01_IE_zero2020

Key Features & Climate

1.1 Introduction - Zero2020 Building Retrofit

In 2012 Cork Institute of Technology in Ireland (CIT) completed the construction phase of zero2020, a pilot project/research testbed for the low energy retrofit of their existing 29,000m^2 teaching building originally constructed in 1974. The retrofit pilot project covered approximately 1.0% of the total building floor area and is shown in Figure 1. The ventilation solution for the retrofit involved a flush faced external louvre system, each section comprising 17 air inlet slots (two sections comprise each vertical louvre bank), with a porosity of 0.057%. Inside the slot louvre ventilation is supplied using dedicated insulated doors controlled either manually or automated based on conditions in the enclosed spaces. The installed anodized aluminum slot louvre has a 45% net free open area for airflow and each louvre bank, comprised of two sections, and has overall structural opening dimensions of 0.30m (w) x 1.60m (h) with a net opening area for each section of 0.102m^2 (there were two louvre banks in the test space). The primary aim of the envelope upgrade is to extend the lifetime of the building and ensure low thermal energy demand and improved occupant comfort. As an example of a “living laboratory” the zero2020 building allows researchers the opportunity to develop and calibrate virtual laboratories to study; microgrid applications, thermal comfort, and demand side management.

Fig.1 ZERO2020 BUILDING RETROFIT TEST-BED IN CORK INSTITUTE OF TECHNOLOGY, IRELAND

Table.1 KEY INFORMATION ABOUT BUILDING

Location	Cork, Ireland
Building Type	Office
Retrofit (Y/N)	Y
Surroundings (Urban / Rural)	Rural
Ventilative Cooling Strategy	Natural
Year of Completion	2012
Floor Area (m^2)	222.5
Shape Coefficient (%)	49
Openable Area to Floor Area Ratio (%)	2.3
Window to Wall Ratio (%)	56
Sensible Internal Load (W/m^2)	29
Climate Zone (KG) (words?)	(Cfb)
No. of Days with T_e max > 25	0
Cooling Season Humidity	Low
Heating Degree days (Kd)	639

1.2 Local Climate

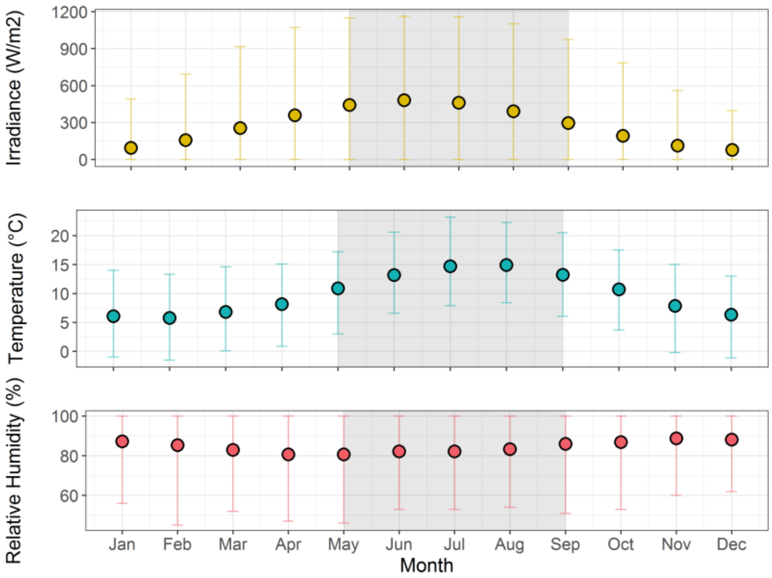

Fig.2 MEAN, MAXIMUM AND MINIMUM EXTERNAL CONDITIONS IN CORK AIRPORT USING TMY3 FROM METEONORM 7 (COOLING SEASON SHOWN SHADED)

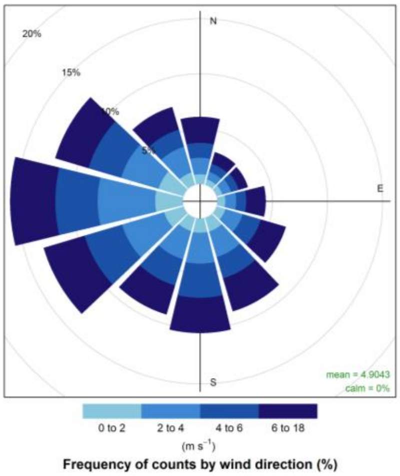

Fig.3 WIND ROSE FOR CORK AIRPORT (TMY3)

2. Building Information

2.1 Description

Due to the nature of retrofit in live buildings, solutions will have to be phased and as non- invasive as possible. A phased, modular, scalable, flexible, durable external retrofit with an intermediate internal retrofit is the most suitable design solution (coupled with a largely off-site build). The refurbished building, shown in Figure 4, which delivered a considerable reduction in energy consumption due to an energy efficient deep-retrofit solution, has functions as both a lecture room and office space is also the National Build Energy Retrofit Test-bed (NBERT) where data is gathered continually on internal and external conditions.

