Single-sided ventilative cooling performance in a low energy retrofit

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Externally applied building envelope retrofit measures intent on upgrading thermophysical properties and air tightness performance can result in substantially modified cooling and ventilation requirements for a given internal space. Field studies presenting demonstrated performance of such situations are still relatively infrequent. The article presents findings from a case study retrofit project (zero2020 testbed) at Cork Institute of Technology in Ireland. Measured performance of an externally applied fenestration module incorporating purposed provided ventilation openings is presented and discussed. Findings show that, depending on configuration, acceptable ventilations rates and internal thermal environments are possible using a single sided ventilative cooling strategy.

Keywords: retrofit, single sided ventilation, purpose provided openings, thermal comfort, zero2020 testbed.

Introduction

Ventilative cooling coupled with exposed thermal mass is widely accepted as an important strategy for reducing summer overheating in non-domestic buildings. Extended monitoring has shown that naturally ventilated buildings typically use less than 50% of the corresponding energy consumption of air conditioned buildings and assessment of ventilative cooling techniques in Europe have shown they may contribute highly to reducing the cooling needs of buildings (Kolokotroni et al, 2008) and be an effective tool for tackling climate change adaptation in existing buildings. Furthermore, increased ventilation rates can also lead to improved work performance. Recently, focus for market activation in the construction sector has shifted towards dealing with the overhaul of the existing building stock. The Irish National Energy Efficiency Action Plan 2013–2020 report has identified refurbishment of existing public sector buildings as a key focus. The report states that there are over 10,000 existing public sector buildings in Ireland. In responding to these external drivers Cork Institute of Technology in Ireland (CIT) have recently completed a pilot project/research testbed, zero2020, for the low energy retrofit of their existing 29,000 m² teaching building constructed in 1974. The retrofit pilot project covered 1.5% of the total building floor area and is shown in **Figure 1**. At both concept and design stage there were no guidelines within the Irish context upon which to base performance targets to achieve a near zero energy building (NZEB) through retrofit.

The design proceeded along a simple strategy of firstly, ensuring compliance with the environmental specification for occupant comfort and secondly to achieve the best fabric and energy performance subject to constraints imposed by budgets and retrofit/structural limitations. The final solution consisted of design and installation of a structurally independent external envelope solution. This resulted in U-values for opaque element 3 times better than current regulations and glazing U-values 6 times better. Further details of the design and specification of the retrofit solution can be found in (O'Sullivan et al. 2013). The objective of this article is to present measured performance of the retrofitted single sided natural ventilation system that utilises a purpose provided slot louvered opening (see **Figure 2**). Ventilation rate performance along with objective and subjective thermal comfort performance of the retrofit building have been experimentally investigated.

Purpose provided ventilative cooling components

For most enclosed spaces in the existing building (left of **Figure 1**) the ventilation system is based on single sided top hung pivoting window sections. There is generally one opening window per structural grid. In the retrofit space fenestration system, the ventilation module uses a flush faced external louvre with individual air inlet sections with 2 ventilation sections per structural grid. On the internal side of the slot louvres there are automated high level insulated doors and manual low level insulated doors providing different control mechanisms. The installed slot louvre system has a net 50% free open area for airflow and overall structural opening dimensions are 0.30 m (w) x 1.60 m (h) with a net opening area of 0.102 m² (e.g. in a single cellular office space there are 2 openings at low level and 2 openings at high level in the test space). Each of the ventilation openings has 17 airflow slots across

Figure 1. External facades; existing 1974 building (left) and retrofitted zero2020 test-bed building (right) where red indicates the location of the thermal comfort study and yellow indicates the location of the ventilation rate performance experiments.

Figure 2. Ventilation system configurations, from left to right: existing building window (CS.01), Retrofit space no ventilation scenario (RS.01), bottom manual louvre only (RS.02), top automated louvre only (RS.03), both louvres opened (RS.04).

the louvre bank. The overall thermal transmittance performance of this unit including doors and linear transmittance is 0.84 W/m²k. The new fenestration module resulted in an overall opaque/transparent area ratio reduction of 20%. Unwanted ventilation through adventitious openings has also been greatly reduced. The retrofit envelope air permeability was tested in accordance with BS EN 13829:2001. The envelope achieved an air permeability of 1.76 (m³/hr)/m² at 50Pa building pressure. The existing structure was measured as 14.77 (m³/hr)/m². In order to quantify the actual range of ventilation rates achievable 38 tracer gas concentration decay tests were completed as part of an experimental field study during summer 2013. The results are summarised in the following section.

