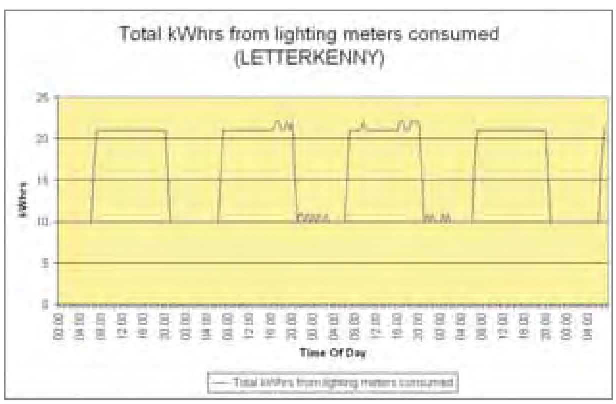

Fig. 10: Total kWhrs from lighting meters (Letterkenny)

The lighting demand from Tesco Tramore (Figure 9) is showing behaviours that is somewhat expected. However, lighting seems to have dropped to zero over the course of three nights. This would need to be investigated to ensure the veracity of this data, as this continually happens throughout the data sample collected. However some behavioural trends can be ascertained. The daylight dimming can be seen to be in operation during the lower troughs during the daylight periods. This time sample is taken during the month of July, where its effects would most likely be most effective.

Letterkenny has also got data for its lighting output (Figure 10). It can be seen that the lighting does not have any peaks or troughs other than those apparent from the night shift. There are small fluctuations, and without being there on the day these recordings happened it would be impossible to say what these are. However, it is important to note that the daylight dimming and any fluctuations in the lighting demand are non-existent in this store.

Tramore's energy profile for the lighting is superior in terms of performance when it comes to energy consumption. The actual level of consumption is also about 25% lower than that of Letterkenny, no doubt due to the high efficient T5 lamps and LED lighting installed throughout the Tesco store.

Comparison of construction cost

The analysis in Table 2 is a breakdown of the cost of the installation and build compared to that of a standard Tesco store.

Due to commercial sensitivity, only limited information is made available, though it does give a good indication for the additional expense that was incurred during this construction.

It is immediately noticeable that every single item on the list was more expensive than that of the standard Tesco store.

Cost Analysis	
This store is based on 2008 prices, on average prices have fallen 20% since construction	
Based on 30,000sq ft retail area store	% of standard item
Timber cladding in lieu of Ranila cladding	389%
Cedar louvre to roof plant in lieu of anodosed aluminimum	120%
Timber frame front, bulk store steel frame in lieu of steel	274%
Triple glazing	173%
Increased specification wall and roof cladding for insulation	125%
Mechanical	235%
Electrical	114%
Refrigeration	162%
Signage	128%
Roof overhang 1.45 at gables	110%

Table 2: Comparison of construction costs for a Passiv Haus supermarket and a standard format star

Summary

So in summary Tesco Tramore does seem to be leaning towards that of an eco-friendly, highly efficient supermarket. This paper does not claim to be a definitive piece of work on the Passiv Haus application to a supermarket, but was written with the goal in mind to show whether or not the initial indications are promising. With results as can be seen in Table 3 for the energy consumption, the results are very encouraging indeed.

Store Location	Type	Sale Floor Area [m^2]	Electricity Consumption Mains Supply	Electricity Consumption (CPH)	Electricity Consumption Total	Electricity Consumption kWh/m^2
Tesco Tramore	Format 30	2,747.4	1,199,375.17	345,836	1,545,211.17	**560**
Letterkenny/ Ballybrack	Format 30	2683	1947,799.00	0.00 (None installed)	1,947,799.00	**726**

Table 3: The electrical consumption of the Tesco stores as kilowatt hours per square metre of the sales floor area (SFA)

Limitations and possible future study

It is important to ensure that the point is made that the purpose of this research is to ascertain the viability of this standard being applied in the manner discussed. Some clear limitations to the data is that of using Tesco's own on-site recording equipment and access to energy bills for the research. This meant an over reliance on Tesco themselves, and although they were more than forthcoming with their help and openness with this information. Some data was collected first hand by the researcher and this validated some of Tesco's data..

For this research to be carried out to it's fullest, a wider array of measurement devices would be required. Light meters, humidity sensors and temperature sensors at more than just two locations within the store would be required. A thermal-imaging camera would be extremely useful in order to examine the details of the construction more clearly. However, the cost of this equipment would make it prohibitively difficult to get.

Also, more on site testing methods for verifying the electrical and gas usage would have been desirable.

It is intended by Tesco that this critical evaluation will allow them improve and enhance what is clearly a very promising innovation. This is the first supermarket in the world to attempt a Passiv Haus construction and this research suggests there will be many more in the future.

Acknowledgements

I would like to thank Tesco and Tesco's then Energy Manager Michael McNerney for their help and permission in accessing the data used within this research.

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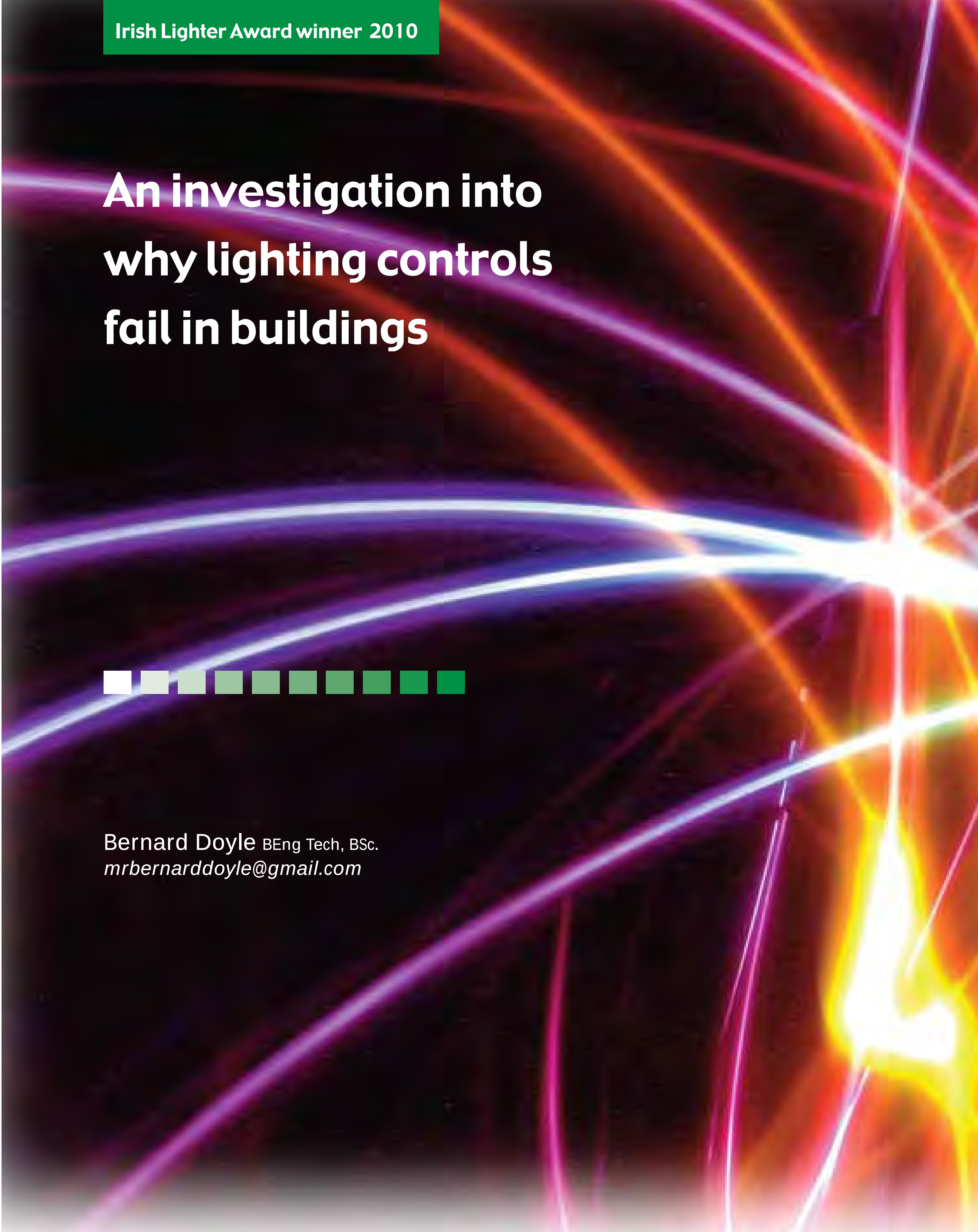

Irish Lighter Award winner 2010

An investigation into why lighting controls fail in buildings

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Abstract

The project began as a post-occupancy evaluation of lighting controls installed in a range of buildings, including a public office building, a shopping centre and a primary school. Actual controlled lighting consumption was to be compared against past billing or simulated energy consumption. However, when the research began it was found that the controls had been removed from two out of the three buildings. Further research proved that it was not unusual for lighting controls to be disconnected following installation.

This raised a much bigger research question – why were the controls disconnected and what were the factors governing success or failure of these systems? To answer this new question a new methodology to that first envisaged had to be established. Investigating the reasons for disconnection could only be achieved by discussion with those involved. To find out what people know, or think, it is necessary to ask them. Interviewing was used to address the new research question.

It was found that little research exists on long-term performance analysis of lighting controls. A framework was created to determine if there is correlation between past findings and the reasons for failure in the case studies. It should be noted that there were minimal findings into the failure of lighting controls systems in buildings in Ireland, which prompted possible additional reasons for the failure of these systems, e.g. differing usage patterns, availability of useful daylight.

The research that followed posed many challenges requiring the use of qualitative data in an engineering environment. In order to answer the research question, a clearly-defined and well-structured methodology was required. It was concluded from the research that the conceptual framework used was appropriate and that the methods were fit for purpose.

Some of the findings included:

- Maintenance costs are comparitively high
- Misinterpretation of commissioning processes
- Incomplete analysis prior to installation
- The requirement for post-occupancy evaluation in current engineering practices

Key Words:
Daylight controls, daylight harvesting, problematic controls.

1. Introduction

1.1 Basis for studies

This project began as a post-occupancy evaluation of existing lighting control systems in an office space to determine the installed financial savings and CO_2 emission reduction. Three buildings were chosen as case studies. It was intended to compare the actual consumption of energy and greenhouse gas emissions due to lighting with automated controls to previous manually-switched systems or simulated systems. However, during the initial stages of data acquisition it became apparent that a large number of developments had significant problems with such controls.

The research question then evolved to a much bigger one, i.e. why were the controls disconnected and what were the factors governing success or failure of these systems? It became apparent that disconnection was not untypical and although considerable research has been conducted into a comparison of control types, little information was available as to the reasons for failure of systems within Ireland. Documented evidence of failed systems is also a rarity. Galasiu et al[1] highlights the lack of availability of information for long-term performance studies of daylight control systems. However, the use of lighting control systems is becoming more relevant as energy consumption, energy costs and greenhouse emissions are pushed to the agenda forefront.

This research attempts to address the issues that result in the disconnection of lighting controls systems in day-to-day use within buildings. The research questions investigate why controls were disconnected from the public office and the shopping centre, but were successfully deployed in the school.

1.2 How will the research be conducted?

As no recordings had been taken of the operating system, no quantitative data existed. The reasons for disconnection can only be established by discussions with those involved during the design stages and at times when problems arise. A qualitative methodology was adapted to address the new research question. Interviewing the parties involved was the method proposed to investigate how the supplier, designer and end user felt about the reasons for disconnection.

2. Research methods

A new approach was required for gathering data and the reasons as to why daylight harvesting systems succeed or fail. Several approaches were considered and the methods used are explained below.

2.1 Research questions

The methodology and methods in any research will be determined by the research questions posed. In this research the questions are:

- Why were controls removed from building A?
- Why were controls removed from Building B?
- What are the reasons for the success of the controls in Building C?
- Are the findings of this research in line with past studies?
- Have faults outside the conceptual framework of this research been discovered?

2.2 Methods

2.2.1 Qualitative research

For the buildings chosen the problems arising were not very well documented. Little quantitative data was available for any of the selected case studies and information is therefore only accessible through survey or discussion with those involved. The research method chosen is to be a combination of qualitative data and case study review or post occupancy evaluation analsysis. According to Hancock and Algozzine,[2] these research traditions are generally classed separately. However, for the case studies chosen, a combination of both approaches seemed more fitting.

Engineering usually involves mathematical processes to provide a solution to a given problem. Engineers therefore prefer a quantitative approach. It is noted that the use of a qualitative approach means that the researcher must …

- have an understanding of the research area
- establish a participant's knowledge of the subject area
- be aware of any hidden agenda by the participant
- be impartial to information obtained
- be aware of their own feelings on the subject.

