# Natural Ventilation, Mechanical Ventilation and Heat Recovery in Non-Domestic Passivhaus Building in the UK Climate Context

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**Abstract:** This study has used validated CFD model by field measurements to assess ventilation performance in high internal heat gains low ceiling auditorium. CFD predicted spatial temperature was compared to three thermal comfort standards. The CFD results show that, for 84W/m$^2$ and 124W/m$^2$ of internal heat gains, MV provides thermally comfortable environment at outdoor temperature range of 17°C – 26°C to 14°C – 26°C , and NV provides it at outdoor temperature range of 20°C – 29°C to 17°C – 29°C. When NV and MV exposes to same outdoor temperature, NV provides less possibility of local thermal discomfort due to reduced temperature stratification compared to MV. Moreover, for NV to work effectively, all openings within and at the perimeter of the domain should have adjustable effective areas. It was concluded that NV extends summer ventilation operating temperature range up to 6°C, whilst MVHR extends it 8°C in winter. However, neither MVHR nor NV is sufficient to provide thermally acceptable indoor environment alone or combined. Thus, a mixed mode approach is necessary.

*Keywords: CFD, Non-Domestic Passivhaus Building in the UK, Ventilation, Thermal Comfort, Building Modelling*

## 1. Introduction

Anthropogenic climate change (cuased by humans) is now widely accepted and thus many countries have taken measures to reduce GHG from buildings (McLeod et al., (2012); Feist et al., (2005); Liu and Linden (2006)). Two promising concepts, Passivhaus and natural ventilation (NV) are emerging to combat these effects.

Recent studies (Wang et al., (2017), Phan et al., (2008), Perez and Østergaard (2014)) in the domestic building sector showed that MVHR is not the best solution for Passivhaus buildings in milder climates, such as the UK for energy efficiency. Therefore, NV stands as a strong candidate to replace MVHR in non-domestic Passivhaus buildings for mild and warm climates. On the other hand, Lambea et al. (2016), emphasise that, heating and cooling demand restrictions of the Passivhaus standard make MVHR mandatory other than few warm climates such as South of Spain and hotter parts of the USA

The literature showed that many studies concentrated on the usage of NV and MVHR in domestic Passivhaus buildings, however, there is lacking research in the non-domestic Passivhaus buildings context, especially in the UK. Non-domestic buildings have a long-life cycle expectancy and are usually large energy consumers. Moreover, it is often challenging and expensive to retrofit ventilation systems into those buildings. Given this, it is crucial to have a robust understanding of how NV could be applied to non-domestic Passivhaus buildings at the design stage.

## 2. Methods

The spatial temperature distribution of the auditorium was predicted by using CFD (PHOENICS) and validated by field measurements. Different occupancy densities, fresh air supply rates for MV and opening sizes and positions for NV were simulated to understand the limitations of both MV and NV. Finally, the outdoor temperatures of the UK were analysed so that comparison between the two could be possible.

## 2.1. The Case Study Building

The case study building was the Medical School Building of Leicester University (see Fig. 1). It was unique at the time of this study, for being the largest non-domestic Passivhaus Building in the UK. The auditorium space was chosen (see Fig. 2) for modelling due to its low ceiling and high internal heat gains conditions proved to be challenging for ventilation design.

Fig. 1. Medical School Building

Fig. 2. Auditorium of Medical School Building

## 2.2. Field Measurements

The indoor spatial temperature of the auditorium was monitored for three days in this study. Twenty-seven HOBO™ temperature loggers were installed at various positions within the domain (see Fig. 3). Loggers had 0.5°C accuracy, but all twenty-seven loggers had been checked for calibration by using a temperature controlled water bath. The fresh air supply rate and its temperature was gathered from the building management system (BMS). However, it was not available for each inlet, thus, total fresh air supply rate was divided into a number of inlets as a way of simplification.