Ventilation & thermal performance in cooling mode

To investigate ventilation performance in cooling mode in the retrofitted space an isolated, 6.0 m² west facing, first floor cellular office (highlighted in yellow in **Figure 1**) employing single sided ventilation was used to measure ventilation rates under various boundary conditions. A similar space in the existing building was used for comparative purposes. The field tests were completed in accordance with the procedures set out in ASTM E741-11. Details can be found in (O'Sullivan et al. 2014). All ventilation rate values presented have been calculated using the decay regression technique. **Figure 3** presents boxplot distributions of results from all tracer gas tests completed under each of the different operating configurations in **Figure 2**.

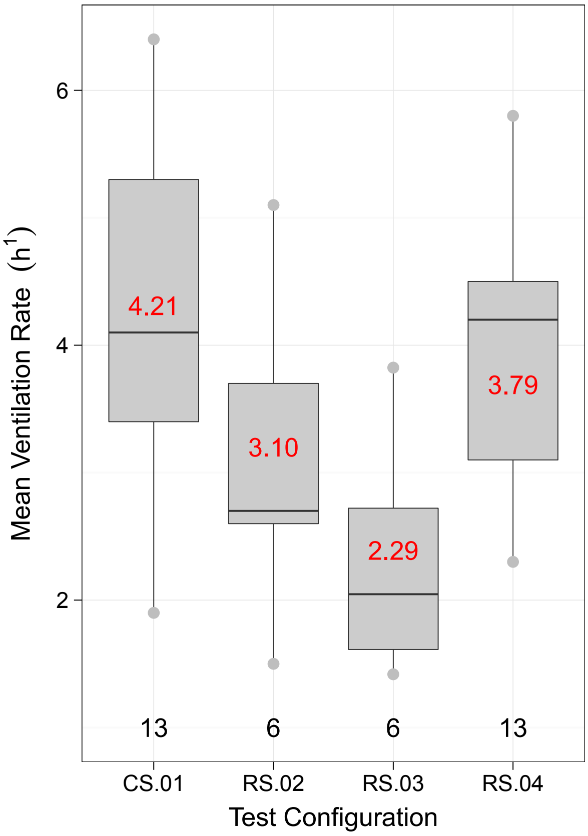

Figure 3. Boxplot distributions of measured mean ventilation rates grouped according to configurations in Figure 2 above (no of tests shown for each, mean ACH shown in red, median shown as bar).

The results show that for a similar spread of boundary conditions the existing control space (top hung window, CS.01) has consistently higher time-averaged ventilation rates with a mean value of 4.2 h^{-1} and standard deviation of 1.5 h^{-1}. In the retrofit space the full height configuration had the best performance profile with a mean value of 3.8 h^{-1} and standard deviation of 1.0 h^{-1} indicating a slightly more concentrated spread of results. Based on the guideline values for indoor air quality classification in BS EN 13779:2007 both the existing control space and retrofit space time averaged ventilation rates can be classified as IDA1 (High). Ventilation rate values were on average lower for the low level RS.02 & high level RS.03 configurations although there were individual instances of values above 5.0 h^{-1}.

As well as ventilation rate performance the potential risk to overheating was also evaluated for each ventilation configuration. Indoor air temperature is often used as an index for evaluating long term risk of overheating in buildings. The extent of exceedance of acceptable conditions is often based on the percentage of annual occupancy hours with indoor air temperatures above a reference exposure threshold value compared to a maximum acceptable percentage exceedance (i.e. 5% of hours above 25 °C for CIBSE, 1% above 28 °C for BRE). To investigate long term performance of the ventilative cooling system, indoor air temperatures were recorded in the single cell retrofit office (highlighted in yellow in **Figure 1**) during an extended period of warm summer conditions (May to October 2013). A range of different configurations were employed in the office during this time. **Figure 4** presents monthly binned percentage of hours' exposure for different reference threshold value. There was some overheating present during July, even with some night cooling in place but in general conditions were acceptable according to the criteria proposed. It should be noted that the percentage will reduce when the full annual hours are factored in.

Thermal comfort perception

In order to evaluate the thermal perception potential of the thermally decoupled low energy space and ventilative cooling system a subjective thermal comfort study was designed and carried out in May 2015 (O'Donovan et al, 2015). The study evaluated all four of the retrofitted ventilation configurations shown in **Figure 2**. The study gathered feedback from 35 participants (10 females, 25 males) as to thermal environment during controlled tests in the open plan seminar room of the building. This is a 42 m² first floor, north facing room employing single sided ventilation (see red in **Figure 1**). Participant feedback on perceived thermal state during the four tests was gathered using two standardised questionnaires based on ISO 10551.