2.2.2 Interviews

Individual interviews were chosen as the main method for data acquisition. Interviewing offers the greatest return on answering of questions as there are numerous techniques such as probes and prompts to induce more information from the interviewee, than simple yes or no answers. This can be one of the downfalls of surveying. Several structures or formats of interview may be employed. Robson[3] describes the relevance of structured versus unstructured interviews and the applications of each.

Semi-structured interview

Pre-determined questions are prepared, but the order can be modified based upon the interviewer's perception of what seems most appropriate. Question wording can be changed and explanations given, particular questions which seem inappropriate with a particular interviewee can be omitted, or additional ones included.[3, p.270]

Powney and Watts[4] suggest a different approach, i.e. respondent interviews and informant interviews. A respondent type approach is where the interviewer maintains control for the duration of the interview, i.e. questions are somewhat structured and guided towards the interviewer's research or interests. The open question style allows for structuring of the interview but will afford the opportunity to analyse the interviewee's true knowledge of the systems and design processes. Face to face interviewing with open style questioning allows probing or any questions to be asked that had not previously been considered.

During the literature review it became apparent that the Weidt Group's study into daylight harvesting, as conducted by Ejadi and Vaidya's,[5] appears to be extremely relevant in this field and it is for this reason that the findings formed the conceptual framework of the research in this document.

2.2.3 Interview transcription

Transcribing as close to the interview session as possible enabled inclusion of emotions or any significant other findings that arose during the interview, in the transcipts. The main benefits of transcribing to text were that important findings in the data was flagged and grouped for further analysis. This is referred to as coding.

2.2.4 Coding of data

Data was analysed following the logic of coding, i.e. categorised under the conceptual framework of Eijadi and Vaidya's[6]. Interviewees' responses were analysed under the headings below:

- Lack of coordination or understanding between the design disciplines concerning the daylighting control system;
- Improper location of daylighting controls;
- Inadequate specification of the controls systems, component parameters and sequence of operations;
- Shop drawings made by contractors that detail the system are not checked, or the lighting designer does not know what to check;
- Field changes to tune a system are not documented and taken back to the designer to complete the feedback loop;
- Findings outside of the conceptual framework.

This template approach will make the analysis of the data more simplistic as questions were specifically created in a template manner to receive answers relating to each of the recommendations of Eijadi and Vaidya. An example of which might be asking the supplier, designer, facilities manager and client about the specific input of a client or client representative during the design stage of the lighting installation. The answers can then be compared under the *"Lack of coordination or understanding between the design disciplines concerning the daylighting control system"* heading.

2.2.5 Reliability and validity of data

It must be noted that any collectable data was based on the expressed opinions and knowledge of the participant on the given subject and, as a result, can only be addressed as qualitative data. In order to provide a fair argument similar questioning was purposefully created for supplier, designer, client and end user of the different case studies. This process, known as a template approach as defined by a study by Crabtree and Miller,[7] also aides coding.

2.3 Addressing the research questions

2.3.1 RQ 1 – Why were controls removed from building A?

Building A is a public office located in South Dublin. Daylighting controls, presence detection and timed controls were installed throughout the building. However, due to several problems some of the control features were disconnected. Interviews were conducted with the facilities manager and the electrical services engineer who carried out the design of building A.

2.3.2 RQ 2 – Why were controls removed from building B?

Building B is a shopping centre located in Co Tipperary. Some of the lighting controls were disconnected after a relatively short period of time following installation. Interviews took place with the centre manager and the electrical services engineer responsible for the design.

2.3.3 RQ 3 – Why were controls successful in building C?

Building C is a primary school located in Co Waterford. In contrast to the other post occupancy evaluations carried out in this research, the daylight controls in Building C remain intact. However, the approach used in Research Questions 1 and 2 above was applied to Building C also. The aim was to determine if similar design methods and installation techniques were used as in Buildings A and B.

Interviews were conducted with the school caretaker to determine if any problems arose and how they were dealt with. Questioning followed the same format as that used in Research Questions 1 and 2.

2.3.4 RQ 4 – Are findings in line with the research?

Once all interviews had been conducted and transcribed they were categorised under the findings of the Weidt Group 2004-2005 Dimming Study. This allowed for a comparison of successes of the case studies against the recommendations of the Weidt Group studies.

2.3.5 RQ 5 – Have faults outside the framework been discovered?

Any other factors of relevance outside the boundaries of this framework were highlighted and may create a path to further research areas.

The three buildings used for the case studies included a public office building, a shopping centre and a school, all of which are located in southern Ireland. Items such as maintenance costs, feasibility studies and weather patterns do not fall under the conceptual framework and shall be addressed in this research.

3 Data presentation and results

Having conducted the interviews with all parties involved, data was initially transcribed and then coded under the common headings listed previously. As discussed in the Research Methods section above, each building was initially analysed separately, under the conceptual framework of this document. This allowed comparisons to be made between what was stated by the client and what was stated by the designer. The findings of each case study were then grouped under the framework headings for further analysis.

3.1 Lack of coordination or understanding between the different design disciplines concerning the day-lighting control system.

3.1.1 Summary of results on coordination between design groups

Although the "lack of coordination or understanding between the different design disciplines concerning the daylight controls system" is a significant factor, it is felt that the role of the end user is overlooked. In order to increase the satisfaction with the installed system, the end user should be one of the leading members of the design team.

For Building B, the Shopping Centre, it is felt that some of the problems may have escalated as the final end user, i.e. the general manager, was not directly involved during the design stage. As the project progressed changes were made from tendered drawings through to construction stage, resulting in discrepancies between schematics, narrative reports, etc. In some instances the supplier does not directly provide training to the end user allowing for misinterpretation, with a possible snowball effect.

For Building C, the primary school, the end user had little input into the switching arrangements. Details were agreed between the electrical services designer and the architect. Having fewer people involved would decrease the opportunity for changes to be made, or misunderstandings to arise.

Di Louie[6] discusses the importance of taking measurements of incoming daylight and creating zones for lighting control systems. When asked about readings being taken prior to installation, the shopping centre general manager stated that he assumed a simulation or readings had been carried out. The designer stated that he assumed such measurements are the responsibility of the lighting controls specialist. On the other hand, the controls supplier laid that responsibility with the design engineer. It would appear that there is no standard format for the design methods, and there is a lack of coordination between those involved.

3.2 Improper location of controls

3.2.1 Summary of results on location of controls

Without the correct analysis of natural daylight, installation of a photocell for the purpose of controlling internal lighting seems irrational. Placing the photocell on the roof to control the internal mall lighting makes little sense.

The design team on the other hand were confident that locating the photocells on the roof was the correct choice. However, on review of Figure 1 *Internal versus External Illuminance* it is quite clear that levels outside the mall area are much greater than natural lighting levels internally.

The ideal location of the sensor should be determined, to ensure that the level being read by the sensor is the same location as where the artificial lighting was used. The importance of the PIR location was also noted, i.e. possibility of injury through improper location. The location process may not always be correct during design stages as room layouts can change and new obstacles may arise.

Fig. 1: Internal versus external illuminance

3.3 Inadequate specification of the controls systems, component parameters, and sequence of operations.

3.3.1 Summary of results on specification

To safeguard against future problems it is concluded from this research that the installed system must be well defined and documented for future users. This can be achieved through adequate labelling and reference manuals. This could however increase the capital cost of supply, installation and commissioning. Expensive maintenance contracts can act as a major deterrent for the installation of such control systems as it is highly probable that payback periods would be significantly increased by purchasing such contracts.

Dimming systems with no override create problems. One would assume that conflicts between devices and overriding facilities should be recognised during commissioning. Failure to recognise such problems in Building A meant having to arrange meetings in certain rooms rather than having full flexibility to use any office available. Override problems found in Building B meant the total disconnection of the daylight controls. Any possible energy and financial savings via this feature were removed.

It seems that lighting control system problems or complete failure can be due to …

- Inadequate documentation
- Inadequate labelling of components
- Inadequate end user training
- Improper use of controller/sensor type
- End user fear of unknown system
- Existing commissioning techniques

3.4 Shop drawings made by contractors that detail the system are not checked, or the lighting designer does not know what to check.

3.4.1 Summary of results of shop drawing analysis

For Building A the lighting designer was of the opinion that the lighting controls were installed and still in use. This implies that shop drawings, or as constructed layouts, were not verified with the finished project. Snagging works may not have been part of the initial scope of works.

In Building B, many differences were found between lighting controls descriptive documents, drawings and installations on site. This again implies that no verification was made between what was proposed and what was installed. It is not clear whose responsibility this task was.

Commissioning seems to be a problem area with the controls systems. There seems to be a lack of boundary lines around each party's responsibilities and no certification verifying complete system operation.

3.5 Field changes to tune a system are not documented and taken back to the designer to complete the feedback loop.

3.5.1 Summary of results of the communication feedback loop

It was stated for Building A, the Public Office Building, that there were "issues with the design not matching the needs when the offices were occupied". One of the problems discussed for example was the use of remote controls in an office. Several steps were taken by the facilities manager to rectify this problem. However, without the knowledge of any problems it would not be surprising if the designer assumed the project a success and specified remote controls on future builds.

Another highlighted problem was the use of PIR's in stairwells. This situation was not conveyed to the designer so could occur again in a similar project.

3.6 Findings outside the conceptual framework

3.6.1 Summary of results outside the conceptual framework

The surprisingly high costs of maintenance contracts is a huge negative drawback on the possible savings achievable through the installation of daylight controls systems. No feasibility study was conducted for any of the buildings used in the case studies above. Had they been performed, and the maintenance contracts been included, it is very likely that the payback period would render the controls as unfeasible.

4 Conclusion

The case studies used in this research were random selections that consisted of two buildings with disconnected lighting controls and one building with a control system that remains in use. The research can therefore be construed as a critical analysis of a sample section and not a selective sample of successful projects, that can often be used for marketing purposes.

It is clear from the summaries of the Data Presentation and Results chapter that there are a vast amount of variables that can lead to the failure of the lighting control systems. Although all three case studies were completely different buildings, i.e. different construction elements, constructed throughout different parts of Ireland and had different end user requirements, the framework allowed for the data from all three case studies to be analysed under similar headings. This helps the reader to understand that the proposed reasons for failure or success are common among differing projects across Ireland. The findings outside of the conceptual framework section allowed for more local analysis of the problems associated with lighting controls. An example would be the high cost of maintenance contracts discovered during the interview with Building A Facilities Manager.

Investigation into the failure of the controls in the case studies, under the framework, found that some of the reasons for disconnection included

Coordination

- no standardised communication channels from supplier to end user
- information lost in translation from supplier to end user
- lack of coordination between design parties
- changing design team persons
- the end user role in the design process

Location of controls

- daylight analysis and zoning required for sensor location
- PIR location at construction stage
- inadequate as constructed layouts
- location of manual controls for override

Specification of control systems

- inadequate specification of installed system
- conflict between installed devices
- improper use of sensor type

As constructed analysis

- lack of commissioning knowledge or coordination
- lack of contracts for engineer to review installed controls

Communication feedback

- lack of feedback of field changes to designer
- lack of post occupancy evaluations by designers

A substantial finding was the misinterpretation of the commissioning process. It would appear that all parties have their own opinions as to what exactly occurs during commissioning, i.e. the supplier feels that commissioning should be performed by the contractor and the designer feels that commissioning should be performed by the lighting specialist. Hence it would appear that there is currently no commissioning process that ensures that the controls had been installed and operate as per the original designs and narrative reports.

Engineers are often sceptical about qualitative research as described in the methodology. However, for this research it was the only way to find out why people made decisions to disconnect controls. The limitations of qualitative research were also discovered during the research process. As an engineer, it is always preferable to see a problem defined clearly and calculated, with appropriate data to prove a theorem. Without sufficient data a different approach is required. Qualitative data is not conclusive and often needs to be formally supported by quantitative data. It must also be recognised that in order to explore what happened, and to establish personal opinions and feelings in a given situation, a qualitative approach offers the possibility of rich and insightful findings.

It is concluded from this research that the framework used was appropriate with methods fit for purpose. It was found that most faults or problems fit within the confines of the headings used within the conceptual framework. Coding was made easier through use of the headings, and data could be easily categorised and evaluated.

Post occupancy evaluation is not a common process in the construction industry and one would imagine that through adequate feedback channels most of the existing problems in current developments could be overcome in future builds by using accumulated data from post occupancy evaluations..

It is hoped that this research can be used as an aid to designers, installers and future research studies to increase the amount of data available on lighting control systems and eradicate minor problems that sometimes end up resulting in the total disconnection of controls. Solving these problems may increase the uptake of lighting controls on a national level and so help to reduce energy consumption and CO2 emissions as per government targets. Studies into a facility for feedback of realtime savings to the end user, along with further long-term assessment performance studies, could also have a substantial impact on the uptake of daylight controls systems.