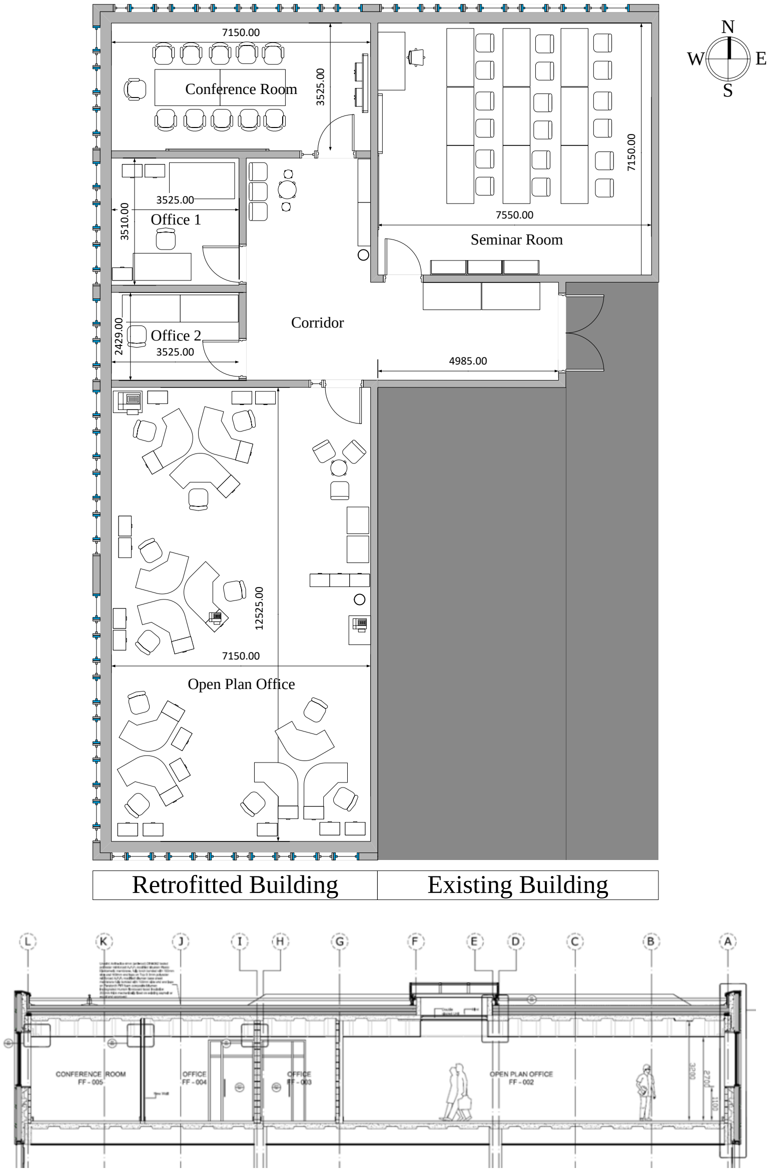

Fig 4. Top of image conveys floor plan of retrofitted building. Bottom of figure illustrates a section of the building.

Table.2 Building Properties

Property	Unit	Value
Occupant density	m^2/p	7
Hours of occupancy	h/week	50
Sensible Internal Load	(W/m^2)	29
Window U-value	W/m^2K	1.09
Window g-value	(-)	0.517
Wall U-value	W/m^2K	0.086
Roof U-value	W/m^2K	0.092
Floor U-value	W/m^2K	0.783
Q-value (from Japan)	$(W/m^2)/K$	0.075
Thermal Mass (ISO 13790)	-	Very Heavy
Window to Wall Ratio	%	66
Air-tightness (@50 Pa)	1/h	1.6
Shape Coefficient (1/m)	%	49

Table.3 Design influences

Parameter	Level of Influence
Initial Costs	⬤
Maintenance Costs	●
Energy costs	⬤
Solar Loads	⬤
Internal Loads	•
External Noise	•
Internal Noise Propagation	•
Air Pollution	•
Rain Ingress	●
Insect prevention	•
Burglary prevention	⬤
Privacy	●
Air Leakage	●

3. Energy Systems

3.1 Heating System

The heating system comprises a Dimplex air-to-water heat pump with a maximum heating power output of 28kW at a COP of 3.6 (10°C ambient air temperature & 35°C supply water temperature). This is located at roof level, Figure 5, which supplies low surface temperature radiators distributed throughout the building at a water temperature of around 35°C. The system is controlled on a common return water temperature with localised occupant control at zone level achieved using thermostatic radiator valves. The system is also operated on a time scheduled basis with different schedules depending on the academic calendar. Figure 6 shows that annually the energy consumption due to heating is less than the PassivHaus criteria for specific heating demand of 15kWh/m^2/a.

3.2 Internal Gains (Lighting and General Services)

NBERT has about 2.8kW of installed lighting or around 12.5W/m^2 in the building is made up of mostly fluorescent T5 fittings. The small power appliances in the building are typical for that of a mixed use educational building. The small power equipment power density typically 22W/m^2. The percentage of consumption varies monthly, general services and lighting can account for over 70% of the energy consumption in most months. With greater than 75kWh/m^2/a attributed to electrical energy consumption improvements could be made.

3.3 Electrical Power Supply (PV, wind turbine & Microgrid)

The NBERT microgrid is a photovoltaic, wind turbine and battery integrated power system connected to the Zero2020 building. The virtual smart grid comprises the national grid, NBERT building, NBERT microgrid and the CIT main campus building. The microgrid powers the Zero2020 building while also exporting energy to the national grid. The microgrid consists of:

- 24kWp PV System (static). (see Figure 7)
- 0.5kWp PV System (dynamic tracking).
- 2.5kWp Wind Turbine.
- 1350Ah Lead Acid Battery.
- Grid tie inverter.