Objective continuous environmental data was also gathered in order to calculate predicted response of participants for each test using the Predicted Mean Vote (PMV) index. **Table 1** indicates the ISO 7730 categories used in this comparison where the values presented are for cooling season performance only. The study was designed to evaluate the capabilities of all ventilation configurations to provide thermal comfort in a simulated overheating scenario, where before each test the seminar room was preheated to 26°C (±1°C).

Figure 5 presents predicted (objective) and subjective frequency of thermal vote for each configuration. Configurations RS.02 (high level only) and RS.03 (low level only) experienced the largest percentage of neutral responses (40%, 43%) with mean thermal sensation votes of –0.40 and –0.49 respectively (Category B). The full height opening configuration (RS.04) had a mean vote of -1.06 putting it outside all ISO7730 thermal environment categories. Subjectively no configuration tested achieved Category A (see **Table 1**).

Table 1. Categories of a thermal environment.

Category	PMV	t_o (°C)
A	-0.2 < PMV < +0.2	24.5 ± 1
B	-0.5 < PMV < +0.5	24.5 ± 1.5
C	-0.7 < PMV < +0.7	24.5 ± 2.5

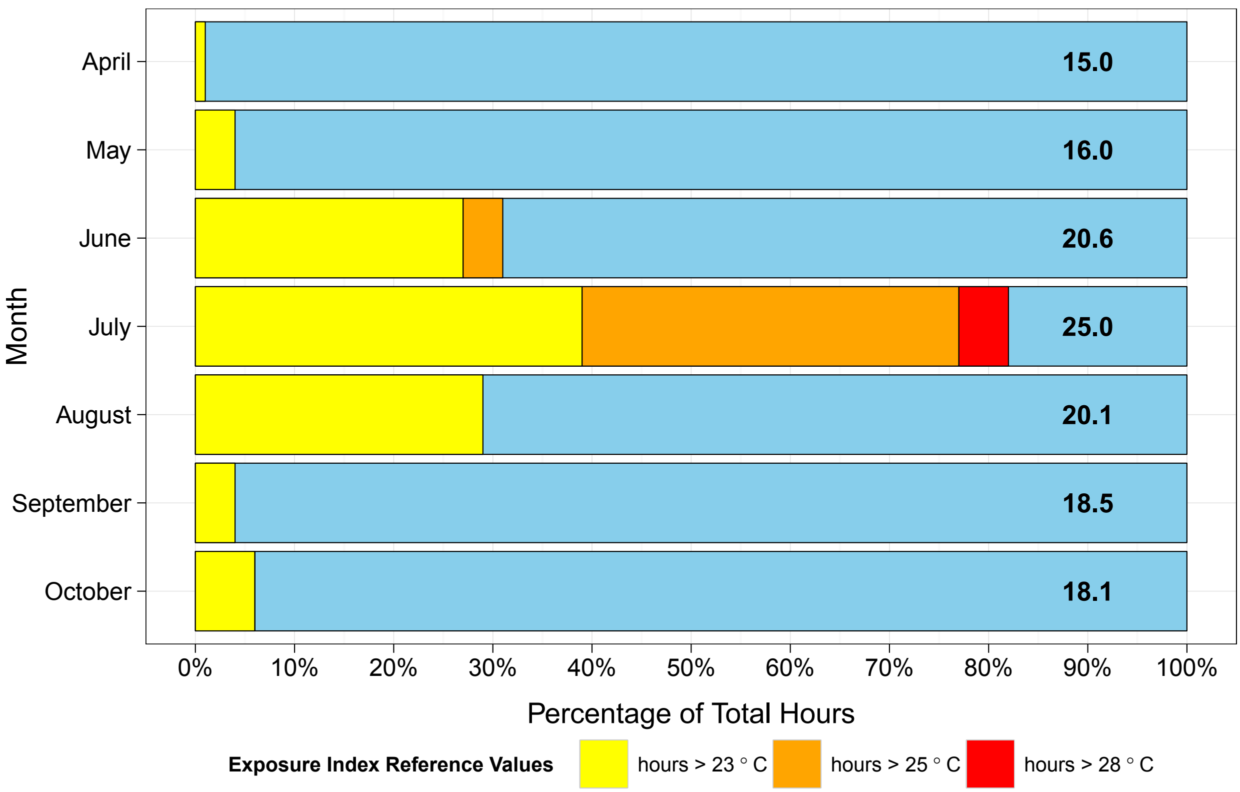

Figure 4. Percentage time exceedance of long term index reference values during extended cooling period in 2013 (Monthly 95th percentile T_{ex} values shown in each month).