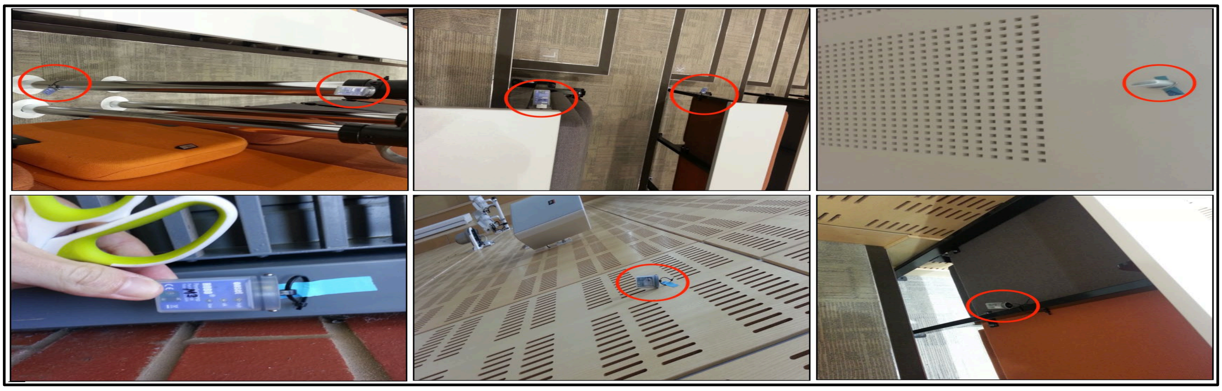

Fig. 3. Layout of HOBO temperature loggers

## 2.3. CFD Modelling

The modelled domain space was 16.8m at X, 14.5m at Y and 8.15m at Z-directions. Since the building was a Passivhaus certified building, all walls were modelled as adiabatic plates. For CFD model validation, realistic boundary conditions from the field were used. In validation simulation, the occupancy was 220 people; MV fresh air flow rate was 25.9l/s per person and extraction was 3.89m3/s. The total internal heat gains for the 220-people occupancy scenario was 84W/m2 of total floor area.

The mesh independence study was performed by generating three meshes with different densities. Main outlet flow rate was monitored for each simulation run and mesh independency proved.

In this study, the standard 2-equation, the k - ε turbulence moded has been used. Launder and Spalding (1974) suggested that, given the computational economy and a broad range of applicability, the k - ε model represents the physical realm best. However, for NV

CFD modelling, the k - ε model failed to achieve a converged solution in PHOENICS, thus the LVEL model was preferred. The LVEL model has been proven to yield similar results to the k - ε model. It is computationally less demanding and can be applied to two and three dimensional problems (Cham.co.uk, n.d.).

### 2.4. Thermal Comfort Performance Indices

Three thermal comfort performance standards were used to assess the performance of NV and MV. ASHRAE standard 55 (2010) (criterion 1), Building Bulletin 101(2006) (criterion 2) and CIBSE Guide A (2016) (criterion 3). If the predicted spatial domain temperatures of CFD comply with the standards, then ventilation case would be considered as a “pass”, otherwise “fail”. The local thermal discomfort possibility would also be considered by examining the temperature gradient from ankles to head level (required to be within 3 $^oC$).

## 3. CFD and the UK Climate Analysis Results

In the domain, inlets were at low level (under-seat) whilst outlets were at high level (above the suspended ceiling). This yielded the overall flow pattern of fresh air coming into the domain from low level inlets and driven by buoyancy due to internal heat gains and eventually leaving the domain from high level outlets. Therefore, incoming air provides required fresh air into the domain and removes the excessive heat from occupied zone.

When the CFD predicted spatial domain temperatures were compared to field measurement results, it was concluded that the CFD model was validated (see Fig. 4). Moreover, the discrepancy between predicted and measured results could be explained by uncertainties.