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Irish Young Lighter & Irish Lighter Awards

These awards – jointly promoted by CIBSE, SLL and ILP – are an annual event with the finals and presentation of prizes being held each September in DIT Kevin St. Typically, the programme of events is as follows:

2.00pm	Young Lighter final begins
4.40pm	Announcement of winners and presention of prizes
5.30pm	Tea/coffee, sandwiches served
6.30pm	Irish Lighter final begins
8.25pm	Announcement of winners and presention of prizes
8.30pm	Wine and finger food Reception in Kevin Street penthouse
10.00pm	Close

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Young Irish Lighter Award winner 2010

An examination into the use of compact fluorescent lamps in the domestic environment

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Abstract

The Irish government, UK government and European Commission have recently passed a ban on the sale of all incandescent/GLS lamps above 100W. This commenced in September 2009, with smaller wattages to be phased out by 2012.

This paper sets out to investigate if compact fluorescent lamps (CFLs) are an adequate, suitable and appropriate replacement for GLS lamps in domestic environments. An overview of CFL performance is undertaken, initially through a literature review and then through laboratory measurements. The findings of this are insightful for all readers using CFLs in their homes.

In-depth research was carried out to examine CFLs, power factor, harmonic distortion and their likely effects on the national grid. The possible risk of an overloaded three-phase neutral conductor are also evaluated, which provides useful information for electrical services design engineers.

1. Introduction

The most popular replacement for GLS lamps appears to be CFLs. This paper will set out to investigate if CFLs are an adequate, suitable and appropriate replacement for GLS lamps in the domestic environment. Initially a literature review will be compiled in an attempt to highlight some of the major issues associated with CFLs. The headings examined are outlined below:

2.1 – Efficacy	**2.7** – Total Lumen Output
2.2 – Embodied Energy	**2.8** – Ultraviolet Radiation
2.3 – Illuminance	**2.9** – Mercury and Re-Cycling
2.4 – Manufacturer Wattages	**2.10** – Power Factor
2.5 – Lamp Life	**2.11** – Total Harmonic Distortion
2.6 – Colour Rendering and Colour Temperature	**2.12** – Pricing and Costs

The literature review conducted indicated a shortage of research findings with respect to power factor, harmonic order currents and levels of total harmonic distortion produced by commercially available CFLs. Experiments were conducted to quantify all three and conclusions were drawn from the results obtained. A set of fifteen CFLs and three GLS lamps were used for all experiments.

Accurately measuring the true power factor of any non-linear load requires root mean squared (RMS) measurements. Standard electrical instruments are only capable of quantifying displacement power factor, while true RMS instruments allow for the inclusion of system harmonics and hence, measure true power factor. Incorporating a true RMS voltmeter, a true RMS amp meter, a variac to stabilise the supply voltage and a wattmeter, to a circuit containing a lampholder allowed for accurate measurement of true CFL and GLS power factor.

Individual harmonic order currents and THD levels were recorded using a single circuit, with different methods of measurement. Again true RMS instrumentation is necessary to give accurate results. Four methods were used to try and assess the harmonic patterns produced by the CFLs tested, namely: two power factor meters (one analogue and one digital), an oscilloscope and a wattmeter plus true RMS volt and amp meters.

2. Literature review

2.1 Efficacy

There appears to be a general consensus that CFLs will provide quite large energy savings over incandescent lamps. Figures around 80%[4] and 75%[5] are often suggested. Table 1, from the Lighting

Association[24] shows direct comparisons between lamp type/lamp wattage and lumen output.

Description	Wattage	Lumen Output (lm)	Efficacy (lm/W)
Incandescent/GLS	25	225	9.0
	40	420	10.5
	60	710	11.8
	75	940	12.5
	100	1360	13.6
	150	2180	14.5
Incandescent – Soft Output	25	200	8.0
	40	370	9.3
	60	630	10.5
	75	840	11.2
	100	1200	12.0
CFL – Stick Shape	5	230	46.0
	8	420	52.5
	11	600	54.5
	14	810	57.9
	18	1100	61.1
CFL – Bulb Shape	5	200	40.0
	8	380	47.5
	12	610	50.8
	16	815	50.9
	20	1160	58.0
CFL – Spiral Shape	5	300	60.0
	8	500	62.5
	12	725	60.4
	15	1000	66.7
	20	1350	67.5
	23	1550	67.4

Table 1: The Lighting Association, Amended to Include Efficacies[24]

It is clear from this that significant savings, due to improved efficacy, can be made from the use of CFLs. The European Commission, the Energy Savings Trust and manufacturers say CFLs use up to 80% less electricity than traditional bulbs, but Kevan Shaw[7] questions how this figure is calculated. According to a spokeswoman for the European Commission, it is calculated "by comparing the best compact fluorescent lamps wattage with the wattage of an equivalent incandescent bulb"[6]. This method results in a 5:1 efficacy ratio between the two types of lamp – a claim the European Commission itself says is an exaggeration when manufacturers use it. It is the "up to" in this 80% claim that is important. The EC spokeswoman says the saving can be as low as 60%[6].

2.2 Embodied energy and pollutants

Another issue is the embodied energy needed to create a CFL. Manufacturers claim that the energy input required to construct a CFL is six times that required to produce a GLS lamp[7]. This would of course be offset by the CFLs longer life, i.e. the CFL will last six times longer. Table 2 shows figures from VITO[7], an environmental research organisation working for the European Commission, which compare energy used in the manufacture of GLS lamps and CFLs

It is clear from these figures that the energy needed to produce a CFL is up to 12 times that needed to produce a GLS lamp.

Energy used in manufacture	Pollutants created in manufacture
GLS = 1MJ of 0.28kWh	GLS = 5mg – none hazardous
CFL = 12MJ or 3.33kWh	CFL =128mg of which 78mg is hazardous

Table 2: Embodied energy

However, the lifetime embodied energy lost in the manufacture of CFLs (1.5-2kWh max) seems insignificant when one considers that a 100W GLS lamp uses approximately 100kWh per annum and a 20W CFL uses about 20kWh, a saving of 80kWh per annum, or 480kWh over six years.

2.3 Illuminance

A recent undergraduate study carried out at The Dublin Institute of Technology[8] compared illuminances from GLS lamps and "equivalent" wattage CFLs. Nine lamps were used, three 100W GLS and six 20W CFLs.

GLS Lamps	Illuminance (Lux)
Solas	760
General Electric	687
Tesco Generic	887
CFLs	**Illuminance (Lux)**
Omnicron	490
Philips	435
B & Q	346
General Electric	398
Philips Soft Tone	572
Solas	362

Table 3: Bernie Illuminance Comparison[8]

It was found that the CFLs produced 50-60% less light on a surface at a distance of 40cm, than the GLS lamps. The average GLS value was 778 lux, compared to 367 from the "equivalent" wattage CFLs. However, a more recent undergraduate study at The Dublin Institute of Technology[9] has shown slightly different results. Browne[9] found that illuminance levels were much more comparable (±20%). This may show an improvement in performance in the time between the two studies, or possibly illustrate the variation between individual lamps and manufacturers. Some tests were conducted for this paper, but their accuracy was considered unreliable and excluded for that reason. Overall it appears that CFLs do produce slightly lower illuminance levels than their so claimed "equivalent" GLS lamps.

2.4 Manufacturer stated "equivalent" wattages

Some users complain that the light quality emitted from CFLs is poor and *not as bright* as their "equivalent" GLS lamps[4]. This may be due to the method of comparison between the two lamps and wattages. CFLs are compared to "soft output" lamps, which have a lower light output (see Table 1 from The Lighting Association)[7][24]. The initial lumen output of each lamp should also be considered. Shaw[7] claims "manufacturers set the equivalence of output to the worst incandescent lamps, with colour coatings". He backs this up with a simple example:

- A 12W CFLi at 660lm is advertised as the equivalent of a 60W GLS at 710lm.
- A 21W CFLi at 1230lm is advertised as the equivalent of a 100W GLS at 1340lm.

This raises issues, but it would seem that manufacturers are just trying to provide a simple method of comparison that is easily understood by lay people. However, it may suggest that manufacturers claims of 5:1 energy savings are closer to 4:1.

2.5 Lamp lifespan

It is claimed by manufacturers that CFLs can "increase lifespan by a factor of 6 to 12 times that of an incandescent lamp"[4]. Lifespan for a lamp is generally stated in hours and for CFLs is usually between 4,000 and 12,000 hours. However, CFLs only manage 85% of their output at 2,000 hours[7]. Hence, what will their lumen output be at 12,000 hours and will this output be sufficient to avoid replacing the lamp? Another complaint is that some CFLs burn out far earlier than their estimated lifespan. A branded bulb from a well-known manufacturer may last the full estimated lifespan, but a budget lamp from the local supermarket may not. Even branded bulbs don't always last as long as expected and this is because the estimated lifespan is an average[7]. During the testing of a batch of bulbs, they are switched on for three hours, then off for twenty minutes and this process is repeated over and over until half the batch has failed. This point is then considered to be the average lifespan[5]. With this in mind, it must be considered that any given bulb could fail at a possible 2,000 hours, when its estimated lifespan is 10,000 hours. However, the Lighting Industry Federation says, "the main manufacturers do their best to make bulbs that cluster around the average life mark"[10]. With the above considered, it is clear that CFLs have a far increased lifespan compared to GLS lamps, but individual CFL lifespan is a variable.

2.6 Colour rendering index and colour temperature

It is clear that the colour rendering of any CFL is poor compared to a GLS lamp[11]. In a recent study at The Dublin Institute of Technology[8], spectral irradiances in the photopic ranges were investigated. Rather than the CFL spectral curve following a curve similar to a Planckian radiator, as with a GLS lamp, the CFLs showed peaks in spectral irradiance separated by regions of little or no irradiance[8]. Beirnie showed that the CFLs tested had an average CRI of 72.1[8]. The reason for this is that the CFLs produced an incomplete spectrum, while the GLS lamps produced a complete spectrum (Figure 1)[8]. A more recent study at The Dublin Institute of Technology[9] produced similar results to Beirne. Browne[9] measured the spectral irradiance of 50 CFLs and found an average CRI of 77.4. Values ranged from 58.4 to 83.2, although this average value is below the CRI of 80 required by the EU, for compliance with the EU quality charter of CFLs[9]. The CFL spectrum lacked the higher wavelengths and hence, the colour red, which our eyes detect as being the warmest. This lack of red light in the CFL spectrum goes a long way to helping us understand their colour appearance and cool colour temperature when compared to a GLS lamp.

GLS Lamps	Colour Rendering Index
Solas	99
General Electric	99.5
Tesco Generic	99.5
CFLs	**Colour Rendering Index**
Omnicron	80
Philips	79
B&Q	77
General Electric	45
Philips Soft Tone	79
Solas	78

Table 4: Beirnie CRI Results[8]

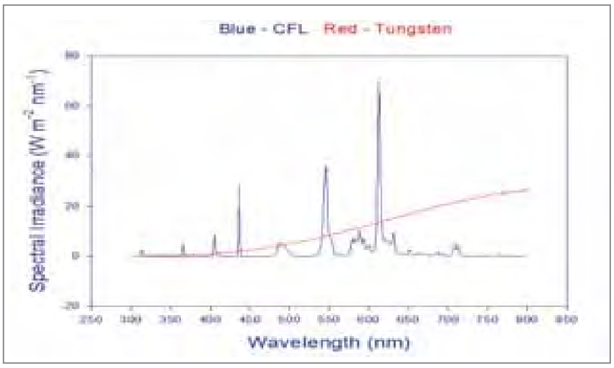

Figure 1: Spectral irradiance of CFLs and GLS[8]

2.7 Total lumen output

To measure the luminous flux of any CFL would require an expensive integrating sphere for the spectroradiometric system used in both Browne and Bernies' studies. This could calculate the luminous flux emitted into the entire region (sphere) around the bulb[9]. However, due to the expense, not many, if any independent studies are publicly available that accurately measure the luminous flux of CFLs. The measurement of illuminance offers a pragmatic validity check for this research.

2.8 Mercury and re-cycling

CFLs use mercury vapour and the question arises of what to do with spent lamps? Mercury is an emotive subject and the general public are aware that heavy metals are potentially dangerous. Figures for mercury content per CFL range between 1.5mg and 6mg, in gaseous or liquid form[7][12]. However, according to European Commission Directive 2002/95/EC[26] on the restriction of hazardous substances in electrical and electronic equipment (RoHS Directive), mercury content in CFLs is limited to 5mg[26]. An indicative benchmark (best available technology) of 1.23mg of mercury in energy efficient CFLs is provided in the above mentioned

Ecodesign Regulation (Annex IV)[26]. Simpson provides various points that could be made to argue the effects of mercury vapour in CFLs[12]:

- The "pro CFL" lobby claims that the amount of mercury that might get into the environment as a result of CFL use is far less than the quantity of mercury that power stations would put into the atmosphere in order to provide the extra energy needed to power GLS lamps.
- The "anti CFL" lobby claims that an estimated 176 tons of mercury will end up in our landfills annually in Europe as a result of the disposal of CFLs.
- It is stated that elemental mercury, as would be emitted from power stations to the atmosphere, is less harmful than organic mercury compounds that arise from landfill mercury by microbial action.

