INVESTIGATING THE EFFECTS OF RESISTANCE PATHWAYS ON AIR FLOW THROUGH NATURALLY VENTILATED BUILDINGS

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ABSTRACT

This research investigates the effect of partitioning in naturally ventilated spaces using salt bath modelling experiments. A scale model was adapted from a section of the School of Slavonic and Eastern European Studies (SSEES) building in University College London (UCL). Motivation for the project is the reduction of energy demand in buildings. Relying on mechanical ventilation over natural ventilation will increase carbon emissions due to the implied increase in energy demand. Natural ventilation systems in buildings need to have inherently low airflow resistances. Therefore resistance pathways can make natural ventilation more problematic as resistance pathways increase the airflow resistance. Experiments have shown that resistance pathways in naturally ventilated spaces can increase the depth of stratification layers by 20-30% in certain areas.

INTRODUCTION

Historically all buildings were naturally ventilated, yet with buildings reaching ever skywards and becoming more complex, alternatives to natural ventilation methods were sought. As a result there was a shift towards using air conditioning units in a bid to optimise the internal quality, particularly in terms of comfort and temperature (P. F. Linden 1999). Rising concerns about global warming in the 1990s reawakened the interest in naturally ventilated offices (Gratia & Deherde 2007). The primary purpose of natural ventilation is to provide acceptable internal air quality, as opposed to providing fresh air for respiration. Individuals require approximately 7.5 litres of fresh air per second for respiration; while typical air changes needed for thermal comfort require at least ten times this amount (P. F. Linden 1999).

Heating, Ventilation and Air Conditioning (HVAC) units are commonplace in offices and multi-occupancy buildings; with nearly 68% of the total energy used in service and residential buildings attributable to these common systems (Stavrakakis et al. 2008), but with the drive to reduce the demand for energy, designers and engineers are now attempting to return to the utilisation of natural ventilation wherever possible.

The aim of this research is to investigate the effect of resistance pathways in naturally ventilated spaces. Natural ventilation is proven to work well within simple, open-plan geometry; with more complicated buildings however, there is a greater need to partition the space to provide different zones. It is important to develop an intuition for the way air moves around a partitioned naturally ventilated building, and how this is affected by changes in the design and in the external conditions (Linden, 1999). It is within the domain of change in design that the current project is situated.

Principal motivation for this research is the reduction of energy demand in buildings and the main objectives are to provide insight for building designers regarding the relationship between natural ventilation performance and resistance pathways; and provide quantifiable data on the effect of resistance pathways in naturally ventilated buildings.

LITERATURE REVIEW

A naturally ventilated building which is operating correctly, can typically consume between 40% (Stavrakakis et al. 2008) and 60% (Hunt & P. F. Linden 2001) less energy than that of comparable air-conditioned buildings. This energy demand reduction is achieved, in part, by using natural ventilation to purge some of the heat contained in a building during summer conditions, which has been found to be both practical (Coley 2002) and very energy efficient (Priyadarsini 2004; A. W. Woods et al. 2009).

It has been shown that high-rise buildings can be completely naturally ventilated (Pasquay 2004) providing it is acceptable for the internal and external temperatures to be the same occasionally. Typically, air entering a building is heated to a temperature of 17–19^{o}C prior to being supplied to the occupants; with an interior temperature being maintained in the region 21–22^{o}C (A. W. Woods et al. 2009). Occupants of naturally ventilated buildings have a propensity to tolerate a larger range of temperatures than in air-conditioned buildings (Emmerich et al. 2011), so it is likely that the proviso of similar external and internal air temperatures will be acceptable.

The most common models to predict the performance of naturally ventilated buildings, are computational fluid dynamics (CFD) models (Stavrakakis et al. 2008). However CFD models rely on simplifications and numerical equations to represent fluid movement in a building. It can sometimes be more appropriate and beneficial to use physical modelling techniques such as salt-bath modelling. This provides a physical simulation of fluid movement rather than numerical. Salt-bath modelling is also referred to as the ‘filling box’ model (Germeles 1975), or the `emptying water-filling box' model (Y Li 2000).