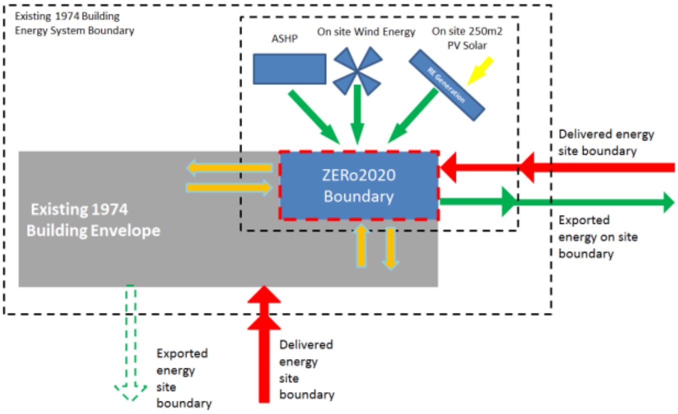

Fig.8 SCHEMATIC DESCRIPTION OF ZERO2020 TESTBED INFRASTRUCTURE

Fig. 5 AIR SOURCE HEAT PUMP ON ROOF OF ZERO2020 BUILDING

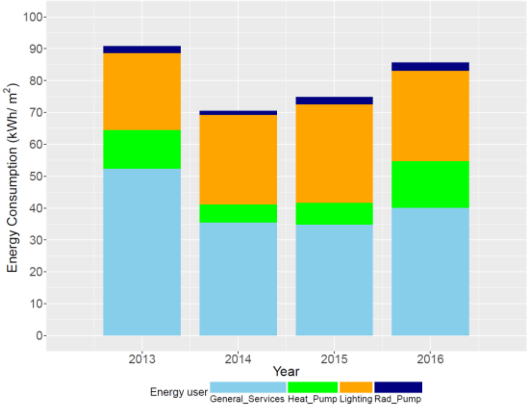

Fig. 6 OBSERVED ANNUAL ENERGY CONSUMPTION FOR NBERT BETWEEN 2013 AND 2016

Fig. 7 INSTALLED PV ARRAY ON ROOF OF EXISTING BUILDING

4. Ventilative Cooling

4.1 Principles

Single sided natural ventilation is the over-arching principle adopted due to the cellular nature of the existing internal layouts and constraints imposed regarding continued operation of the existing building. Large opening heights are employed to promote buoyancy forces in hot summer periods. Some instances of cross flow exist in the open plan office space when openings are activated on both south and west façades. Cooling is available during occupied hours through the activation of the openings. A combination of occupancy level manual openings and high level automated openings is available for increasing ventilative cooling (see Figure 8). Although there is reasonably consistent W-SW wind forces the system relies is predominantly buoyancy driven when operated in full height mode during the cooling season. A night cooling strategy is also available.

4.2 Components

The Multi Configuration Slotted Louvre (MCSL) ventilation solution for the retrofit consists of a flush faced external louvre system, (Figure 9). The insulated ventilation door is positioned inside of this louvre and is in the open position during operation. Each section comprises 17 air inlet slots with a porosity of 0.057%. The anodized aluminium slot louvre has a 47.5% net free open area for airflow and each louvre bank, comprised of two vertical louvre sections, has overall structural opening dimensions of 0.30m (w) x 1.60m (h) with a net opening area for each section of 0.102m^2. Table 4 contains component capacity dimensioning information. Figure 9 contain physical dimensioning data.