Energystar®, a U.S Environmental Protection Agency[25] provides figures on how it believes CFLs will cut down on mercury emissions compared to GLS lamps. It compares a 13W CFL and a 60W GLS lamp.

Light Bulb Type	Watts	Hours of Use	kWh Use	National Average Mercury Emissions (mg/kWh)	Mercury from Electricity Use (mg)	Mercury from Land Filling (mg)	Total Mercury (mg)
CFL	13	8,000	104	0.012	1.2	0.6	1.8
Incandescent	60	8,000	480	0.012	5.8	0	5.8

Table 5: Energystar mercury emission comparison[25]

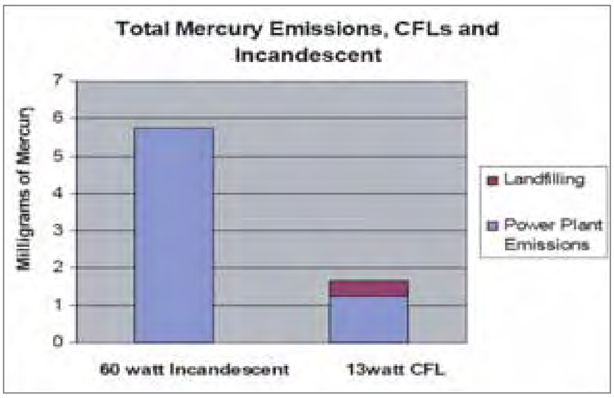

Figure 2: Energystar stated mercury emission savings[25]

Energystar® states that electricity generation is the single biggest source of mercury emissions in the U.S.[25]. It believes that the 13W CFL above will save 374kWh over its' lifetime, thus avoiding 4.0mg of mercury emissions through generation[25]. This figure will drop if the bulb goes to landfill.

Assuming manufacturers' figures are correct, then to replace the 2.1 billion incandescent lamps sold each year, about 350 million CFLs will have to be sold annually[7]. This means that in a few years, almost 350 million CFLs will reach their end of life cycle. While the methods for recycling of fluorescent lamps have become well established in industry and commerce, the domestic consumer is likely to dispose of CFLs in their non-recyclable refuse bag. This will result in either landfill or incineration for most CFLs. This is possibly the worst way of disposing of mercury. In landfill, certain microbes digest mercury and excrete it as methyl mercury, a compound almost twenty times more toxic than metallic mercury[7]. Methyl mercury is easily soluble and could leak out of the landfill into water courses and eventually the sea, where it may get into fish and could possibly become poisonous to humans that consume these fish[7]. It is also not particularly clear what the recycling process will actually do with CFLs. Apart from mercury, CFLs include plastic and electronic components, which may be uneconomical to recycle in any way[12]. Shaw believes that there are limited paths for recycling and in his experience, many lamp recycling companies will not take CFLs and those that do can charge substantial sums, between £0.50 and £1.00 per lamp[7]. A local lamp recycling company provided details about the process that they use for recycling CFLs. Their method is almost identical to that described by Shaw[7]. The ballast is not separated from the lamp, but rather the entire lamp is crushed and materials then separated. The glass element of the CFL can't be re-used as glass due to the phosphors used to contain ultraviolet radiation, but Shaw[7] states that this can still be used for some construction materials like road paint and wool insulation. The mercury contained within the CFL is mixed in with the phosphors and glass particles and the local lamp recycling company uses a distillation process to remove it. The control gear and plastic components are then shredded and heated to extract solder and other low melting point metals, as the plastics are largely burned in the process. The remains, with the ferrous metals extracted, are then sent to landfill. Shaw claims that there is probably less than 1gm of fully recyclable material recovered from each lamp that typically weighs around 80gm[7]. The local lamp recycling company was unwilling to disclose exact information on this. It should also be noted that this particular company charges €0.95 per CFL, but another major retailer in Dublin offers a recycling service free of charge for CFLs that are purchased in its store.

2.9 Ultraviolet radiation (UVR)

For some time there has been an awareness of the negative effects of ultraviolet radiation on human health. Most notorious are the acute erythemal effects, such as sunburn and skin cancer. The International Commission for Non-Ionising Radiation Protection (ICNIRP) and the World Health Organisation recommend a daily effective irradiance of 30Jm^{-2} in the ultraviolet radiation range[14]. Recent research at The Dublin Institute of Technology[15] and by The UK Health Protection Agency[16] have analysed the spectral irradiance of a group of commercially available CFLs. Both studies found similar and interesting results. Because of their mercury content, the CFLs emitted significant quantities of UVA, epically at 365nm. Many of the CFLs had sizeable outputs at 313nm (UVB) and in some cases, at 254nm (UVC). The ultraviolet radiation emitted from the double envelope CFLs was much reduced when compared with that emitted from the single envelope CFLs[15][16][9]. Table 6 and Figure 2 are taken from Cantwells'[15] study and give further details indicating exact quantities, in mWm^2, of ultraviolet radiation emitted at specific wavelengths and the Mean Spectral Irradiance.

Distance = 20mm	UVC (250-280mm)	UVB (280-315mm)	UVA (315-400mm)	Mean Effective Irradiance
Single Envelope	0.52	570	7900	13
Double Envelope	0.37	20	2100	0.46
Distance = 200mm				
Single Envelope	0.49	15	170	0.43
Double Envelope	0.36	0.87	66	0.09

Table 6: Mean total irradiance (mWm^{-2})

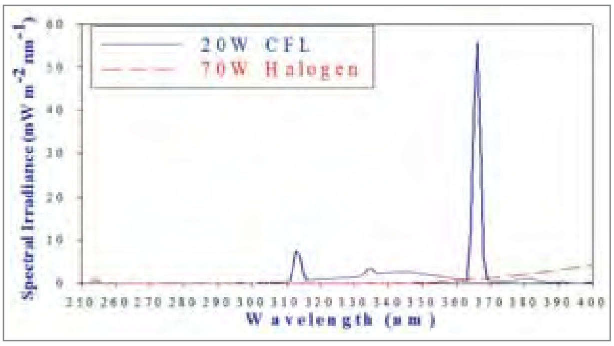

Figure 3: Spectral irradiance of a 20W CFL (blue)

Distance from long axis of CFL = 200mm	<8 hours	8-10 hours	>10 hours
% Single Envelopes	9.4	5.6	85
% Double Envelopes	0.0	0.0	100

Table 7: Time to exceed the ICNIRP Exposure Limit value of $30Jm^{-2}$ at 200mm

In Cantwells' study, the biologically effective exposure from each lamp was assessed using the ICNIRP weighting function[14] and compared to exposure limit values to evaluate potentially hazardous exposures. No double envelope CFL exceeded the limit value of 30Jm-2 at 200mm from the lamp within eight hours[15][16][9]. However, 9.4% of the single envelope CFLs exceeded the ICNIRP limit value in less than eight hours (Table 7)[15]. Similar results were found in other studies[15][9]. This may be due to incorrect or incomplete application of the phosphors coating to the CFL envelope. The Artificial Optical Radiation Directive[20] has become law throughout the European Union as of the 27 April 2010. The Directive requires businesses, including those based in the home, to limit the exposure of workers to optical radiation, including exposure to ultraviolet radiation hazards from general lighting. Since the exposure limits are based on the ICNIRP values, this research may be of significance in this regard. Long term eye exposure at 200mm from a lamp, or in a close proximity to the source, is unlikely due to the eyes' aversion response to a bright source. However, unintentional long-term skin exposure is foreseeable at close distances from the CFLs, e.g. hands under a desk lamp or short-term activity near the source. It should also be noted that exposure levels may be substantially increased by reflection from a lamp shade or a luminaire reflector[16]. The above considered, The UK Health Protection Agency recommends a distance of >30cm from CFLs for area and task lighting[16].

2.9.1 Persons with photosensitive disorders

Ultraviolet radiation is particularly hazardous to those with photo-sensitive skin disorders, such as lupus erythematosus, xeroderma pigmentosum and skin cancer[27][28]. Although exposure limits have been established for people with normal skin, they have not been determined for those with photosensitive disorders[27][28]. Sayre[28] states: "UV exposure in doses similar to those emitted from CFLs have been shown to induce DNA damage, tumour formation and erythemal. Additional studies must be done to determine the lowest dose capable of causing damage in photosensitive patients". Until these studies are conducted, it is widely recommended that patients with photosensitive disorders use bulbs that emit the lowest levels of ultraviolet radiation with a glass envelope or filter[27][28][29]. CFLs will obviously not fall into this category. GLS lamps are recommended where possible[27][28][29]. Failing this, Sayre recommends that Halogen lamps should be "doped or covered with glass prior to use"[27].

2.10 Power factor

It is claimed that GLS lamps have a power factor of unity, or close to unity[4][5][7]. There is concern that CFLs have a poor power factor[4][5][7]. As power factor reduces, apparent power increases and all components in a distribution system, such as generators, conductors, transformers and switchgear need to be increased in size. The literature review conducted indicated a shortage in publicly available results for the direct measurement of CFL power factor. It is for this reason that this research addresses the measurement of power factor in detail.

2.11 Total harmonic distortion (THD)

Many loads connected to the national grid require a continuous sinusoidal power supply and if the power quality of the grid is allowed to deteriorate, it could have significant costs associated with it. The current waveform drawn from the supply by a CFL is not even close to sinusoidal (as the electronic CFL draws current in bursts) and if used in large numbers, could be constantly returning dirty power to the national grid. An independent study in New Zealand proved that on a 300kVA supply, a total of 33.4kVA (18.4kW) of CFLs produced 5% total harmonic distortion (THD), which exceeded the national limit on THD[19]. The European standards are more lenient for low order harmonics and THD than in New Zealand[19]. New Zealand has a large HVDC inter-connector between its' North and South islands and it is for this reason that their harmonic limits are so stringent. Watson believes that widespread use of CFLs will cause significant deterioration in the quality of power supplied by utility companies[19].

It would seem obvious that prevention is far more costly than finding a solution for the problem. This research performs harmonic measurement and analysis to assess the possible impact CFLs will have on power quality before they come into widespread use.

2.12 Pricing and costs

There are many varieties of CFLs on the market at the moment and they vary in price. Prices in Ireland, appear to be as low as €0.99 and as high as €8.95. From this it seems that the market price may not be determined by the cost of the product, but in turn by the retailers and manufacturers' profit margins. It appears that the typical mark up in the UK is 500%[7]. With such a high mark up, one must wonder about the quality of product being purchased by the retailer and sold to the consumer. Running costs for CFLs must also be questioned. If the true wattage of CFLs is not as stated by manufacturers, then the running costs will be altered accordingly.

3. The research

A set of 15 CFLs and three GLS lamps are used for all experiments unless stated otherwise.

Research questions

3.1 What is the measured wattage and true power factor for a group of commercially-available CFLs in Ireland?

3.2 What are the levels of THD being produced by the tested CFLs and what effect will this have on the supply utility distribution system?

3.3 What is the actual “warm up time” for most CFLs?

3.4 How much variation, in price, exists between the similar CFLs and different manufactures?

3.5 What are the running costs and true CO2 savings from domestic CFLs?

3.1 Power factor

Power factor is defined as the ratio of the real power (W) flowing to a load, to the apparent power (VA) in the circuit[13][25]. It is a dimensionless number between 0 and 1. Real power is the capacity of the circuit for performing work in a particular time. Apparent power is the product of the current and voltage of the circuit. This research examines the power factor of a group of 15 CFLs and three GLS lamps.

Methodology

1. Circuit set up as in Figure 4 and Figure 5.
2. Time was allowed for any inrush currents to steady and values were then recorded for wattage, current, voltage and power factor for all fifteen CFLs and each of the three GLS lamps.

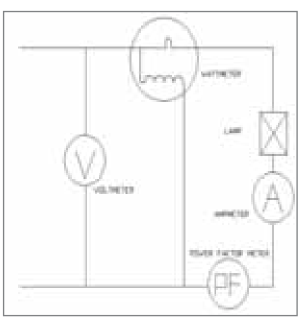

Fig. 4: Circuit set up

Fig. 5: Circuit illustration

Note: It can be seen in Figure 4 that the voltmeter used is not placed directly across the lamp. It is assumed that the volt drop across the meters will be negligible.