In the early design stages of a naturally ventilated building, salt-bath modelling can be used to identify the stratification level in any given space. This stratification level is the warm upper layer of air that due to its lesser density sits on top of the cooler, denser, fresh air that is brought into the building. In a study looking at the effects of thermal radiation on airflow with displacement ventilation (Yuguo Li et al. 1993), it was found that vertical temperature stratification is a combined effect of convection (both natural and forced), conduction and thermal radiation.

Ventilation flow rate governs the temperature gradient in a stack driven ventilation system (Mundt 1995), which in turn is controlled by the size and positioning of the openings in the building; if the openings are not sufficiently large, or erroneously situated, the stratification layer will descend into occupied regions (Hunt & P. F. Linden 2001). It has been found (Coley 2002) that ventilation rates will increase at a power of 0.5, as either vertical separation between the vents grows, or the difference in temperature between the inside and outside air increases. Internal stratification and flow regimes are also affected by the presence of an exhaust stack attached to one of the openings, namely the high level exhaust opening (SD Fitzgerald 2008).

METHOD

Creating a scale model

The SSEES building opened in 2005, it is a naturally ventilated building situated in London. SSEES is one of the schools that form University College London (UCL). The building was designed by Short and Associates, and resembles a ‘D’ shape in ‘plan’ view with a light well at its centre (as shown in Figure 1).

SSEES operates with a centre-in, edge-out form of stack ventilation; meaning fresh air is brought into the centre of the building through a light well type structure (Lomas & Yingchun Ji 2009), and flows out towards the edge of the building. It uses year-round natural ventilation; a process made possible by ‘downdraught cooling’ during the spring/summer, which cools the air as it enters the building.

A section of the third floor was deemed most suitable for analysis, as it is a mid-level floor providing typical stack pressures, and it is heavily partitioned. The partitioning takes two forms in the relevant section of the building.

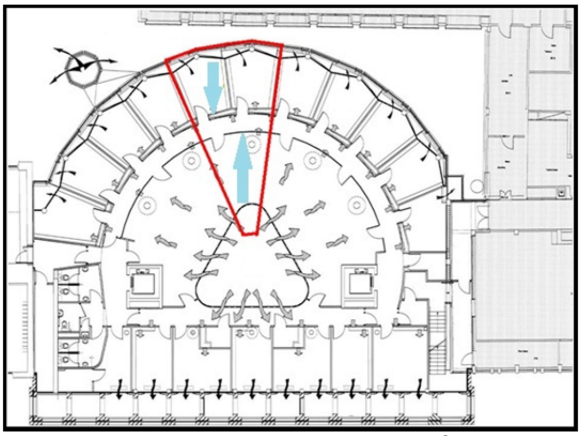

Figure 1 - Image shows a plan view of the SSEES building (Short et al. 2009)**. The resistance pathways are indicated in this image by blue arrows, while the red boundary line depicts the section of the building to be modelled.**

Air flows from the light well into research offices; which have partitions made of glass panels, with a 200mm deep opening along the top and bottom edges of each panel. After passing through the first resistance pathway, fresh air enters a walkway and onto the partition of the academic offices (as shown in Figure 3).

The partitions of the academic offices are acoustic corridors. When sound, and air, enters the ventilation opening in the walkway, it is deflected from its initial trajectory. Essentially sound, and air, is forced to turn a corner to continue flowing. This happens a second time upon reaching the ventilation opening of the academic office (as shown in Figure 2).