It could be noted that measured values tend to be slightly higher than calculated values. One of the reasons for this could be explained as radiative heat exchange between sensors and surrounding heat sources. However, in the CFD model, only the convective part of the heat exchange had been solved. Furthermore, it could be noted that human errors in geometry measurements also played a critical role that could lead to uncertainty. These errors resulted in an inconsistency in geometry on site, on plans (which was the main source for modelling geometry) and in the model. All geometrical imperfections like this, rounding up the values while performing site geometrical measurements and modelling simplifications caused every object that was modelled to not reflecting 100% reality. As a result, this yielded approximate positions for inlets, outlets, sensors, and other objects which would affect the spatial temperature distribution.

Moreover, simplifications and assumptions relating to boundary conditions such as, aligning inlet and outlet positions, unknown occupancy distribution, dividing total supply air flow rate to the number of inlets, considering the spply air temperature would be the same at the air handling unit and inlets, unknown pressure loss coefficient of perforated ceiling, expected to contribute most to the overall uncertainty compared to other simplifications such as steps and row alignments. Last but not least, the CFD simulation tool has a degree of uncertainity because of computer round-off, iterative convergence, and discretization errors Hajdukiewicz et al., (2013), Grc.nasa.gov, (2008)).

In order to resolve which ventilation system is more suitable throughout different times of the year from a thermal comfort point of view, the UK climate had to be analysed for both 8 and 24 hours operation schedules. From Energy Plus database, five regions: London (Gatwick Airport), Birmingham Airport, Sheffield (Finningley), Edinburgh (Leuchars), and

Aberdeen (Dyce Airport) were selected. Furthermore, data was sorted according to temperature bands and cold temeprature extreme range trimmed by 3% occupied hours.

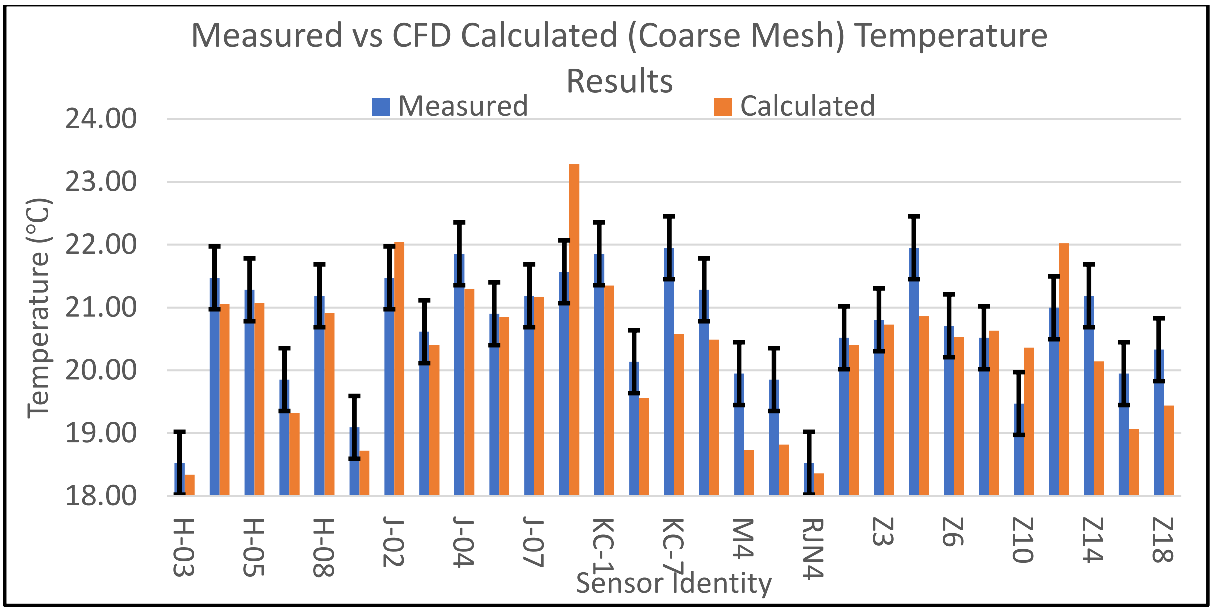


Fig. 4. Measured against CFD Predicted (Coarse Mesh) Spot Temperature Values

## 4. Discussion and Limitations

During the monitoring period, it was observed that during one of the lectures, the auditorium heated and cooled at the same time. This resulted in unstable internal temperatures and energy waste. This case showed that for such buildings, an automation had to be set-up and commissioned carefully.