Lamp Type	Lamp Ref. No.	Lamp Shape	Manufacturer	Manufacturer Stated Wattage	Measured Power Factor	Calculated Power Factor	Volt-Amps (VA)
CFL	29	Spiral	Philips	20W	0.90	0.55	36.4
CFL	39	Stick	Philips	18W	0.99	0.57	29.9
CFL	38	Spiral	Philips	15W	0.87	0.53	28.3
CFL	26	Bulb	Philips	20W	0.98	0.58	34.5
CFL	68	Stick	Philips	20W	0.99	0.61	30.9
CFL	27	Bulb	Philips	20W	0.99	0.61	34.6
CFL	42	Bulb	Solus	16W	0.99	0.50	32.1
CFL	32	Stick	B & Q	20W	0.99	0.59	32.0
CFL	41	Bulb	Solus	16W	0.99	0.52	30.1
CFL	35	Stick	Tesco	20W	0.98	0.62	35.6
CFL	31	Stick	B&Q	18W	0.99	0.57	31.8
CFL	30	Stick	B&Q	20W	0.99	0.59	33.8
CFL	45	Bulb	GE	15W	0.97	0.57	24.4
CFL	33	Stick	B&Q	20W	0.99	0.58	31.2
CFL	34	Stick	Tesco	15W	0.99	0.62	35.4
				Average =	0.97	0.57	
GLS	1		Eveready	100W	1	1	100.4
GLS	1		Solus	60W	1	1	60.1
GLS	3		Solus	40W	1	1	40

Table 8: Measued wattages and power factor

It should be noted that the power factor meter used in this experiment is an analogue meter and only records displacement power factor. It was included only to indicate the difference between true power factor and displacement power factor. Displacement power factor gives an accurate indication of the power factor in linear circuits only. As the CFLs being used are predominantly non-linear loads (i.e. they draw current in sharp bursts or pulses), the readings from the true RMS volt and amp meters were used, along with the measured wattages, to give values for true power factor (calculated power factor, Table 8).

Discussion, finding and analysis

The manufacturer-stated wattages for most of the CFLs were very accurate when compared with those wattages recorded. The largest deviation was just 2W, which only occurred twice from the 15 tested lamps. These deviations do not suggest anything unusual and provide no real insight to suggest manufacturers may be stating incorrect wattages. The reason for the high VA (apparent power) of all the CFLs is the poor power factor associated with them. The average power factor from the group of 15 CFLs was 0.57, with the best being 0.62 and the worst being 0.52. When this is compared to the GLS lamps, they have a far higher power factor of almost unity. The average VA for the group of CFLs was almost double the measured wattage (18.47W compared to 32.13VA). With the GLS lamps, the VA and wattage were almost identical. Many people appear to have mistaken how poor power factor will affect power consumption and CO2 savings from a given CFL. To illustrate this with an example: Using a typical 12W CFL and a current of 110mA, would give an apparent power of 25.3VA. This will have significant implications for the supply system, but not the actual power used. What also must be remembered is that this increased stress on the electrical utilities has to be balanced against the reduced power usage from replacing GLS lamps with CFLs.

3.2 Total harmonic distortion (THD)

CFLs are fed by power supply units, which conduct current only during a very small part of the 50Hz period so that the current taken from the AC supply has the shape of a short pulse[21]. This leaves the remaining, distorted, sine wave to be returned to the national grid, producing distortion to the voltage and current waveforms of the supply system.

Methodology

1. Circuit set up as shown in Figure 6 and Figure 7.
2. CFL numbers 38, 42, 45, 39, 26 and 35 were used.
3. The six CFLs were placed into the lamp holders and switched on two at a time, and all available readings were recorded when new lamps were added to the circuit.

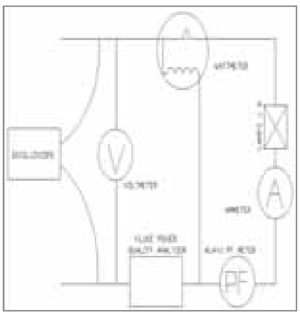

Fig. 6: Circuit set up

Fig. 7: Circuit illustration

Results:

Of the four measurement methods used, the Fluke Power Quality Analyser (digital TPF meter) results proved to be most useful when compared with the true RMS volt and Amp meters:

Fluke power quality analyser:

Lamp Type	V	A	W	VA	VAR	PF	DPF	THD(%)
38,42	236.2	0.23	30	58	50	0.51	0.87	81.3
38,42,45,39	236.2	0.454	61	108	90	0.56	0.89	79
38,42,45,39,26,35	235.4	0.756	101	175	143	0.58	0.89	76
2x40W Philips GLS	235	0.344	81	81	7	1	1	1.6

Table 9: Total harmonic distortion

Figure 9 shows the high levels of THD, up to 81.3%, produced by the group of CFLs, compared to the negligible levels of THD produced by the GLS lamps.

Figure 10 shows the levels of current experienced on each individual harmonic frequency. The levels of current on the 3rd harmonic are of particular interest.

Oscilloscope – two GLS lamps in parallel

It can be seen from the Figures 8 and 9 that the GLS lamps produced virtually no harmonic currents on higher order frequencies and caused almost no distortion to the oscilloscope voltage or current waveforms.

Frequency	38,42	38,42,45,39	38,42,45,39,26,35
Fundamental	0.147	0.289	0.474
3rd	0.122	0.235	0.383
5th	0.091	0.17	0.278
7th	0.073	0.135	0.219
9th	0.062	0.113	0.174
11th	0.049	0.076	0.101
13th	0.032	0.033	0.026
17th	0.015	0.018	0.024
21st	0.018	0.021	0.009
25th	0.017	0.012	0.006

Table 10: Harmonic order currents

Figures 8 and 9: two GLS lamps in parallel

Note: It can be seen that the top of the voltage and Current waveforms are flattened slightly. These small distortions were present before any lamps were added to the circuit and are caused by harmonics already existing in the electrical supply.

Oscilloscope – two CFLs in parallel

Figures 10 and 11: two CFLs in parallel

The GLS lamps were removed and two CFLs added to the circuit. Figure 10 shows the harmonic currents produced on lower order frequencies when the non-linear CFLs are introduced, while Figure 11 shows the harmonic distortion produced on the Voltage and current waveforms.

Oscilloscope – four CFLs in parallel

From Figure 12, when two extra CFLs are added to the circuit, a slight increase in harmonic currents on the lower order frequencies is experienced, but a reduction in higher order currents. Figure 13 also shows how the harmonic distortion on the voltage and current waveform is amplified.

Oscilloscope – six CFLs in parallel

Figure 14 shows that higher order harmonic currents have again

Figures 12 and 13: four CFLs in parallel

Figures 14 and 15: six CFLs in parallel

decreased, when two extra CFLs are added. Lower order currents have increased. The distortion to the voltage and current waveforms has been noticeably amplified.

From Figure 14, the total current of 728mA for six CFLs in a circuit should be noted.

Discussion, findings and analysis

The objective of this experiment was to quantify the levels of total harmonic distortion caused to the supply current waveform by CFLs. This could then be compared to GLS lamps. In domestic dwellings, CFLs would be paralleled, usually with six to 10 lamps per circuit. Six CFLs were used in parallel for this experiment. The GLS lamps produced virtually no total harmonic distortion (less than 2%) on the current waveform, where the CFLs produced an average of 79% THD. It can be seen that this large distortion of the current waveform has a noticeable effect on the levels of THD in the voltage waveform. The levels of total harmonic distortion experienced on the current waveform get slightly larger as more CFLs are added to the circuit.

"The biggest problem when installing non-linear loads is the risk of overloading the neutral conductor"[21].

The neutral conductor of most three-phase supply systems experiences very low current levels and is usually not protected by fuses or circuit breakers. The CFLs tested produced significant levels of third order harmonic currents. With this in mind, it is conceivable to think that with large-scale usage, they may provide problems for power quality and distribution systems. Many researchers state high harmonic distortion is the main drawback of CFLs. It is true that for the CFLs tested, the relative current distortion expressed as a percent of the fundamental exceeded 80%. However, since the current on the fundamental frequency is very low (120mA per CFL approx), the values of harmonic currents are very low too. This large harmonic distortion will comprise of only a small percentage of the overall load.

It is important to note that using CFLs reduces the total current in the distribution system and provides released capacity for energy suppliers!

3.3 Time to reach full Lumen output

A common complaint among CFL users is the time that lamps take to reach their full brightness. This short piece of research sets out to investigate the actual warm up time of the group of tested CFLs.

Methodology

1. The time taken for each lamp to reach its full lumen output was recorded using an amp meter and an illuminance meter.
2. The time was not stopped until the value shown on the illuminance meter had steadied for more than 10 seconds, this 10 seconds was then subtracted from the time on the stop-watch, to give as accurate as possible a time at which the lamp reached full lumen output.
3. This was done seven times per lamp and an average value recorded.

Results:

Lamp Type	Lamp Ref. No.	Lamp Shape	Manufacturer	Manufacturer Stated Wattage	Average Time to Reach Full Output (Sec)
CFL	29	Spiral	Philips	20W	53
CFL	39	Stick	Philips	18W	70
CFL	38	Spiral	Philips	15W	57
CFL	26	Bulb	Philips	20W	126
CFL	68	Stick	Philips	20W	55
CFL	27	Bulb	Philips	20W	105
CFL	42	Bulb	Solus	16W	75
CFL	32	Stick	B&Q	20W	91
CFL	41	Bulb	Solus	16W	74
CFL	35	Stick	Tesco	20W	62
CFL	31	Stick	B&Q	18W	85
CFL	30	Stick	B&Q	20W	76
CFL	45	Bulb	GE	15W	221
CFL	33	Stick	B&Q	20W	84
CFL	34	Stick	Tesco	15W	55
				Average =	85.90
GLS	1		Eveready	100W	2
GLS	2		Solus	60W	2
GLS	3		Solus	40W	2

Table 11: Time to reach full lumen output

Discussion, findings and analysis

A common consumer complaint with CFLs is the time the lamps take to reach its full brightness. The reason for this "warm up time" is the time needed to excite the mercury vapour within the fluorescent lamp to the levels needed to provide full lumen output. This small experiment was set up to investigate the associated warm-up time with the group of CFLs. It is clear that the associated warm-up time does exist and is quite noticeable when compared to a GLS lamp, which has almost instantaneous full lumen output. It is clear that some CFLs perform better in this area than others. The spiral and stick type lamps proved to be far quicker to reach full output than bulb types. This might suggest that bulb types may be generally more suited for a room where the lights may be on for long periods of time, e.g. television rooms, lounge rooms, etc and the spiral and stick types may be better for use in situations where the lights will be frequently switched and quick full lumen output is needed, e.g. bathrooms, closets, garages, stairwells, etc.

	Spiral	Bulb	Stick
Average (sec)	55	120.2	72.25

Table 12: Warm up time with tube shape

Another important issue to draw from this is the health and safety concerns if CFLs are located on stairs and landings and particularly in the homes of elderly people or those with impaired eyesight.

3.4 Costs in Ireland

From the literature review conducted, it was presumed that the cost of CFLs would vary. With this in mind, investigation into the price of the fifteen CFLs used in this research was conducted.

CFL Price Vs Performance

The price for each of the lamps was investigated to see if there is any correlation between the purchase price of a lamp and the performance it will provide. The price list can be seen in Table 13. All prices were sourced from local DIY shops and supermarkets. Where this was not possible, online catalogues were used and prices converted to Euro.

The variation in the price of the CFLs can be seen to be quite significant, with the cheapest CFL being one-fifth the cost of the most expensive, despite both being the same wattage. Comparisons are possible between any of the tested lamps, but for this section a sample comparison between the most expensive and the cheapest lamp will be conducted using the price, lumen output (manufacturer stated), average illuminance (research not included in this paper) and the measured VA. It can be seen from Table 14, that despite the price difference of over 500%, the two lamps perform almost equally well under the compared headings. Similar results are obtained when comparing prices and performance of other CFLs. This would lead to questions about the mark-up price of CFLs and whether or not some manufacturers are trying to exploit the ban of the GLS lamp.

Lamp Type Stated Wattage	Philips – Ref 39 18W	B&Q Ref 31 18W
Price	€11.02	€1.95
Lumens	1100 lm	1200 lm
Average Illuminance	300.4 lux	354.4 lux
Volt Amps	29.9 VA	31.7 VA

Table 14: Comparison – cheapest vs most expensive

Lamp Type	Lamp No.	Manufacturer	Manufacturer Stated Wattage	Price – €
CFL	29	Philips	20W	9.50
CFL	39	Philips	18W	11.02
CFL	38	Philips	15W	7.87
CFL	26	Philips	20W	10.99
CFL	68	Philips	20W	8.55
CFL	27	Philips	20W	10.99
CFL	42	Solus	16W	4.35
CFL	32	B&Q	20W	2.20
CFL	41	Solus	16W	4.35
CFL	35	Tesco	20W	3.25
CFL	31	B&Q	18W	1.95
CFL	30	B&Q	20W	2.20
CFL	45	GE	15W	4.37
CFL	33	B&Q	20W	2.20
CFL	34	Tesco	20W	3.25
GLS	1	Eveready	100W	0.99
GLS	1	Solus	60W	0.85
GLS	3	Solus	40W	0.85

Table 13: CFL price comparison

3.5 At-a-glance calculations – running costs and carbon emissions:

Running costs

The running costs of CFLs are easily calculated using the kWh price from an electricity supplier and the estimated hourly usage per day, week, month or year. The calculations below assume 1000 hour usage per annum, roughly 2.7 hours per day and use Electricity Supply Board Ireland kWh prices[22].