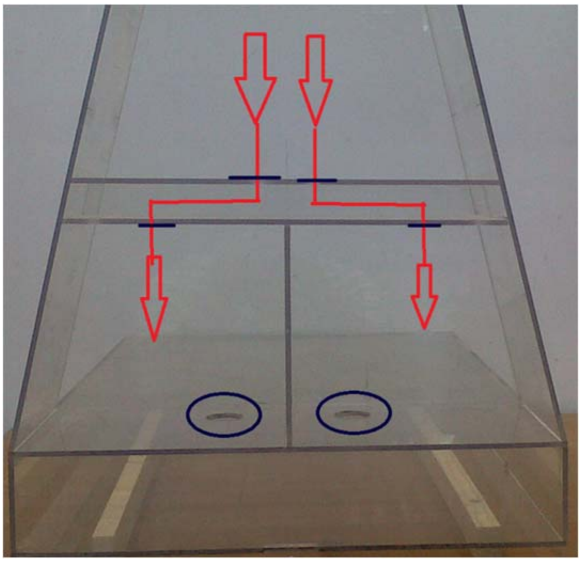

Figure 2 - Image shows part of the scale model, highlighting the obstruction to air flow caused by the acoustic corridor of the academic offices. Red lines and arrows depict airflow; Blue lines highlight the model openings.

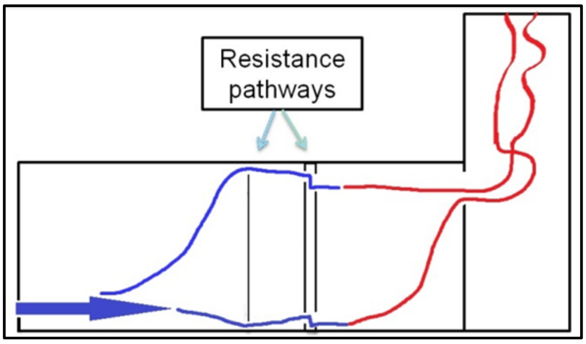

Figure 3 - A schematic side view of the scale model, showing the airflow through the building while navigating through the resistance pathways.

For this project, the partition at the research room is resistance pathway 1. The acoustic corridor that partitions the academic offices is resistance pathway 2.

The scale model represents the SSEES building section with an approximate scale of 1:50, resulting in an exhaust stack of 60cm in length. It was appropriate to use this scale in relation to the water tank being used (1.4mx1.6mx1.0m made of Perspex 0.03m thick). To make the study more generalised to resistance pathways in naturally ventilated spaces, the opening sizes of the inlet and acoustic corridor would be equal to approximately 2% of the total floor area. The exhaust opening sizes were scaled from the actual exhaust windows in the SSEES building; therefore, they are larger than 2% of the floor area. Doing this further focuses the study on the resistance pathways and occupied areas.

Calculations of the openings can be seen below:

$$Total\ Floor\ Area = 52.5m^2$$
$$Inlet\ opening = 52.5 \times 2\% = 1.05m^2$$
$$Resistance\ Pathway\ (RP)2$$
$$(four\ openings\ on\ each\ panel)$$
$$= 1.05 \div 4 = 0.2625m^2$$

Simple calculations can provide the radius from the area and therefore the diameter of the circle needed to provide the required opening sizes:

$Area\ of\ a\ circle\ (A) = \pi \times r^2,$

Therefore: $r^2 = A \div \pi,$

Hence: $r = \sqrt{(A \div \pi)}$

Since: $Diameter\ of\ a\ circle\ (D) = 2 \times r,$

The equation used to convert the opening areas into circle diameters is:

$$D = 2 \times (\sqrt{(A \div \pi)})$$

For this experiment, the opening area of 1.05m^2 is converted to 1.05cm^2 and then multiplied by 5 to give a 1:50 scale. Meaning, the circular inlet opening in this model needs to be 5.25cm^2 with a diameter of 2.585cm. With the acoustic corridor, to achieve an area of 2% of the total floor area, each opening would need an area of 1.31cm^2 and a diameter of 1.293cm. Resistance pathway 1 has rectangular openings at the top and the bottom of the partition, with a scale area of 25.4cm^2. The outlet opening leading to the exhaust stack, situated in each of the academic offices, has an area of 1.51m^2, which is scaled to a diameter of 3.1cm.