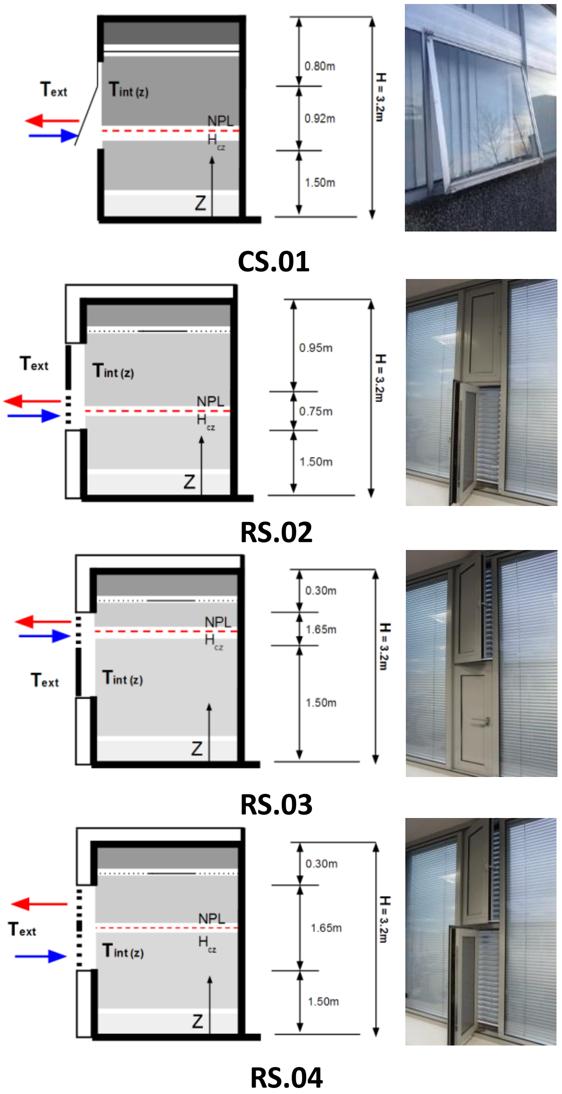

Fig. 9 SINGLE SIDED VENTILATION PRINCIPLE

Table. 4 COMPONENTS CAPACITY DIMENSIONING

Parameter	Value
Type (As per SOTAR)	Guiding
Free opening area	0.102m^2
Discharge Coefficient (Cd)	0.55 - 0.7
Overall Dimensions (1 louvre bank)	0.3m x 1.6m
Porosity (A_w/A_f)	0.057%
POF (Rs.02/3 / Rs.04)	2.1 / 3.6 %
Typical Q (RS.02/Rs.03/Rs.04) ACH	2/2/5

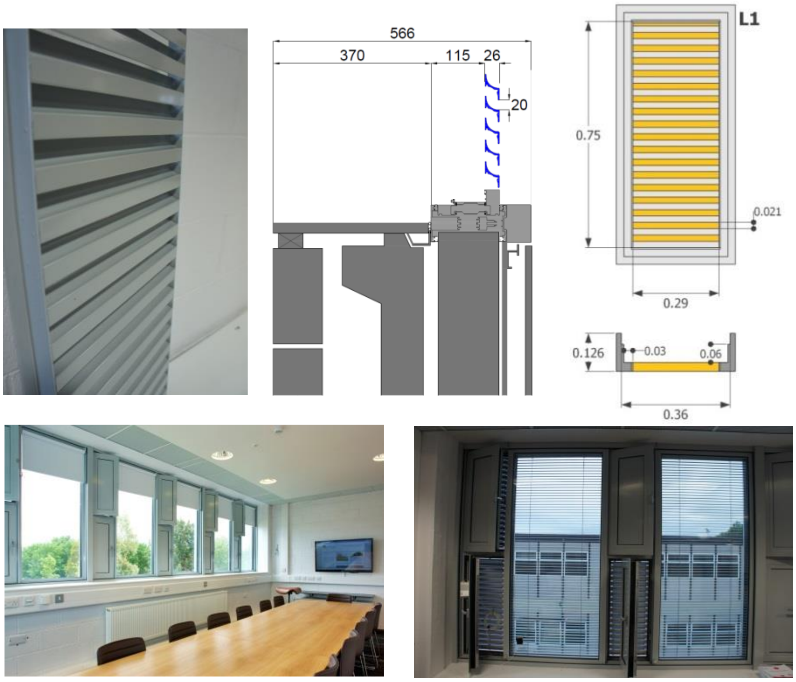

Fig. 10 SLOTTED LOUVRE VENTILATION COMPONENT

5. Control Strategy

5.1 Control Strategy Overview

The Control strategy for the ventilation system is largely based on the actuation of the high level automated insulated doors. The low level insulated ventilation doors are manually operated and there usage relies on the occupant perception of the internal environment. Figure 11 presents the control strategy flowchart. Table 5 below lists the controlling parameters.

Table. 5 CONTROL STRATEGY PARAMETERS

Parameter	Input/Output/Target	Value
Zone Temperature	Input	Variable
Zone Setpoint Temperature	Target	21°C
Night Cooling zone set point	Target	15°C
External Temperature	Input	Variable
External Temperature low limit	Target	10°C
Ventilation Door Position	Output	0% / 100%

5.2 Control Strategy Description

The high level automated ventilation louvres are activated based on internal zone temperatures. There are dedicated single zone temperature sensors for each room in building. When the following conditions are met then the high level insulated ventilation doors positions are driven to the fully open position. (The external louvres are permanently retained in place and have a static position):

- zone temperature above a certain value
- external temperatures above a certain value
- precipitation is below a certain value

Local override switches are available for manual control of the high level automated openings. These override switches control grouped banks of louvres as shown in Figure 12.