Philips 20W CFL – Ref No. 29

20W x 1,000hr/yr = 20kWh/yr x €0.1506 = €3.01 per annum.

Assume ten lamps per household – €3·01 x 10 = €30·10 per annum running costs.

Eveready 100W GLS – Ref No.1

100W x 1,000hr/yr = 100kWh/yr x €0.1506 = €15.06 per annum.

Assume ten lamps per household – €15.06 x 10 = €150.6 per annum running costs.

Savings per annum – €120.50

Note: In Ireland, domestic tariffs do not penalise for poor power factor. Should this be implemented in the future, the potential monetary savings from CFLs may be reduced.

CO2 Emissions

Again the predicted kWh usage for the year can be used to estimate the potential CO2 savings possible from switching to CFLs. The Carbon Trust provides a conversion figure of 0. 544kg/CO2 per kWh for grid electricity[23] and this will be used for the purposes of calculations.

Philips 20W CFL – Ref No.29

20W x 1,000hr/yr = 20kWh/yr x 0·544kg/CO2 = 10·88 kg/CO2 per annum.

Assume ten lamps per household – 10.88 kg/CO2 x 10 = 108.8kg/CO2 per annum.

Eveready 100W GLS – Ref No.1

100W x 1,000hr/yr = 100kWh/yr x 0.544kg/CO2 = 54•4kg/CO2 per annum.

Assume ten lamps per household – 54.4kg/CO2 x 10 = 544kg/CO2 per annum.

Savings per annum, per household – 435.2kg/CO2

Lamp Type	Lamp Cost	Lamp Life	Lifetime Cost (12 Years)	CO2 Emissions (12 Years)
200W CFL	€9.50	12,000	€45.62	130.6kg
100W GLS	€0.99	1,000	€192.60	652.8kg

Table 15: Running costs and CO2 emissions comparison for "equivalent" lamps

4. Conclusions

It can be seen that manufacturer-stated CFL wattages were accurate, but an average true power factor of 0.57 has a significant effect on the apparent power. It leads to an apparent power that is on average, almost 60% greater than the manufacturer-stated wattage. Some of the problems that this may cause for electrical utilities are increased volt drops or a need to increase the rating of all system components, such as generators, conductors, transformers, switchgear, etc. Many researchers suggest that high harmonic distortion is the main drawback of CFLs. It is true that for the CFLs tested, the relative current distortion expressed as a percentage of the fundamental exceeded 80%. However, since the current on the fundamental frequency is very low, the values of harmonic currents returned to the distribution system are very low too, compared with GLS lamps. This minimises risks of distribution equipment overheating, transformer secondary voltage distortion and possible overload three-phase neutral conductors. The associated "warm up time" with CFLs does exist and is quite noticeable when compared to a GLS lamp, which has almost instantaneous full lumen output. Some CFLs appear to perform better in this area than others. The spiral and stick type lamps proved to be far quicker to reach full output than bulb types. Care should be taken when using CFLs in the homes of elderly people and those with impaired eyesight. The variation in the price of the CFLs is quite significant, with the cheapest CFL being almost one-fifth the price of the most expensive, even though they are the same wattage. From the comparison in Table 14, it can be seen that despite the obvious difference in price, there is little difference in the performance (under the headings examined) of the two CFLs. The financial and environmental benefits of using CFLs in domestic lighting are clearly visible from the calculations in section 3.5.

It is clear that CFLs have a far greater efficacy (lumen/watt) than their GLS equivalent. Using their manufacturer-stated lumen output, the CFLs used in this research had an average efficacy of 58.41 lumens/watt, compared to 13.3 lumens/watt from a GLS lamp. It would appear that CFLs contain a far greater embodied energy, but this is not significant enough to offset the potential savings they provide compared to GLS lamps. At present, it seems that CFLs produce slightly less illuminance than their GLS "equivalents". When manufacturers are stating equivalent wattages, there is some discrepancy between the methods of comparison. However, it appears that this is merely an effort to provide an easily understood method of comparison for the general public. CFL lamp life is hard to analyse critically. CFL lamp life is stated as being six to 12 times that of a GLS lamp, but questions are raised about what CFL lumen output will be towards the end of their lifespan and if this will be sufficient to avoid replacing the lamp. It is understood that stated lifespan is an average. CFLs produce an incomplete electromagnetic spectrum. They lack higher wavelengths, which contain the colour red. It is for this reason that they produce a cool colour temperature. This seems to be a significant factor for most users, but the use of lampshades may offset this somewhat. The spectral irradiance of CFLs does not follow that of a Planckian radiator, as with a GLS lamp. It instead shows peaks in spectral irradiance, separated by regions of little or no irradiance. It is for this reason that the colour rendering index of CFLs is lower than that of a GLS lamp. In the studies reviewed, the average CRI for CFLs was approximately 78. Very few independent studies exist that accurately measure the total lumen output of CFLs, but this research suggests a comparative ratio of 4.5:1, not the 5:1 stated by manufacturers may be more accurate. There are two sides to the debate on mercury content within CFLs. Some argue that more mercury will be released through the generation of electricity for GLS lamps than could possibly be released by incorrect disposal of CFLs. Others argue that the smaller quantities of mercury and mercury compounds (e.g. methyl mercury) that end up in landfills will do far more damage than the larger quantities released directly into our atmosphere. This paper suggests that only a very small fraction of each CFL will actually be recyclable. It is clear that some CFLs emit ultraviolet radiation. The reasoning behind this seems to be incomplete, inadequate or incorrect application of the phosphors coating to lamp envelopes. Cantwells' study found that 9.4% of single envelope CFLs exceed the ICNIRP recommended limit value of 30Jm-2 within eight hours at a distance of 200mm. No double envelope CFLs exceed this value. As of 27 April 2010, this limit cannot be exceeded in places of work, under EU law. The UK EPA recommends a distance of >30cm from CFLs for area and task lighting. The effects of CFLs and their emission of ultra-violet radiation must be taken very seriously where persons with photosensitive skin conditions are concerned.

While we must recognise and acknowledge the shortcomings of CFLs, the potential savings in energy, running costs and CO2 emissions provide a powerful argument that CFLs are an improved alternative to GLS lamps.

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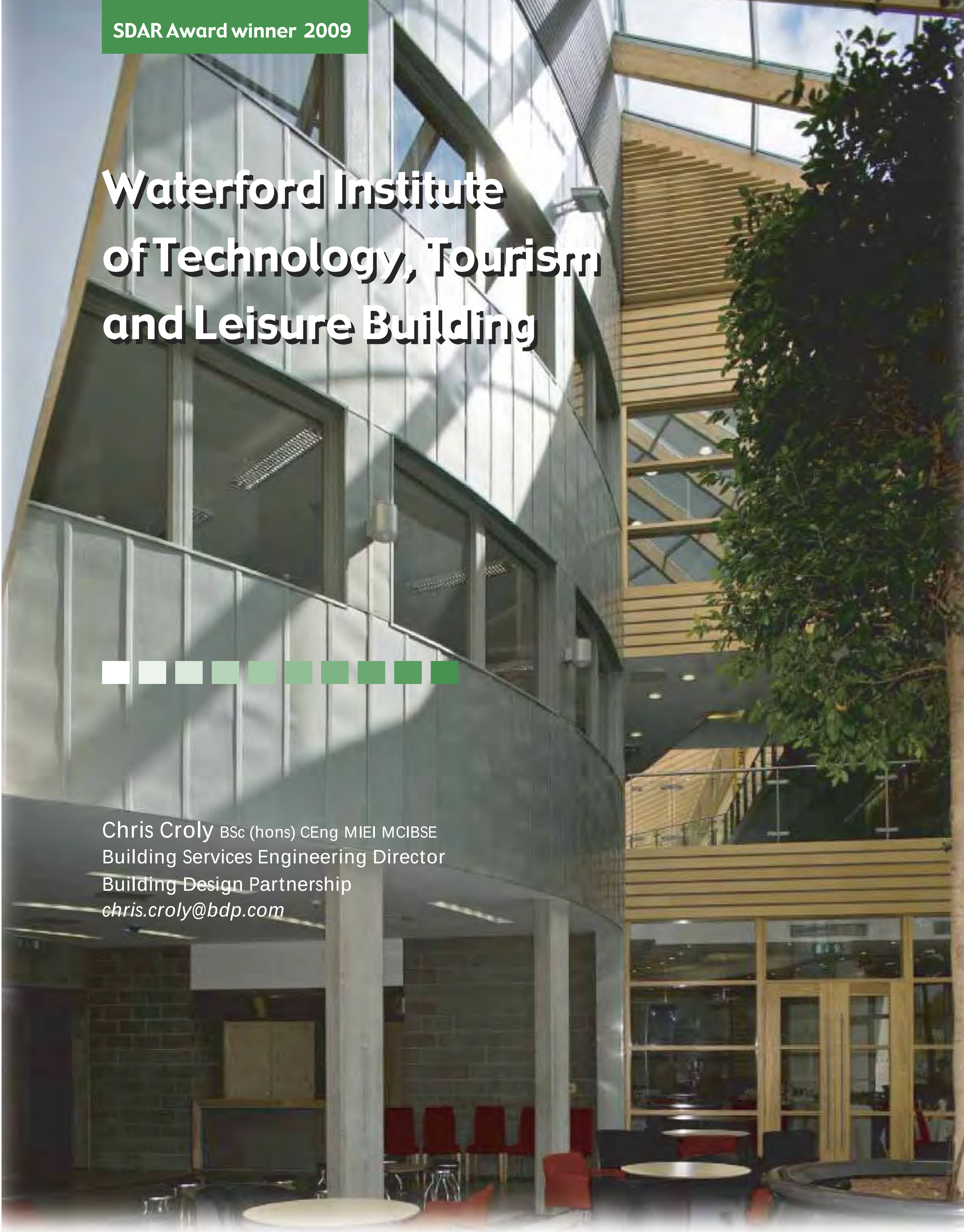

SDAR Award winner 2009

Waterford Institute of Technology, Tourism and Leisure Building

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Abstract

The Tourism and Leisure Building at Waterford Institute of Technology contains all of the passive design elements that would be expected in a landmark environmentally-conscious educational development. The design however also addresses energy conservation in complex, high-energy kitchen systems in an innovative way, bringing a new level of environmental performance to catering in Ireland.

A new standard

The Tourism and Leisure Building presented a series of exciting design challenges, the most significant of which was the control of environmental conditions within its compact training kitchens, while minimising the building's environmental impact.

There were several precedents for this type of building, both nationally and internationally, and these were studied in detail. Making significant improvements to the environmental performance of this building type required a first principles approach, and the abandoning of any pre-conceived ideas on how the design of the building and its systems should be approached. The result was several new ideas that not only produced a successful design for this building but offered useful lessons for the design of future catering facilities. It was the designer's intention that the building would prove to be an educational tool in every sense of the term.

True first principles innovation and building optimisation cannot be achieved if unnecessary constraints are applied by isolating concepts to a single discipline. This is why an integrated approach to design was essential for this project, with the buildings shape, form, orientation, and facade developed with a full under-standing of its impact on the systems and environments that it contained.

A study of the building demonstrates that many of its visual elements have been moulded around the desire to optimise the building's environmental performance.

While the approach to the building's kitchen spaces stand out as a new contribution to building design techniques, the design of the rest of the building and systems also merit exploration as they follow many principles of passive design and have offered some useful contributions to the study of passive building design.

Low energy kitchen design

The building brief called for the accommodation of eight teaching kitchens. The two production kitchens and the pastry and larder kitchens are relatively typical kitchen spaces but the four training kitchens instantly presented themselves for special consideration.

A training kitchen is characterised by an extremely high density of cooking equipment spread evenly throughout the room. The traditional approach to this type of space is either to install a significant, energy-hungry air conditioning system or to accept the extremely hot temperatures that will result.

The treatment of the training kitchen must also take into account the following:

- A large proportion of the heat generated is radiant which makes it more difficult to address.
- Gas burning equipment can generate high levels of combustion waste gasses.
- The spread of equipment makes it difficult to capture heat at source.