In reality, it is not possible for the scale model to have the exact opening sizes as calculated. The openings will be made in the model using a drill and therefore the drill bits available will determine the

Opening	Area (m2)	Scale Area (cm2)	Opening Diameter (cm)
Inlet	**1.05**	**5.25**	**2.59**
RP 1	**5.08**	**25.40**	**-**
RP 2	**0.26**	**1.31**	**1.29**
Exhaust	**1.51**	**7.55**	**3.10**

openings.
lists the opening sizes used for the inlet, resistance

Table 1 - The table shows the size and area of each opening in the scale model

pathways and the exhaust openings.

Opening	Area (m^2)	Scale Area (cm^2)	Opening Diameter (cm)
Inlet	**1.05**	**5.25**	**2.59**
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Materials

- Large water tank (1.40m x 1.60m x 1.0m made of Perspex 0.03m thick)
- Water supply
- Hose pipe to connect to the water supply
- Constant header tank
- Mechanical pump to force saline solution into the constant header tank
- Flow meter
- Sodium chloride
- Blue food colouring
- Ruler
- Camera

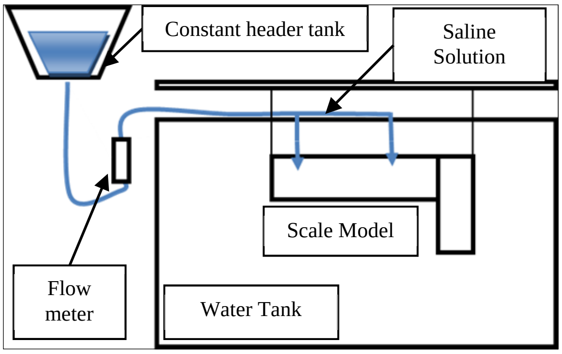

Figure 4 - Image shows experimental setup

Physical Modelling

Salt-bath modelling consist of a scale model being immersed in a fresh water tank, with heat sources represented by saline solution, introduced through a nozzle (Baines & Turner 1969; PF Linden & G. Lane-Serff 1990) fed by a header tank. The saline solution is created by inserting 500 grams of sodium chloride into a small mixing tank attached to the mechanical pump. 228ml of blue food colouring is added to the mixing tank, followed by approximately 20 litres of water. The pump is turned on for 20 minutes, with the valves closed, allowing the water, food colouring and sodium chloride to thoroughly mix. Once mixed, the saline solution is forced by the pump against gravity, to the constant header tank, which is situated at a higher level than the water tank. This allows the saline solution to enter the water tank using gravity as the lone driver.

The saline solution has a greater density than that of fresh water, similar to the density differences found between warm and cool air. It is these differences in temperature, that create the small pressure drops that are required to drive ventilation flows between two chambers (Tovar et al. 2007). Delivery of the saline solution through a nozzle means that a turbulent plume is achieved, the behaviour of which agrees well with the behaviour of a plume generated by a heat source as predicted in CFD modelling (Y. Ji & M. J. Cook 2007). This could be deemed essential, as it has been found that a turbulent plume in a confined region, can lead to stratification of the fluid surrounding the plume (Worster & Huppert 2006).

Using a saline solution allows the model to achieve dynamical similarity, as the effects of friction and diffusion can be appropriately scaled when brine is used to create density differences (Hunt & P. F. Linden 2001). Further advantages of using salt-bath modelling are that flow visualisation is straightforward and complex flow patterns can be easily determined (P. F. Linden et al. 1990). Furthermore, visual images obtained during the experiments can be used to provide validation data for simple mathematical models (Sandbach & Gregory F. Lane-Serff 2011) and clear physical explanation for the phenomenon of 'transport against the gradient ' (Baines & Turner 1969).