This study concludes that the NV provides better indoor thermal climate compared to MV when they are both exposed to the same outdoor temperatures, due to the lack of temperature gradient from ankles to head level. This was because of the increased ventilation rates of NV and the capability of buoyancy driven air to remove more internal heat from the domain, hence less temperature stratification within the domain.

This study agrees with Perez and Østergaard, (2014) that the Passivhaus is prone to overheating. This was more notable with MV and NV extended summer operating temperature ranges. However, this study agrees with Lambea et al., (2016) and shows that MV with HR is necessary for the UK winter climate conditions even for high internal heat gains non-domestic Passivhaus buildings.

This study also agrees with Maryanczyk et al., (2014) by concluding that, MV is not able to provide enough air flow rate for summer cooling, unlike NV. This study also reveals that not only the flow rates but means of delivering it by adjusting opening sizes and position helped to extend operating boundaries of NV.

When the CFD results in Table 1 were compared to the UK climate analysis results, it could be concluded that neither MV nor NV are sufficient alone to provide a thermally comfortable environment for non-domestic Passivhaus buildings in the UK climate (See Fig 5). Furthermore, it was clear that a mixed-mode approach was necessary for high internal gains, low ceiling non-domestic Passivhaus space and the UK climate context.

Like many research, this research was not without limitations either. The assumptions which were made regarding boundary conditions negatively affected the accuracy of the model. The spatial occupancy distribution, the exact size and location of the outlet(s) for MV and flow rates for each inlet were also not known.