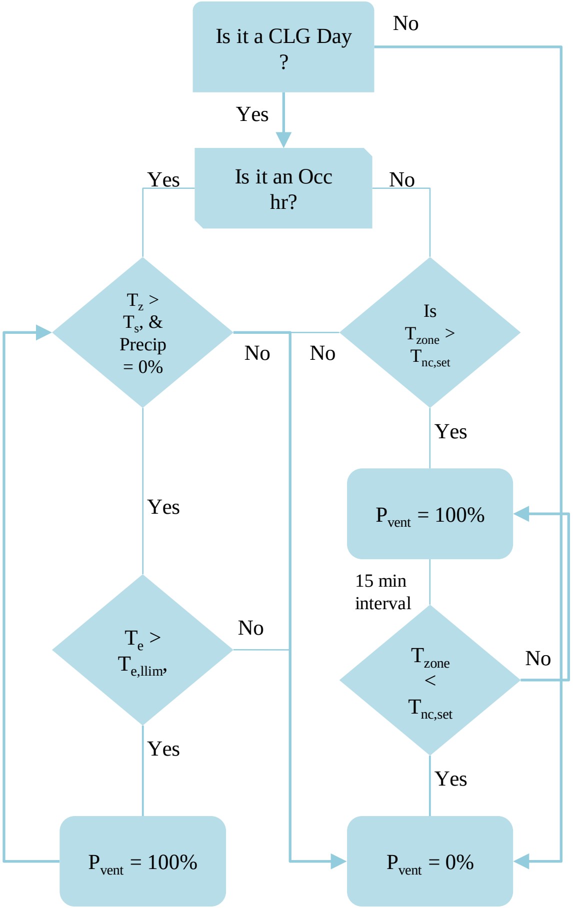

Fig. 11 AUTOMATED DOOR CONTROL FLOWCHART

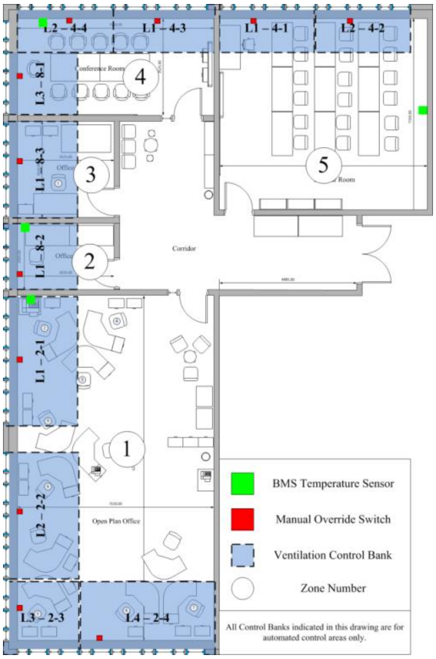

Fig. 12 AUTOMATED LOUVRE BANK CONTROL SECTIONS

6. Design Simulation

6.1 Summary

As part of the design scope various tools were at different stages to evaluate performance and assist in the specification of equipment and components. At detailed design stage a Whole Building Energy Simulation, (WBES), model was developed to investigate the risk of overheating for the building as well as specification of ventilation opening areas for each zone. The code and software was Apache/IES for thermal analysis and IES Macro Flo for airflow modelling. The simulation studies were conducted by Arup Engineers. Table 6 highlights what tools were utilised at each stage of the project while Table 7 summarises the target design performance criteria.

Table. 6 DESIGN STAGE SIMULATION SUMMARY

Stage	Tool	Function
Scope Development	Part L / CIBSE Guide A	Define Environmental Criteria
Concept Design	CIBSE Admittance	Initial Overheating Check
Detailed Design	IES Apache & Macro Flo	Thermal Analysis, Loads & ACR
Construction Design	Degree Day Study / PHPP	Energy Performance

6.2 Simulation of overheating risk

The simulated overheating risk indicated in Figure 14 using IES indicated that the highest level of overheating in the typical year would be in the in the seminar room. The total building level amount of hours greater than 25°C was calculated to be around 3% of the time annually. There were no hours in the typical year that was above 28°C.

6.3 Simulation of ACR

The simulated air changes rates indicated in Figure 15 in each zone due to infiltration was between 0.025 and 0.056. The highest simulated air change rates were seen in the Conference room which has the capability of using cross flow ventilation. Single sided office spaces like in Office 1 and Office 2 and the Seminar room the observed maximum air change rates were around 10.

Table. 7 DESIGN CRITERIA

Parameter	Value
T_e , Summer External Temp	26°C
T_z , Summer Operative Temp	25°C
Overheating criteria	T_z < 28°C for 99% hr_{occ}
Min IAQ air supply rate	10 ls^{-1} /pers
Cooling air supply rate	30 ls^{-1} /pers
Noise Level Rating (CIBSE)	NR30

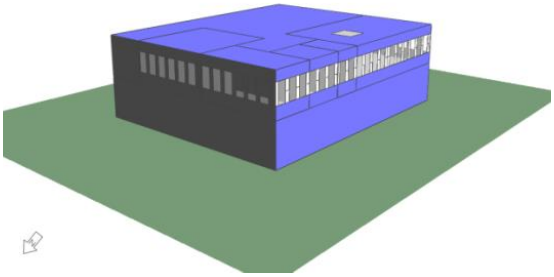

Fig. 13 DESIGN STAGE SIMULATION OF RETROFITTED BUILDING USING IES.

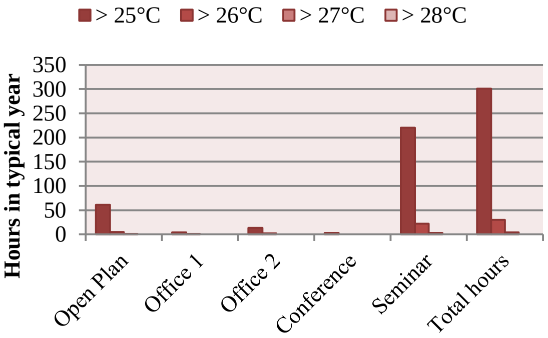

Fig. 14 DESIGN STAGE ESTIMATED HOURS OF OVERHEATING (AIR TEMPERATURE)