There are 2 things that can affect the plume created in a salt-bath model; flow rate of the saline solution (maintained at 300 cc^3/m or 0.005 l/s in this research) and reduced gravity – the buoyancy force which is defined as g':

$$g' = g\frac{\Delta\rho}{\rho} = g\frac{\Delta T}{T},$$

Where g is acceleration due to gravity, $\frac{\Delta\rho}{\rho}$ is the fractional change in density, caused by a change in temperature $\frac{\Delta T}{T}$ (P. F. Linden 1999).

RESULTS

The salt-bath experiments were carried out on five different configurations of the scale model. Run one was simulated with no resistance pathways inserted, creating an open plan building space, while run two was simulated with resistance pathway 1 inserted. The third run swapped resistance pathway 1 for resistance pathway 2, and run four was simulated with both resistance pathways inserted in conjunction. For the fifth simulation, both resistance pathways remained in place but only one heat source was simulated. Stratification levels in each zone were recorded and are stated in proportion to the room height, $\frac{h}{H}$; where h is the stratification height from ground level, and H is the total height of the rooms.

Figure 5 shows the stratification levels that were recorded during the first salt bath experiment, on the open plan layout of the scale model. As such, Figure 5 shows the base-case stratification levels. Comparisons between the base-case stratification levels and those found in subsequent experiments show the effect of resistance pathways on the model.

During the filling stage of the experiment, the saline solution reached a stratification level at 47% of the room height after the first minute. By the second minute of filling, the solution had filled 60% of the room, and levelled at 63% of the total room height in the third minute. The stratification level remained steady at this level, deepening in colour as the test went on. After the fourteenth minute of the experiment, the saline solution reached a steady state at 67%.

Once the saline solution had reached a steady state, and the stratification level was stable, the saline delivery system was switched off and the model was allowed to empty. The rate at which the model cooled was significantly slower than the rate at which it filled; with the stratification level rising to 47% of the total room height in the first minute.

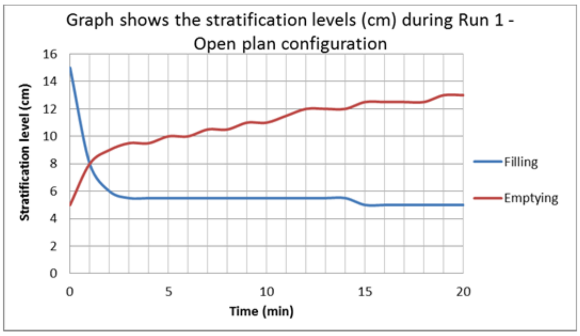

Figure 5 - The graph shows the stratification levels throughout the filling and emptying phases of the first model run.

Within five minutes of the emptying simulation, the saline solution filled 33% of the room, lowering to 27% after the tenth minute; by the fifteenth minute, the saline solution occupied only 17% of the model height. The simulation reached a steady state after nineteen minutes, resulting in a stratification level 13% of the total room height, a level at which it remained through the rest of the experiment.

Run two – Resistance pathway 1 inserted

Similar results were found during the second run of salt-bath modelling as were found in the first run. The rate of stratification increase in this run is almost identical to that of the first, with the saline solution filling 67% of zone two (academic offices) after only three minutes. During the first two minutes zone one (research room) fills at a slightly faster rate (5cm/min) than zone two (4.5cm/min). After this point, and up until the sixteenth minute, zone two has a lower stratification level than zone one. It is thought that the deeper stratification level in zone two is due to the saline solution in this zone being prevented from fully mixing with the fluid in zone one.

During the emptying phase of the modelling, it was found that zone one empties faster than zone two over the initial four minutes; but the emptying rates of each zone became equal after this point. This could be due to the saline solution that enters the exhaust stack from zone two being replaced by the solution in zone one. After five minutes of emptying, the stratification levels had gone from filling 67% of each zone to filling only 33% of each zone. Furthermore, after ten minutes of the model emptying, the saline solution occupied only 23% of the room height in each zone.

Run three – Resistance pathway 2 inserted

A greater effect on the rate and level of stratification was observed when the salt-bath model was run with resistance pathway two inserted, as opposed to the simulation with only resistance pathway 1. The overall rate of stratification was slower than the previous two runs; after the first minute saline solution occupied 33% of zone three (academic offices). At the same point in the simulation, saline solution filled 20% of zone one (research room) and only 7% of zone two (acoustic corridor).