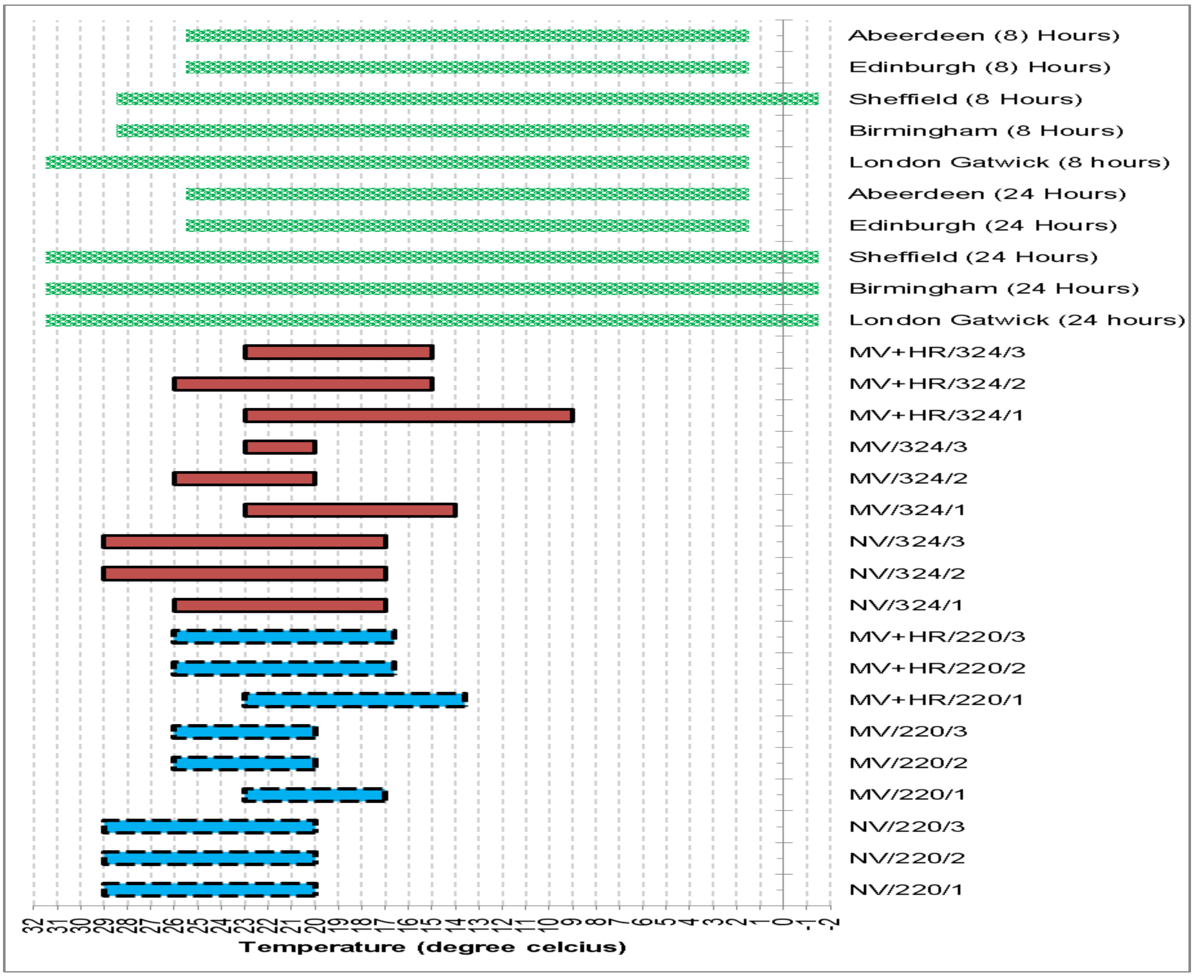


Fig. 5. Comparison of temperature operating ranges of MV, MVHR and NV to the UK temperatures

## 5. Conclusions and Further Work

The following conclusions were drawn from this work:

1. Carefully designed and commissioned automation systems are required to control complicated building services in such a building context.
2. NV is a valuable asset in high internal heat gains and low ceiling non-domestic Passivhaus building context. NV alone was sufficient in providing cooling in the Edinburgh/Aberdeen (8 and 24 hours schedule), Birmingham/Sheffield (8 hours schedule) regions.
3. NV extended summer operating temperature boundary of MV up to 6°C for both 84W/m$^2$ and 124W/m$^2$ internal heat gains conditions.
4. Variable openings in size and location within and perimeter of the domain were required to get best out of NV.
5. MV extended winter operating temperatures by 3°C for both 84W/m$^2$ and 124W/m$^2$ internal heat gains conditions. Furthermore, implementation of HR into MV extended winter operating temperatures by 3.4°C and 5°C for 84W/m$^2$ and 124W/m$^2$ internal heat gains conditions respectively.
6. Fixed flow rate AHU limited the winter performance of MV. Variable flow rate AHU could extend winter operating temperatures by 3°C for 220 occupancy conditions.
7. For the same outdoor temperature, NV provided less thermal stratification within the domain compared to MV, thus less possibility of local thermal discomfort. This was due to NV’s ability to provide more fresh air at slower speed into the domain to remove more

internal heat from the domain. The absence of fan power requirement of NV will also increase energy efficiency.

8. Neither NV nor MVHR were sufficient to provide thermally comfortable environments for all UK regions at all the times. Thus, mixed mode approach (NV+MV(HR)) with additional means of active or passive cooling and heating should be considered in that building and climate context.

Finally, it is recommended that further research needs to be conducted for an advanced understanding of ventilation energy performances. Great potential lies for further modelling of the building by using suggested ventilation approach and dynamic thermal modelling tools. Consequently, one could be able to compare the energy efficiency, heating and cooling loads to the national standard building of a similar type and non-domestic Passivhaus building working solely with MVHR.

## 6. Acknowledgement

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