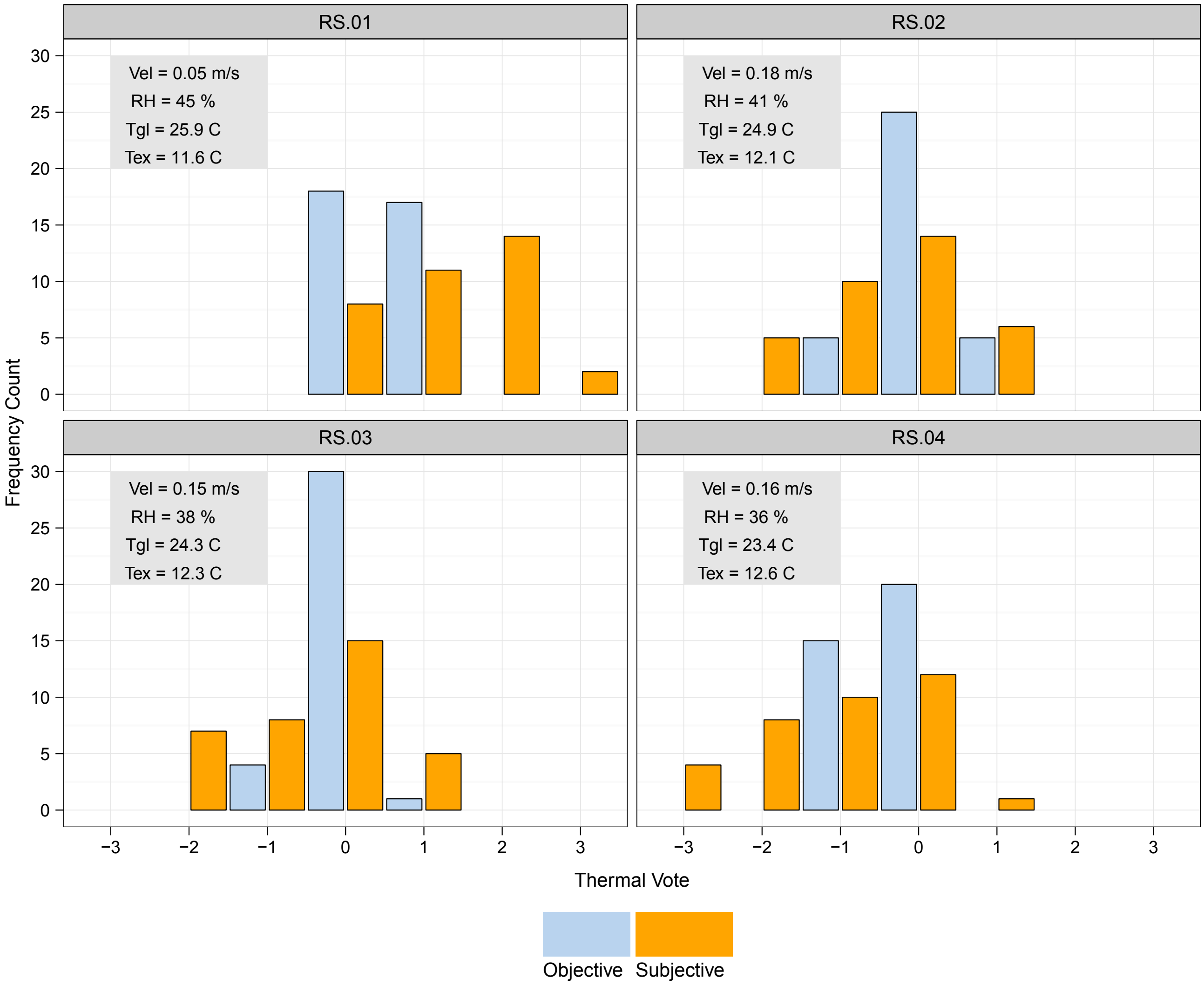

Figure 5. Results thermal comfort study showing objective and subjective thermal sensation votes for retrofitted space ventilation configurations shown in Figure 2 (Vel = Indoor air velocity, Tgl = Indoor Globe Temperature, Text = External Air Temperature, RH = Relative Humidity).

Conclusion

Overall good ventilation rates were achievable in the retrofit space with the new purpose provided slot louvred openings operated using a single sided ventilation strategy. Although there was a reduced envelope temperature difference due to the improved thermal performance of the building resulting in weaker buoyancy forces compared with the existing building the large opening height of the RS4.0 configuration seemed to ensure comparable performance. The thermal comfort study suggests that using high level only openings or low level only openings provided the most satisfactory thermal environments. It is therefore possible to achieve effective ventilative cooling using certain configurations but care must be taken when low external air temperatures are present using large openings that provide air flow directly to the occupied zone resulting in potential overcooling and local thermal discomfort. ■

References

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