The logical starting point for the design was the reduction of source heat gains which involved a detailed examination of the catering equipment required. A brief analysis of the catering equipment identified significant inefficiencies and poor associated energy performance. Much of the energy delivered to catering equipment was found to transfer to room gains with only a small proportion delivered to its target product.

A study was then carried out of alternative recently-developed equipment that offered an improved efficiency. While it would be interesting to use advanced low-energy equipment throughout the facility, it was important that the students be exposed to a variety of catering equipment and, for this reason, it was not possible to install the advanced equipment identified in all kitchens. The design team however overcame this barrier by proposing a solution to the client which involved the dedication of one of the kitchens as a *"kitchen of the future"* which would contain only low-energy cooking equipment such as induction cookers and infra-red salamanders. This was a brave move for the college who have embraced the concept and will use the kitchen to train the next generation of chefs in the concepts of sustainable cooking.

The use of electric induction cookers is not necessarily an intuitive low energy selection as they rely on carbon intensive electricity; however they are so much more efficient than traditional hobs that

the net effect on both the reduced direct energy requirement and the space cooling requirement was significant when compared with natural gas hobs.

The efficiency of an induction hob is derived from both its direct heating of the product without waste and also from its ability to turn off automatically and instantly when a pot is removed. (It must be remembered that traditional cooking scenarios involve leaving a gas hob on continuously even when not in use, due to the inconvenience of the relighting cycle).

Even in the kitchens that contained traditional equipment a number of potential efficiency improvements were identified such as appropriately-shaped hob outlets and improved equipment insulation.

The design team used this opportunity to call on the catering industry to introduce an equipment efficiency rating system similar to that used for domestic appliances as this was not required at the time of design and was a considerable contributor to the poor standards of catering equipment energy performance at the time.

Heat gains – solar

Following the minimisation of equipment loads and heat gains, the next logical step was to consider solar and lighting gains.

Lighting gains were easily reduced through the use of high frequency T5 fittings and associated occupancy detection controls (which were not commonly used at the time of design).

Natural light is very beneficial in kitchens and it was important that the design offered quality daylight to the kitchens but a number of innovative concepts were required to reduce associated solar heat gains to the south-facing kitchens.

The building is sculpted to offer natural shading to the glazing and the kitchen glazing is further protected through the use of innovative, solar selective light shelves built into the glazing units. This concept continues up the building to provide natural solar protection to the building's computer rooms which are also almost entirely naturally ventilated.

The benefits of daylight are much greater than the offsetting of artificial light. Natural light introduces a sense of contact with the external environment, a natural variety and sense of orientation and location within the building.

The kitchens are relatively deep due to layout constraints but as engineers BDP developed a special internal roof light configuration at the back of the kitchens that linked with the external environment via the atrium and served several functions. The roof

light offered a contact with the external environment but also introduces a special link between the calm buildings circulation and the active kitchen facilities through a visual link overlooking the kitchen from the atrium. This link allows the building's students and visitors to experience and appreciate the activity housed within the building.

This internal roof light within the kitchens required some significant engineering in order to prevent condensation from the humid kitchen environment and a build up of grease on the glazing. The use of the building over the last year has demonstrated that the air injection technique used in conjunction with the careful selection of equipment, including a dry bain-marie (to prevent steam generation), was extremely successful.

The systems

Once the source of heat gain had been addressed and attenuated as much as was practical, it was necessary to select the mechanical systems required to remove heat from the space and to introduce fresh, cool air to the kitchens.

Each kitchen type had to be examined separately to determine an optimum solution.

Production kitchens

The production kitchens contain islands of equipment that are tightly gathered together to form a single concentrated heat source.

For these rooms the most appropriate solution is to remove heat at source through the use of a kitchen canopy directly above the cooking equipment. Many traditional canopies are designed on the basis of a fixed capture face velocity which results in considerable over-sizing of the flow rates required.

The modern hoods used for these production kitchens are carefully aerodynamically profiled with the extraction placed towards the outside face of the canopy to minimise the capture-velocity to approximately half of that traditionally required.

Consideration must also be given to the introduction of fresh air and the canopy location affords the opportunity to supply fresh air through the face of the canopy directly in the working area of the cooks. This approach maximises the cooling effect of this fresh air both through the delivery of external air to the occupied zone and also through the use of air movement in the occupied zone that improves the sense of fresh air cooling.

The result was a low volume air supply system that produces a very comfortable environment without the need for air conditioning.

The controls strategy used for the production kitchens also works hard to reduce energy usage.

During low load conditions, it turns off the supply air and opens a series of motorised windows. It then slowly ramps up the air flow requirements to match the load.

The use of opening windows in kitchens in the form of a mixed-mode strategy is a low-energy solution that is often ignored due to complexity of control or fears of contamination.

Contamination is easily handled through the use of fly mesh screens on the windows and the controls strategy was carefully developed to include routines that close the windows during particularly cold or windy weather when draughts may be a concern. Local window over-rides are also provided allowing the users to open, or close the windows for a number of hours before the controls system resumes control.

Training kitchens

The training kitchens are a very different case as their loads are more evenly distributed throughout the room. The use of canopies within a training kitchen would not be appropriate for several reasons:

- The entrainment area required would result in air flow rates that are considerably higher than required by alternative solutions due to the large total entrainment area required.
- Visual continuity is particularly important within a training kitchen where a single chef must lead a large class.
- A large number of protruding canopies would obstruct the use of natural light in these spaces.
- The large number of workstations provided would result in a high cost solution.

A ventilated ceiling offers a useful solution for this room type as it is held out of the main operating zone and extracts evenly over the full room. A ventilated ceiling does not require any particular entrainment velocity to work effectively and works well with particularly low flow rates.

Traditional ventilated ceilings are fitted with both supply diffusers and extract grilles at high level within the ceiling and are fed by an air conditioned air supply. The result is a highly carbon intensive solution.

The removal of air conditioning from these rooms was important in order to minimise their carbon impact and an innovative new solution was required to avoid the need for air conditioning.

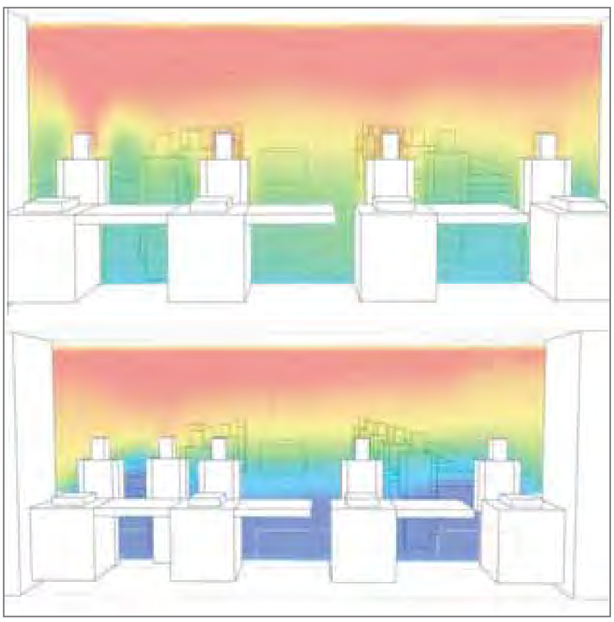
The difficulty with high level supply air in a kitchen is that the temperature at ceiling level is very high and air introduced instantly entrains its surrounding hot air. For this reason the supply air must be cooled considerably, simply to reach the occupied zone successfully.

A displacement ventilation solution allows air to be introduced within the occupied zone, where it flows across the room, is heated by heat gains and rises to high level for removal. This strategy offers the occupants air at the coolest possible temperature and leaves them standing in a pool of cool air. The air is drawn naturally to the locations where it is most needed by the room's heat gains.

At the time of the building's design there were no previous examples of the application of displacement systems to kitchens in Ireland and we were also unable to identify any international examples of its application to kitchens. Its successful use is therefore important in the forming of a useful case study.

The design of a displacement system within a kitchen, however, offered some technical challenges in determining its performance in the absence of any precedents. The effects of displacement ventilation is traditionally calculated through the use of formulae that rely on the assumption that heat-rise with height within the room is linear and uniform at all lateral points within the room. This assumption does not however hold for a kitchen design.

A kitchen is characterised by a series of high-intensity point loads and a significant three-dimensional natural plume transfer mechanism takes place that would lead to significant errors if a linear, two-dimensional model was used.



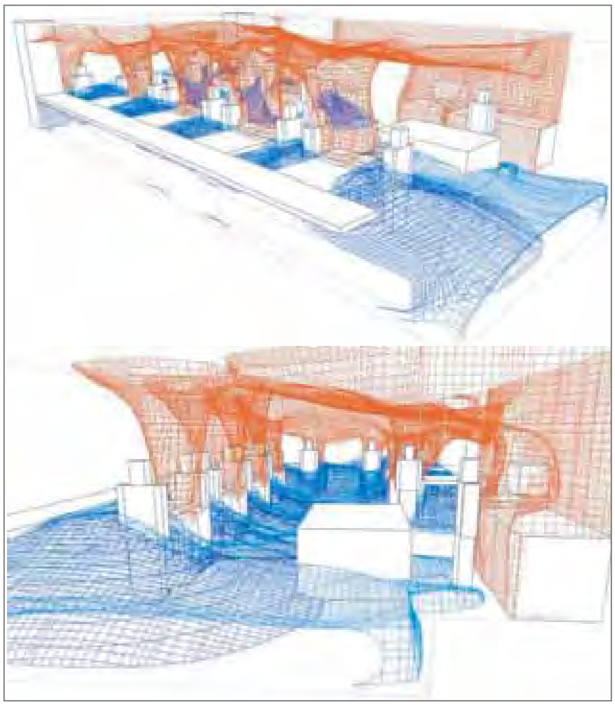
An advanced three-dimensional computational fluid dynamic model was required of air flow within the kitchens to determine the systems effectiveness.

The benefits of the displacement approach over the traditional high level approach can be visualised in the accompanying images.

The first image (below left) shows the temperature distribution within a traditional kitchen design, and the second shows the improvement achieved with our design concept under identical air flow conditions.

The temperature to colour scales uses are the same for both images so the benefits of the displacement system are self-evident from the images below.

The concept can be further analysed by the isotherm simulation image (below) which shows cool air flowing in at low level and the kitchen hot spots contained over cooking areas. The non-linearity is clearly visible from the image.



Computational fluid dynamics (CFD) is often used purely for illustrative purposes and it is important to test the benefits of its use by asking the simple question: What design changes were made as a result of the CFD analysis?

In this case there were a number of important design outcomes of the analysis; the first was the re-arrangement of some of the equipment within the room. It became evident that the gas cooking equipment which provided higher heat gains should be located away from the area of the room that was also subject to solar heat gains as the combined effect produced a local hot spot that was easily eliminated through the relocation of equipment.

The results were also used to optimise the location of supply air grilles to hold cool air at low level as long as possible and avoid forced pluming of cool air.

The results of the CFD analysis were also used to determine the design flow rates required to hold a cool air zone within the occupied zone.

The use of CFD was therefore vital to the success of the project.

It is also important to ask if the analysis was accurate and, to answer this question, a number of load tests were carried out on completion of the building. Temperatures were measured at a number of locations and elevations within the kitchens during the load tests and were found to be almost identical to the simulated results.

The load tests were also used to carefully test some of the complex control routines applied, and to ensure that carbon monoxide levels within the kitchens were not compromised by the low-energy, reduced-air volume strategies.

Once the displacement system had been designed and optimised, its controls were then optimised through a series of sophisticated routines that minimise energy use in a number of interesting ways. These are briefly outlined below:

- Natural ventilation is automatically used at low loads, through insect screened window openings.The automatic windows are carefully controlled to avoid draughts and remain open when appropriate at higher load conditions to form a hybrid ventilation strategy.
- Variable speed drives automatically adapt to the required load, taking into account the cooking load and the use of natural ventilation for make-up air.
- The kitchens automatically switch to high level supply during very cold conditions, operating as an interesting form of kitchen air heat recovery within the ceiling plenum and at high level in the room. This is a simple addition to the strategy that totally eliminates the need for pre-heating of the supply air during cold conditions.
- Carbon monoxide sensors allow the fans to operate at low speed without risk to the users. Load testing has demonstrated that even in the event of the failure of the carbon monoxide sensors, levels within the kitchen remain well within reasonable limits but the sensors provide a useful additional safety measure.

- The natural ventilation is used in conjunction with the mechanical systems in a hybrid mode to optimise internal conditions. There are user over-ride switches provided to allow the user to open or close the windows for a number of hours before control is returned to the building management system.

In a drive to use the building as a learning tool and to also optimise its control systems, a remote connection has been provided to the consultant engineer's offices which has allowed for interesting observation over a considerable monitoring period.

With complex controls systems it is always a concern that the users will find the system difficult to understand. However, observations both on site and through the remote system have shown that the system optimisation controls work well and that the users under-stand the systems operation. Part of the success of a complex controls system is maintaining a simple user interface and allowing appropriate temporary user over ride.

