Generating Thermal Stratification in the Controlled Active Ventilation Environment Laboratory (CAVE)

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SUMMARY
A large-scale facility with bespoke HVAC systems was used to generate a high-gradient thermal stratification in a space of ceiling height 9.5m by controlling supply temperatures at high level to 28°C and at low levels to 10.5°C. The resulting stratification was monitored at high spatial and temporal resolution and it was found that mixing processes diffuse the gradient until eventually a stable stratification ranging from 14 to 22°C is maintained. The experiment illustrates the buoyancy effects that serve to create and disrupt temperature distribution and ventilation in large spaces, and the performance gap between design and operation.

KEYWORDS
Experimental Facilities, Thermal stratification, Ventilation, HVAC, Indoor Air Quality

1 INTRODUCTION

In large indoor spaces with high ceilings, such as theatres, atria, and auditoria, size and geometry of the space, the occurrence of thermal stratification, and the presence of stagnation zones with poor airflow and low ventilation rates, all lead to wide variability in thermal comfort and Indoor Air Quality (Adzic et al, 2022). High resolution monitoring of CO_2 concentrations to study ventilation effectiveness was widely used to evaluate potential for risk of transmission during the Covid pandemic (Malki-Epshtein et al., 2023). Chojer et al. (2020) review the literature on use of low-cost indoor IAQ monitoring devices for "living lab" studies. But there are significant challenges in carrying out post-occupancy evaluation and monitoring in occupied buildings, which can be intrusive and disruptive. Most field studies monitor buildings passively but do not verify how these internal conditions are achieved within the HVAC system settings, and cannot test improvements. Where modelling validation is concerned, it is desirable to have a full characterization of physical and environmental parameters such as Temperature (T), Relative Humidity (RH), airspeed and flow direction inside the room and at the ventilation inlets and outlets, surface temperatures and even gas concentrations. However, monitoring studies are rarely able to achieve these substantial needs.
Accurate, full-scale, controlled experimental studies are scarce in literature (Nishizawa et al., 2004, Jiang et al., 2004) due to a high operational complexity and cost. The large-scale facility *Controlled Active Ventilation Environment* (CAVE) was designed for physical testing of full-scale buildings under a range of mechanical ventilation scenarios. This study attempts to create a thermal stratification in the lab space and monitor the resulting stratification.

2 METHODS

The CAVE laboratory is a fully insulated large chamber, which has a floor plan area of 204m^2 and floor-to-ceiling height of 9.54m and a dedicated AHU controlled by sensors at 1 m height increments from ground to 9m, to create a range of internal environments (Figure 1a). Air can be supplied at high and low levels and extracted at high and low levels, with full control over the temperature of the supplies through VAVs with localised heating coils. In addition to the sensors controlling the BMS system, 82 SensAir Explora loggers distributed around the lab for high resolution monitoring, report T and RH data every 2 minutes. For this study, the lab was first controlled to achieve 20°C at a height of 4m, allowing natural stratification to take place without interference, and once this had stabilised for at least an hour, it was set to create a high-gradient thermal stratification by fixing the air supply at low level to 1260 l/s at 10.5°C from 12 outlets in total, and the air supply at high level to 1260 l/s at 28°C from 12 outlets in total. Supply was balanced by 4 extracts at each level, which were all open and set to a total of 1260l/s at each level. The AHU was set to recirculation only, zero fresh air.

3 RESULTS AND DISCUSSION

Mild stratification existed even when the lab was set to achieve 20°C. Once the stratification experiment was initiated, the lab took several hours to stabilise and achieve steady state. Figures 1b,c show a vertical profile of temperatures measured in the centre of the North wall at heights between 0.5 and 9.5 m before the experiment was initiated and once it stabilised. It is seen that it is possible to achieve and maintain a higher gradient of stratification, but despite supplying air at 28 at high level and 10 at low level, mixing processes serve to smooth out the gradient substantially so that the achieved temperature range is between 22 and 14.

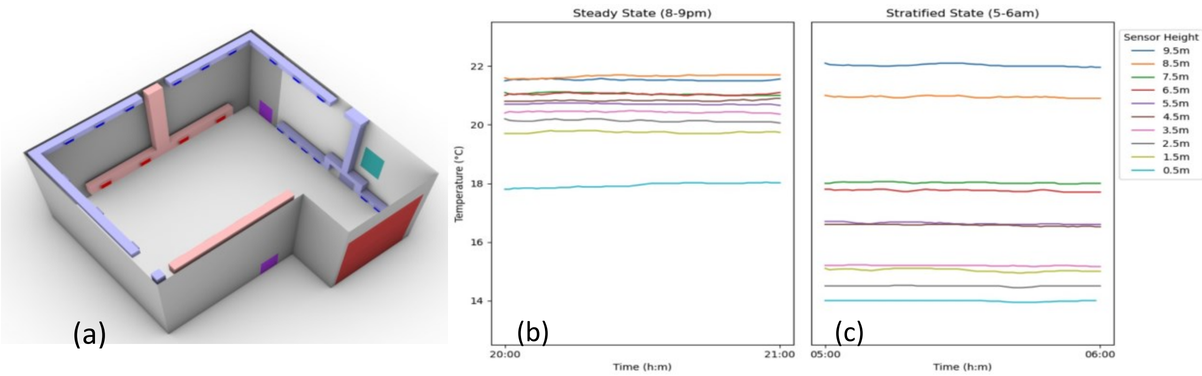

Figure 1 a) Schematic of the CAVE lab b) Temperature data as a function of height before the stratification experiment was set and (c) after the stratification was set

5 CONCLUSIONS

The study illustrates the performance gap between design and control for thermal comfort in large spaces and the importance of mixing. Due to the 9.5m vertical height of the testing facility, the measured values can accurately account for buoyancy and mixing processes, in comparison with scaled down models. Work is ongoing to quantify these processes and the buoyancy driven flows further through a wide range of instrumentation in the lab and to quantify the uncertainties in the measured data, from standard BMS sensors to scientific sensors.

6 REFERENCES

Adzic F, Roberts BM, Hathway EA, Kaur Matharu R, Ciric L, Wild O, Cook M, Malki-Epshtein L. 2022. *Building and Environment*. 223(9):109392

Chojer H, Branco PTBS, Martins FG, Alvim-Ferraz MCM, Sousa SIV. 2020. *Science of The Total Environment* Vol. 727 (138385)

Jiang Y, Alexander D, Jenkins H, Arthur R, Chen Q. 2003. J*ournal of Wind Engineering and Industrial Aerodynamics* 91, 331–353

Malki-Epshtein L, Adzic F, Roberts BM, Hathway EA, Iddon C, Mustafa M, Cook M. 2023. *Building Services Engineering Research and Technology* 44, 113–133

Nishizawa S, Sawachi T, Ken-ichi N, Seto H, Ishikawa Y. 2004. *International Journal of Ventilation* 2, 419–429