After seven minutes of running the filling phase of the simulation, the stratification in zones one and two had levelled out at 53% of the total room height. However, zone three still had a deeper stratification level, filling 60% of the zone. By the eighth minute the stratification layer in zone two had increased beyond that of zone one and was level with zone three at 60%; the stratification in zone one remaining 53% full of saline solution.

The stratification levels in zones one and three meet after ten minutes of simulation. With the exception of a slight deviation in the eleventh minute, the solution occupies 67% of each of these zones for the remainder of the model simulation. However, the stratification layer in zone two continues to deepen, steadying at 73% of the model height. Eventually the stratification layer in zone two settles after the seventeenth minute, filling approximately 77% of the space.

During the emptying stage of the model run, the cooling of zones one and three occurs at the same rate, during the first minute. In the fifth minute, saline solution occupied 47% of zone one, but only 33% of zone three. Zone three continues to empty at a faster rate than zone one, until the tenth minute when the stratification level is maintained shortly. In the fourteenth minute, the layers of saline solution in zone three and zone one converge at 23% of the room height. The stratification levels settle after the nineteenth minute, leaving 13% of the model containing saline solution.

Run four – Both resistance pathways in conjunction

Within the first minute of filling, zones two and four (corridor and academic offices respectively) have a stratification layer that is 33% the depth of the room height. In comparison zone one (research room) level is 20%, and zone three (acoustic corridor) has a level of 13%. The difference between the stratification levels across the zones becomes even more apparent in the third minute of filling; when levels get to 50% in zone one, 73% in zone two, 27% in zone three and 63% in zone four.

After running the model for five minutes, the stratification levels in zone two levelled at 87% and remained at this level throughout the experiment. By this point, the stratification layer in zone four had also reached a steady state and settled at 67%. However zone one was still filling in a relatively uniform manner and had a stratification depth of 57% of the total room height, with zone three having a level 47% of the room depth. The stratification levels throughout the filling stage of this simulation are shown in Figure 6.

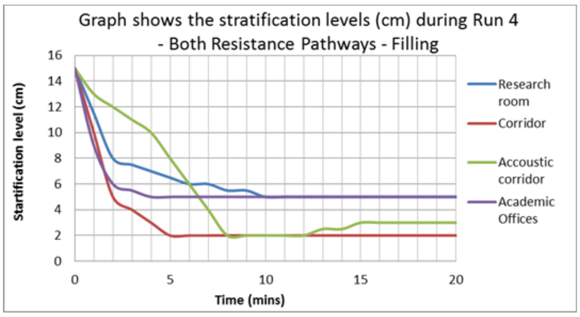

Figure 6 - Graph shows the varying stratification levels in each of the four zones during the filling stage of the scale model.

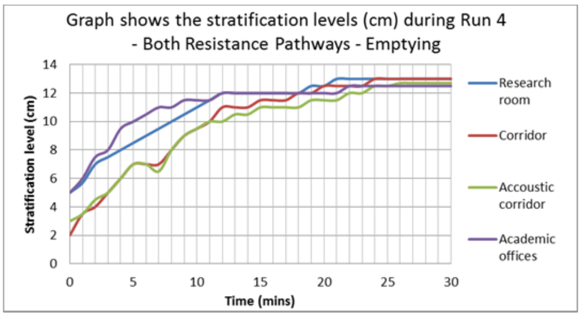

Figure 7 - Graph shows the differences in stratification levels across the four zones of the scale model during the fourth run of the salt-bath model experiments.

Between the fifth and eighth minute the stratification level inside zone three increases at a rate of 2cm every minute where it meets the level recorded in zone two. After ten minutes of simulation the levels observed in zone one become equal to the steady state level of zone four at 67% of the room height, with zones two and three having saline solution layers up to 87% of the room depth. No further changes in the stratification layers occurred across the model, with the exception of zone three thinning out slightly to its final steady state of 80%.