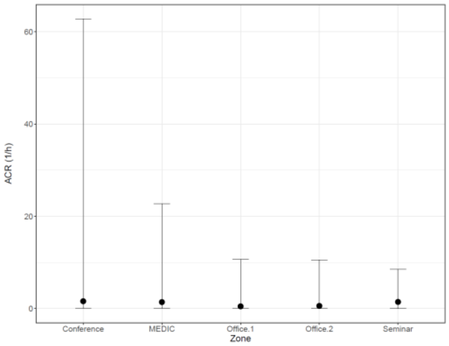

Fig. 15 ESTIMATED DESIGN STAGE AIR CHANGE RATES FOR EACH BUILDING ZONE

7. Performance Evaluation

7.1 Long-term performance evaluation

The cooling season occupancy levels in NBERT are in proportion to is small size. Following the academic calendar. During the cooling season (May to September) occupancy in the building is on average at 6 people during occupied hours (07:00 – 17:00). However, hours of occupancy can extend to the late evening towards the end of a typical week in cooling season. The building also has some typical weekend occupancy as a result of lectures.

NBERT operates typically in free running mode with infrequent use of its air source heat pump. By observing Figure 17 it can be seen that in Cork there is a lot of potential to naturally ventilate, with over 80% of the observed exponentially weighted external temperatures between 2013 and 2016 data between 5°C and 20°C. The general comfort performance of the building is good, when using the adaptive comfort standard EN 15251:2007, with 80-90% of occupied comfort recordings were in category III or higher. Generally, the percentage of occupied comfort recordings in category IV seldom exceeds 17%, as is shown in Figure 18. The majority of incidences in category IV were due to overcooling as opposed to overheating.

While annualised and average comfort conditions convey a situation where overcooling is more predominant, these averages are based on all zones. This could lead to some unoccupied zones skewing building level averages. If we take an isolated period in a cooling season in Figure 19 we can see that at room level overheating exists. However, when Table 8 is examined it seems that from a long-term perspective overheating is not an issue in the building.

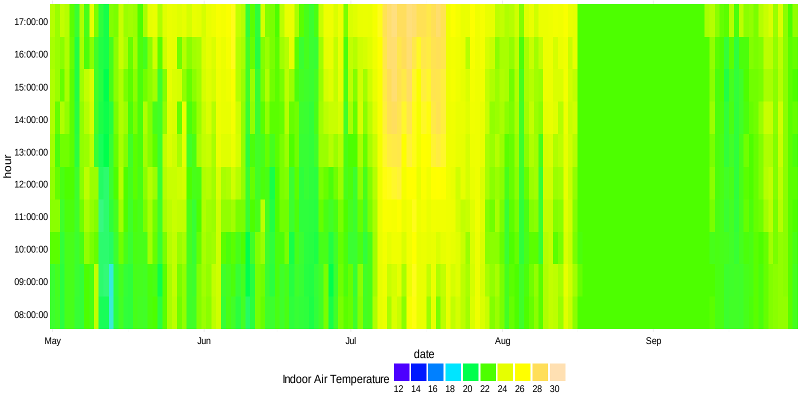

Fig. 19 Indoor air temperature heatmap Room b294 May – September 2013

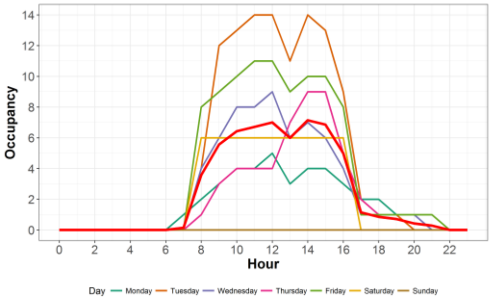

Fig. 16 Mean daily cooling season occupancy mean indicated in red

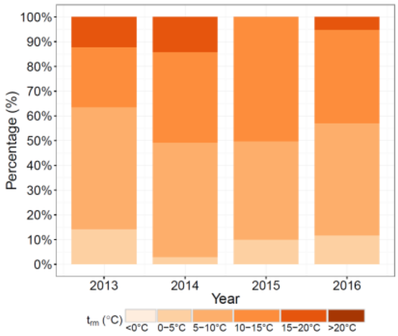

Fig.17 Percentage of exponentially weighted mean external temperatures for Cork Airport from 2013 to 2016

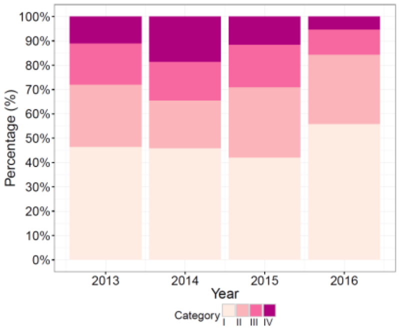

Fig.18 Long-term thermal comfort performance of NBERT

Table 8 Summary of CIBSE overheating criteria in NBERT during 2013

Room	CR1	CR2	CR3	h*
Seminar Room	0	0	0	0.0000
Conference Room	0.6	0	0	0.0050
Office 1	0.2	1	2	0.0020
Office 2	0	0	0	0.0006
Open Plan Office	1.05	0	0	0.9800

7.2 Ventilation Rates

Air Change rates (ACR) were measured at the building using a tracer gas concentration decay test method during two periods; July 2013 and August 2014. In July 2013 38 TGC decay tests were completed in total. Tests were completed in accordance with the procedures set out in ASTM E741-11. CO_2 concentration analysers were AlphaSense IRCA1 Non Dispersive Infra-Red (NDIR) Sensors. CO_2 sampling frequency was 0.1Hz. For further details see (O'Sullivan and Kolokotroni, 2014). Figure 20 presents distribution of ACR values obtained from measurements, while Table 9 presents summary performance data for eac MCSL configuration. In August 2014 measurements specifically investigated ACR through 1 low level louvre section with the insulated door removed in order to compare the performance of the louvre component with a simple opening aperture. 44 measurements were taken using a range of different opening dimensions. Table 10 presents efficiency coefficients for wind driven ventilation based on measured volumetric flowrates normalised using the free opening area and reference wind speed at 6.0m above roof level during measurements.