Hot water

Hot water use in teaching kitchens is significant and is required over a short period following each teaching session.

The environmental impact of the kitchen's hot water consumption is reduced by the use of dedicated condensing hot water heaters that were not available on the market at the time of tender but were added as they became available during the construction period, allowing the building to benefit from the latest technology available for this key energy consumer.

General layout

The building form was carefully laid out on a linear plan in order to expose south and north facades with the philosophy that due south gains can be dealt with effectively through shading methods.

The south facade is divided by a number of dynamic recesses, one of which is shown in the following photo (page 59). These recesses allow the drawing of daylight and natural ventilation into the building without exposing it to excessive heat gain. These recesses were carefully modelled to optimise the natural shading effects.

The south wall form is also assisted by the unusual use of a facade stack wall that conceals the large kitchen ventilation ducts. These ducts are carefully positioned to allow windows to project through the spaces between the ducts. The moving of the ducts to the external wall allowed a buffer zone to be generated that forms natural recesses to reduce solar gain. The co-ordination and optimisation of details of this type is a tribute to the design team's co-ordination of all disciplines.

A generous central atrium divides the building allowing stack ventilation, and also allows the night cooling of exposed internal block work which provides cooling to the majority of internal rooms as they back onto the atrium. This night cooling strategy provides the simplicity of night cooling without the security concerns of motorised external windows.

The building's main atrium is flooded with light, drawing light all the way down to the kitchen corridors, and transferring light through internal glazing to the kitchens.

A smaller secondary atrium is used to draw light to the back of the restaurant area where the food prepared by the students is consumed, offering further training opportunities for pupils.

Light is also drawn through the building with a series of roof lights, so that the building's users are constantly in contact with the natural environment.

Unwanted air leakage is the largest source of heat loss from a building of this type and an air tightness target of $5m^3/m^2/hr$ at a test pressure of 50Pa was achieved. This is a particularly impressive achievement when it is considered that no specialist sealants, membranes or blocks were used. An achievement that is often thought not to be possible with traditional construction and the

building has served as a useful demonstration of what can be achieved through careful detailing and quality workmanship.

Control

The building's controls also contain many innovative strategies that are designed to reduce the buildings energy consumption, including the use of direct weather compensated condensing boilers.

The board room and restaurant spaces also contain innovative control strategies that automatically detect the room's requirements and adjust the ventilation to suit, prioritising natural ventilation as their primary cooling measure.

The use of load-sensing control strategies offers significant advantages over traditional methods by reducing energy consumption and management requirements.

The building also contains an internet-based remote monitoring system which allows the design engineers to optimise the control systems and follow the buildings progress.

The building's lighting system is a low energy system complete with automatic controls that turn off lights when rooms are un-occupied or when adequate daylight is available.

This is also one of the first buildings to be fitted with waterless urinals, demonstrating the client's commitment to lowering the environmental footprint of their buildings and offering a demonstration of the best new conservation methods available.

Modern tools

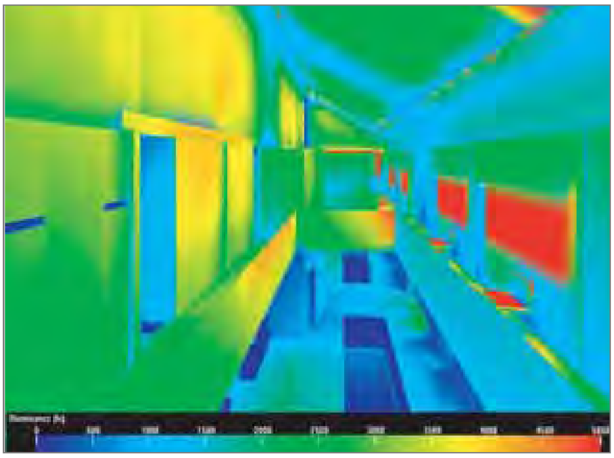
The CFD study used to analyse the complex air flow within the kitchens demonstrated the application of modern engineering techniques to this project. The project also took advantage of a number of other advanced, in-house engineering techniques to study the building.

The atrium daylight and the transfer of light between the atrium and surrounding rooms is a complex process that cannot be accurately studied with standard daylight analysis software. An advanced radiocity-based calculation method was used to fully account for the complex light reflectances through the depth of the atrium and to adjacent rooms.

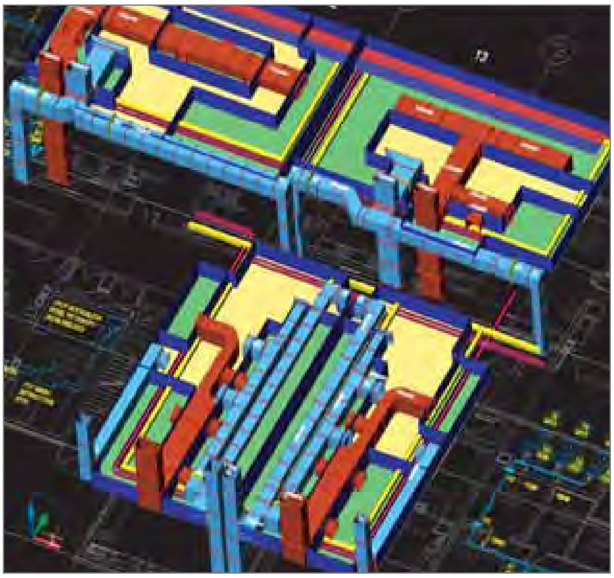
The following images show an early simulation model image of the atrium that was used to study glare and the associated light level results output.

The advanced daylight simulations were used at an early stage of the project to advise the project architect on the required glazing areas and distribution.

Radiocity study of solar glare in the atrium space.



Lux level results for the atrium space.



The natural ventilation and thermal mass interaction was studied through the use of a complete building dynamic simulation.

The project was run as a "paperless" project with almost no drawings printed and all communication carried out using a project email mailbox. While this paperless project technique is now commonly used, it was an innovative concept at the time of the projects design.

The project also adopted the use of BIM (Building Information Modelling) techniques to model the complex services layouts within the limited ceiling voids above the kitchens. This modelling allowed a number of complex co-ordination issues to be identified and resolved prior to construction.

Lessons offered

This building extends its teaching function beyond its primary purpose of a tourism and leisure building.

The building offers a useful case study on the use of passive design techniques that are optimised for an educational building. It also offers useful results for several new, innovative techniques such as the use of displacement ventilation in kitchens, the use of advanced catering equipment, the use of hybrid natural ventilation and complex controls in a high-usage catering facility. It is hoped that many of the lessons and results achieved can assist in the development of future low energy buildings of a similar nature.

It is also hoped that the provision of training in the use of low energy catering equipment will encourage the future chefs and managers who are trained in the building to invest in these low energy methods.

The building air tightness target and techniques were also a useful training exercise for the builders involved who gained the knowledge of how to produce future low energy buildings without additional costs.

All of the building's low energy techniques were achieved at **no additional capital cost** and are the result of genuine engineering techniques rather than expensive add on technologies.

Lessons for the future

While the building was recently completed, it was designed over five years ago and the techniques used should be viewed in the context of this time scale as there have been considerable changes in technology over this period.

The building achieved grant funding from SEI for the incorporation of a number of additional energy conservation measures including the provision of heat recovery on the kitchen ventilation system which would have made an interesting additional case study. Unfortunately the grant funding was cancelled due to project delays (with the overall building funding) and the grant funding was removed, preventing the installation of the heat recovery.

While heat recovery is not traditionally assumed appropriate for kitchen systems due to concerns over exchanger fouling, an examination of the system fans after a year of intensive use (with no grease build up) indicates that the heat recovery system would have been successful if installed. A UV filtering proposal had been proposed as an additional heat exchanger protection mechanism as UV light can prevent grease build up.

An analysis was also carried out on the potential use of micro combined heat and power for the building as the building has a relatively large hot water load. At the time of design the calculations determined that a payback period in the order of 60 years would be achieved but in the last five years there have been considerable reductions in the cost of small CHP units and it is likely that the application of CHP to a building of this type might be attractive in current and future market conditions, offering notable additional energy savings.

The building's overall energy performance is set to consume less than half the energy consumed by a similar building constructed to good practice standards. The building offers a unique case study of the use of displacement kitchen ventilation in Irish conditions.

Appendix A

Performance metrics

Kitchen of the future:

The energy savings associated with the provision of the advanced, low energy catering equipment within the *"kitchen of the future"* were calculated as shown in the table below. The calculation took into account both the savings in energy consumption associated with the equipment and the associated reduction in space conditioning energy.

Per kitchen	
Energy saving (cooking and ventilation)	19,792 kWh/yr
Saving in CO_2 Emissions	3 Tonne / Year
Cost Saving	€3,202.58 per year

Kitchen displacement ventilation strategy

The use of the displacement ventilation strategy, compared with an alternative high level supply strategy was calculated to generate the following savings.

Energy saving	20,216 kWh/yr
Saving in CO_2 Emissions	16 Tonne / Year
Cost Saving	€2,670 per year
Additional cost	€40,814.78
Payback period	15 years

Lighting controls:

The use of low energy lighting and associated controls was calculated to result in an annual saving of approximately €9,000 and to have an additional cost of €65,000 which results in a payback period of 7.2 years.

It should be noted that at the time of design (five years ago) low energy lighting and controls was not commonly used and over the last five years the costs of same have dramatically reduced.

CHP:

An analysis of the use of CHP in the building showed that the system would have a 60 year payback period. Note that CHP engine prices have reduced considerably over the last five years and the payback period under current prices would be in the order of ten years.

Overall energy monitoring:

The building's monitoring system shows the combined heating and hot water energy usage during the first year of operation to be 158 kWh/m^2/yr which is a very impressive figure for a building of this type. A comparative building of this type would consume 217 kWh/m^2/yr according to the CIBSE good practice guidelines.

The monitoring also shows that hot water energy consumption was only 6% of the total heating energy use which is surprisingly low and that the kitchen fan energy was only 7% of the total electrical energy usage. This small fan energy usage supports the observations that the advanced controls strategy results in the fans often being run at low volumes and the natural ventilation and mixed mode option being used extensively.

The total water consumption of the building is 20m^3/day which is as expected.

Care must however be taken when viewing energy information from the first year of a building's operation and preliminary results can often be misleading as an indication of the long-term performance of a building of this type.

The electrical energy is monitored by several meters:

- Overall electrical
- Typical kitchen
- Kitchen plant energy

This monitoring information will prove very useful for future project design as very limited data exists on training kitchen energy usage in an Irish climate.

Initial teething problems existed with the electrical energy meters which were resolved half way through the year. For this reason full-year electrical energy information is not currently available but will be published later in the monitoring period.

Kitchen CFD testing

As the design of the displacement system relied heavily on the results of the CFD modelling it was important to test the completed kitchens and compare the results with the modelling.

A completed kitchen was applied with a known heat load and temperature measurements were taken at various locations in the kitchen, most importantly at an operator's position, at various heights.

The results were compared with the CFD model when applied with identical loads and the results were remarkably similar, showing that the use of CFD was a valid design method for the kitchen displacement systems.

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CIBSE SDAR* Awards

The Finalists 2011: Rory Burke, Colm Saul, Jonathan Tooth (JV Tierney), Declan Leonard, Michael F. Keohane (PMG), Marc Wegner (DIT Post Graduate).

The SDAR* Awards is an initiative by CIBSE Ireland, organised by the School of Electrical Engineering in DIT, supported by *bs news*, and sponsored by John Sisk & Son. SDAR stands for Sustainable Design & Applied Research and it applies to engineering of the built environment. It is different to other competitions in that it is intended to encourage applied research, disseminate knowledge gained from this research, and raise the level and quality of innovation in projects. Entries must critically evaluate what they are doing and examine, in a transparent way, mistakes as well as successes on innovative projects. In this way the profession builds capacity to innovate successfully, and moves from ideologically-driven projects sometimes offering poor value, to evidence-based innovations that provide proven value.

Entries for SDAR* Awards 2012 are due in soon

Abstracts of interesting or innovative projects in which there is data, analysis and evidence of success or failure are likely to be short listed.

One page abstracts are invited by **October 31st 2011** and should be submitted electronically to kevin.kelly@dit.ie by this date.

The five judges of the event in 2010 were all industry senior figures:

- **Alan Duggan**, Arup and Chairman CIBSE Ireland
- **Justin Keane**, John Sisk & Son and CIBSE
- **Brian Geraghty**. BGA Associates and CIBSE
- **Kevin O Rourke**, SEAI
- **Kevin Gaughan**, School of Electrical Engineering Systems DIT.

The event was organised by staff of the Department of Electrical Services Engineering in DIT as part of their parallel SDAR* research centre. *http://eleceng.dit.ie/sdar/*

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