The rate of emptying (shown in Figure 7) during the initial two minutes of the model run was almost identical across all four zones. Following this there was a deviation between zone one and zone four, with the latter reducing to 33% at five minutes and the former at 43%. In spite of the faster rate of decrease seen initially in zone four, by the eleventh minute the stratification level was equal to that of zone one at 23%. Zone one stratification layer decreases in a remarkably uniform manner, reducing at a rate of 0.5cm per minute until the saline solution occupies only 20% of the model height after twelve minutes.

Looking at the graph it is possible to see that zone two and zone three have a very similar emptying rate. A steady stratification depth of 20% is observed in zone four until the twenty-first minute, after which it becomes slightly thinner still and reaches a completely steady state of 17% throughout the simulation. Zone one does not maintain such a steady level, with small decreases in saline solution depths as the test approaches the twenty minute stage. At twenty-one minutes the stratification level in zone one settles at its final depth of 13%. While the simulation approaches the twenty-five minute mark, zone two settles at the same level as zone one.

Run five – Single heat source

It was not initially planned to run a simulation using a single heat source, as the model covers three rooms each with their own heat sources. However, it was thought that carrying out a simulation using a single heat source might provide a clearer visual representation of how fluid moves through the resistance pathways. In the SSEES building, the level of occupancy can vary from day to day. It is likely that the academic offices and the research room are both occupied, but this will not always be the case. This model run shows what happens to the stratification levels when only one of the rooms is occupied.

Logically, with the heat source located in zone one (research room) this zone fills the fastest. The saline solution spreads across the ceiling of the zone one, flows through the opening at the top of the first resistance pathway and begins to stratify in zone two (corridor). Once the layer of saline solution in this zone has reached the level at which the inlet openings of RP2 are situated, the fluid starts to build up inside zone three (acoustic corridor). In turn, the solution makes its way through the acoustic corridor into zone four and starts to stratify.

There were two main points of interest about the stratification levels once the simulation had reached a steady state; the first of which is how remarkably flat the stratification layer becomes in zone four. During the previous simulations with a resistance pathway inserted, the stratification level was continually more distinct in the academic offices than in the research room; but none more so than in this simulation.

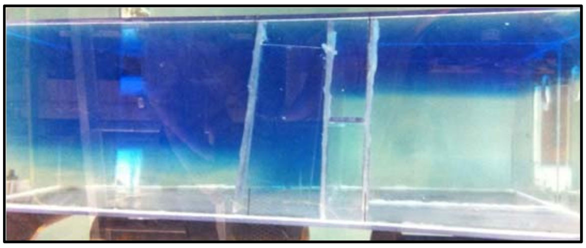

Figure 8- Image shows the stratification levels of run five. Left to right, the image shows the research office, the walkway, acoustic corridor and the academic offices.

The other interesting observation found during this simulation is the heights at which the stratification levels settled. In each of the previous model runs, the steady state maintained the stratification layer depths at 67% in zone one and the academic offices, regardless of the model configuration. With only one heat source present, the steady state created a stratification layer as deep as 73% of the model height in zone one, and closer to 33% in the academic offices.

The effect of resistance pathways

During the filling phase of the salt-bath modelling, steady state stratification levels in the research room and the academic offices remained constant across all model runs. However, the stratification levels from run three show an increase of 15% in zone 2, which is the space inside resistance pathway 2. This would indicate that heat is contained within the acoustic corridor, somehow prevented from flowing into the academic offices.

Stratification levels found during run four highlight even further that partitioning naturally ventilated building affects airflow. **Error! Reference source not found.** shows a 30% increase in stratification layer depth is found in zone 2, which in this run is the corridor between the research room and academic offices. The fifth run shows a change from the base case on the stratification levels of all four zones, with the zone one increasing by 9% and zone four reducing by 45%.