Table 9 SUMMARY STATISTICS FOR ACR MEASUREMENTS OF MCSL SYSTEM

Config	Max ACR	Min ACR	SD ACR	Ave ACR	Wind Speed	Wind /Lee	Temp Diff
CS.01	6.4	1.9	1.5	4.2	1.4 – 5.2	9/4	4.2 – 8.9
RS.02	5.8	2.3	1.0	3.8	1.4 – 5.2	7/6	0.5 – 5.5
RS.03	5.1	1.5	1.3	3.1	3.3 – 4.2	4/2	1.1 – 5.3
RS.04	3.8	1.4	0.9	2.3	1.5 – 4.5	4/2	0.4 – 7.1

7.3 ACR Driving Forces through the MCSL system

Different driving forces for airflow rates are present depending on which opening configuration is selected. The full height configuration RS.04 is buoyancy dominant while RS.02 is wind dominant. RS.03 is less well defined, likely due to its location relative to the room floor level. When openings are dominated by different driving forces this can have implications for correctly predicting the airflow rates and when a particular opening should be used as part of a control strategy.

Table 10 NORMALISED VOLUMETRIC FLOWRATES

Type	All Wind Direction	Windward Direction	Leeward Direction
Slot Louvre	0.067	0.073	0.043
Plain Opening	0.039	0.040	0.036

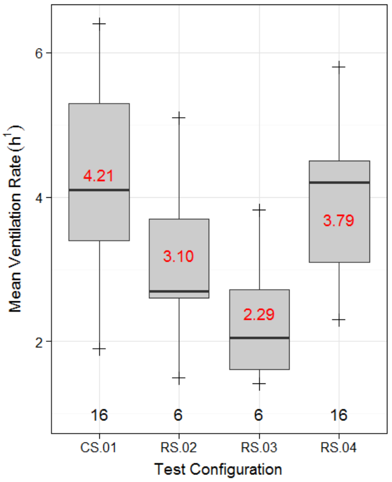

Fig. 20 ACR MEASURED IN RETROFIT AND EXISTING BUILDING DURING SUMMER 2013

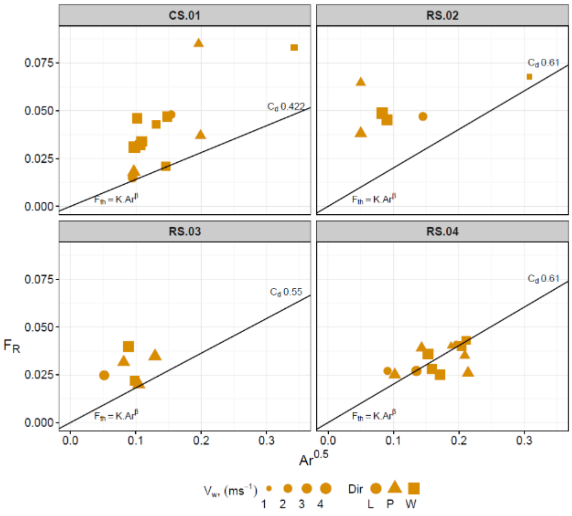

Fig. 21 ARCHIMEDES NUMBER VS FLOW NUMBER

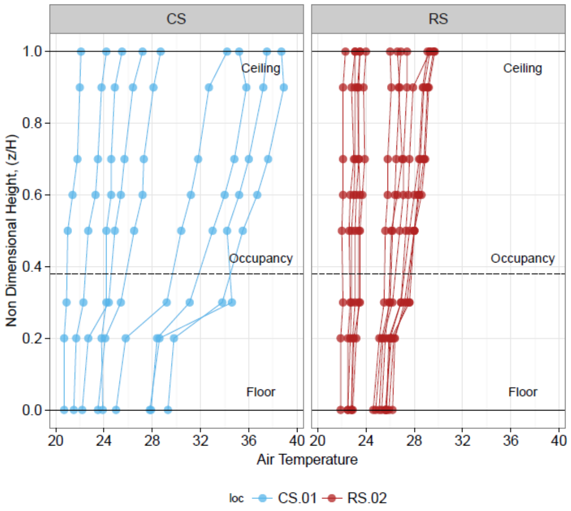

Fig. 22 STRATIFICATION IN EXISTING & RETROFIT BLDG

7.4 Internal Thermal Stratification

The internal thermal stratification was measured during various ACR tests in 2013. All data was obtained during a particularly warm period with external temperatures reaching 10 year highs. Vertical temperature distribution under free cooling from outdoor air has been substantially modified following the retrofit works. In the retrofit space temperatures at the surface of the exposed roof slab are often 2-3°C higher than would be reported based on a mid-level zone thermostat which can be significant when designing systems for ventilate cooling of a low energy space.

7.5 Occupants thermal comfort for MCSL

The thermal comfort performance of the buildings slotted louvre ventilation system in response to overheating scenarios was assessed in a field study in May of 2015. In total the study evaluated the thermal perception of 35 participants a sample of participants are seen in Figure 23. The exponentially weighted mean external air temperature over the course of the study was 12°C. Four ventilation configurations, the buildings 3 main configurations were investigated with one extra control configuration (No Ventilation, RS-01). Subjectively, the configurations with smaller opening areas (RS-02 and RS-03) provided satisfactory levels of categorical comfort when compared to the standards utilised as in shown in Table 11. RS-02 and RS-03 did observe categorical differences in two of the three standards presented, which may suggest that a difference in comfort exists between openings of the same area but at different heights. The full height opening (RS-04) was seen to have the potential to overcool the control space, as a result of the high temperature differences observed between the internal and external environment during the study.

The results suggest that ASHRAE 55 predicts the categorical levels of discomfort accurately for overheating scenarios (RS-01) and for small louvre openings (RS-02 and RS-03). While EN 15251 and ISO 7730 underestimate the levels of discomfort experienced for all the configurations investigated. The failure for any standard investigated to predict the categorical levels of discomfort experienced in RS-04 could be due to the negative temperature ramps observed when using that configuration to resolve overheating as shown in Figure 24. However it is also possible that a negative subjective association may be present with larger openings in comparison to smaller openings aside from the negative temperature ramps observed, that may have led to the magnitude of the negative MTSV. Another possible reason for the difference between actual and predicted results could be due to the index or model used in predicting categorical comfort in all standards.

Fig. 23 Image of field study conducted on the 28-29th of May 2015

Table. 11 Subjective performance of each configuration assessed with respect to existing standards

Config.	MTSV	ISO 7730	EN 15251	ASHRAE 55
RS-01	1.3	-	IV	Unacceptable
RS-02	-0.5	C	III	Acceptable
RS-03	-0.4	B	II	Acceptable
RS-04	-1.1	-	IV	Unacceptable

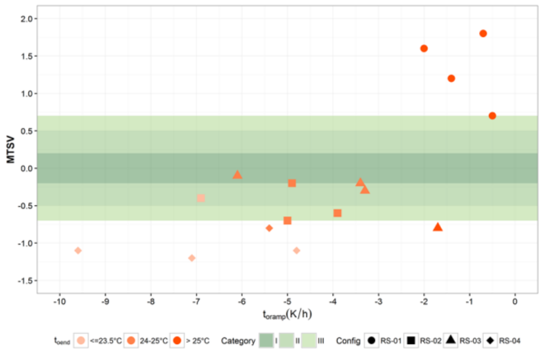

Fig. 24 Scatterplot of relationship between MTSV and operative temperature ramp from the start to the finish of a test.

8. Lessons Learned

8.1 Summary

The MCSL system has demonstrated good performance under a range of weather conditions and building usage. The system was a bespoke, factory built modular solution and its easily scalable nature means it has potential for use in other larger projects. The VC using single sided ventilation provided an acceptable internal thermal environment although instances of overcooling during shoulder seasons is possible and care must be taken when using automated control of openings during these periods. The solution is simple in its implementation and has proven to be effective with the combined manual and automated approach for the openings. The brochure contains summary information from over 4 years of research at NBERT relating to the VC solution. It is strongly recommended that the reader explore all publications listed in the references section 9.1 for a better understanding of the results and outcomes presented herein. The reader is also invited to explore further the data and the building at http://www.nbert.xyz.

8.2 Detailed list of lessons learned

Table. 12 KEY LESSONS LEARNED **DESIGN AND CONSTRUCTION**

Item	Lesson	Importance
1	The architectural input to the envelope design is a key factor when developing the VC strategy. The design requires close collaboration between engineers and architects to avoid poor performance or retrospective	H
2	Simulation of bespoke ventilation components can be difficult to undertake. Often designers will use standard approaches to investigate performance given their fee structure. Clients need to invest in proper assessment of bespoke solutions before proceeding with the construction	H
3	Commissioning of systems and performance evaluation for each season (soft landing) is critical	H
4	Confirmation from the client in writing that they understand and accept that free-running buildings have thermal comfort assessment based on not exceeding temperature thresholds for stated % hours as opposed to maintaining a set point continuously is important	M
5	Designers and contractors should be able to demonstrate delivering ventilative cooling designs based on post occupancy performance monitoring of buildings they have previously completed.	M

Table. 13 KEY LESSONS LEARNED **OPERATION / POST OCCUPANCY**

Item	Lesson	Importance
1	Consideration should be given to the number of openings in each room. A high amount of openings may result in many not being activated by the occupants	M
2	Allowance should be made for fine tuning and tweaking of the control strategy for the VC system. It can take considerable time to establish an effective strategy with variable values and parameter settings	M
3	The effectiveness of occupant manually operated louvres to control ventilative cooling reduces over time (months). Occupants take less responsibility for maintaining indoor climatic conditions and engage less with the building use.	H
4	Data collection and internal environmental monitoring is only justified if there is a budget to: (a) to maintain the system (b) to analyse and report on the data collected	M

9. References & Key Contacts

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9.1 Key Contacts

Table. 14 KEY PROJECT CONTACTS

Company	Role	Contact
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