The results from the emptying phase (shown in **Error! Reference source not found.**) of the model runs confirm that resistance pathways have an effect on stratification layer depth in naturally ventilated buildings. Corresponding with the pattern seen during the filling stage, the stratification levels in run two are identical to the base case, but changes are found in runs three and four.

Run three shows that after reaching a steady state the stratification levels in the research room and academic offices are equal to those found in the base case. However, the depth of saline solution layer inside the acoustic corridor shows a 54% increase from the depth of the stratification level; again, this shows that the acoustic corridor is retaining heat.

Interestingly, the emptying phase in run four provides even stronger indications that resistance pathways affect the performance of naturally ventilated buildings. As opposed to the results shown previously, the stratification level in the research room and academic offices are not equal. The results show that for the first time the corridor between the resistance pathways settled at the same height as the base case, as did the research room. Both the acoustic corridor and the academic offices record a 31% increase in the volume of saline solution retained during the emptying stage.

CONCLUSION

The salt-bath experiments were used to provide data on how stratification levels can change in a building with the introduction of resistance pathways. Prior to starting this research project it was expected that increasing the number of resistance pathways in a naturally ventilated building would have a greater impact on the buildings air flow. Through carrying out salt-bath modelling tests on the scale model with both of the resistance pathways inserted this was shown to be true. Partitioning can lead to increases in the depth of stratification layers by 20-30% in unoccupied areas during the day; further leading to a 31% increase in the depth of stratification layers, in occupied areas, during cooling.

It has been shown that resistance pathways with openings situated along the length of the top and bottom have less of an effect on stratification levels in naturally ventilated buildings when compared to acoustic corridors. Acoustic corridors retain heat inside their internal void during night-cooling; although this does not affect the stratification levels during occupied hours, it does have an effect on how the building purges. The greatest effect that resistance pathways have on air flow is found when they are situated close to one another. Additional work could be carried out looking at how the distance between two resistance pathways affects the air flow through, and stratification levels within, naturally ventilated buildings.

This research would be complimented by investigating how changes in the number of heat sources present affects the air flow and stratification levels of a naturally ventilated sub-zoned building. Advantages of this study would provide greater insight as to how best design a naturally ventilated building that has to accommodate fluctuating heat sources. Further studies could incorporate running simulations consecutively on the same configuration, to investigate if stratification levels are affected by the presence of warm air retained in the building from the previous day; and to install flow metres at the model openings to measure the flow rate of fluid entering/exiting the model.

ACKNOWLEDGEMENT

This research was supported with funding from the Engineering and Physical Sciences Research Council (EPSRC) and was undertaken within the London-Loughborough Centre for Doctoral Training (Lo-Lo CDT) in Energy Demand Reduction.

The author would also like to acknowledge the advice and guidance of Dr Malcolm Cook, the supervisor of this research.

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Filling									
	Run 1	Run 2		Run 3		Run 4		Run 5	
Zone 1	0.67	0.67	100%	0.67	100%	0.67	100%	0.73	109%
Zone 2	-	0.67	100%	0.77	115%	0.87	130%	0.87	130%
Zone 3	-	-	-	0.67	100%	0.80	119%	0.80	119%
Zone 4	-	-	-	-	-	0.67	100%	0.37	55%

Table 2- The table shows the steady state stratification levels from the filling stage of the salt-bath modelling experiments. The table displays the base case stratification level from run one, levels of each zone from subsequent runs and the percentage of change from the base case.

Emptying								
	Run 1	Run 2		Run 3		Run 4	
Zone 1	0.13	0.13	100%	0.13	100%	0.13	100%
Zone 2	-	0.13	100%	0.20	154%	0.13	100%
Zone 3	-	-	-	0.13	100%	0.17	131%
Zone 4	-	-	-	-	-	0.17	131%

Table 3 - The table shows the steady state stratification levels from the emptying stage of the salt-bath modelling experiments. The table displays the base case stratification level from run one, levels of each zone from subsequent runs and the percentage of change from the base case.