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Testing of a Downflow Ventilation System for High Risk Infectious Disease Isolation Rooms.

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Summary

Isolation room airflows for infectious diseases are designed to minimise the risk of transmission of airborne pathogens to those outside the room and to protect healthcare workers who tend to the patient. This study considers the risk in the vicinity of the patient and conducts an experimental investigation into a downflow ventilation design to evaluate whether it is capable of providing protection to a healthcare worker. Anemometry and smoke tests are conducted in a mock up room to assess influence of ventilation rate, extract design, heat loads and flow local to a healthcare worker. Results show a good downward flow can be established, but a fan speed capable of delivering 0.35m/s and central extract are required to create a uniform flow. Heat loads and a healthcare worker leaning over the bed both compromise downflow effectiveness; local flow acceleration and exhaust can mitigate to some extent.

1 Introduction

Design of isolation rooms for the prevention of airborne transmitted diseases depend on the risk of infection and the hazard category of the pathogen. To contain infectious patients, the traditional design has been for negatively pressurised isolation rooms, whilst, to prevent infection entering a space, the space has been positively pressurised. Another alternative is the neutral pressure room with a positively pressurised ventilated lobby (PPVL), advocated by the UK Department of Health[1,2]. In all cases these rooms provide a well-mixed airflow and are recommended for up to hazard category 3 pathogens.

Isolation rooms for hazard category 4 pathogens require a very different approach. Although there is little evidence for airborne transmission, the severity of such infections is such that additional precautions are taken, including when designing airflow. Such rooms are typically are designed for very high negative pressure with the patient located inside a ventilated tent within the room. However, this minimises the ability to provide care to the patient. This study investigates whether a new design based on a downflow ventilation could eliminate the tent, in order to facilitate care to the patient[3]. This paper describes how this design concept was built and tested at BSRIA in 2012.

2 Methodology

A reduced size mock-up of the patient room (Figure 1) was constructed with dimensions 3.1 x 2.5 x 3 m height to explore the airflow patterns under a range of design configurations. The room was built within a BSRIA environmental chamber to ensure stability of the room conditions. The ventilation strategy was downward displacement; the air in the room was intended to flow uniformly

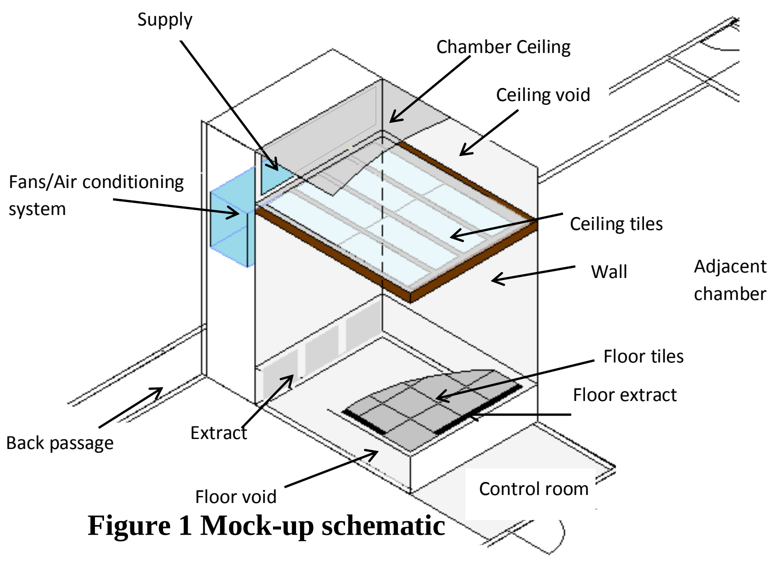


Figure 1 Mock-up schematic

downwards with air supplied into a void in the ceiling and entering the room through eight membrane tiles. Air was extracted at floor level, via grilles and a perimeter extract. The design of the room was based on operating theatres; it was intended to achieve a speed of 0.2 $m.s^{-1}$ at the patient's bed. To enable the required flow rates in the test facility the extract air was recirculated.This would not happen in reality; in a CL4 room none of the air should be recirculated as the design intention is not to dilute the dose the staff might receive, but to make it as near as possible to zero.

Several tests were carried out to determine the airflow patterns in the room including airtightness, anemometry and smoke visualisation. The room was tested empty, with a bed and with heatloads provided by DIN men to simulate staff and patient. The experiments considered different floor extract configurations, with an extract underneath the bed and with different supply fan speeds as well as local control of the flow close to the patient.

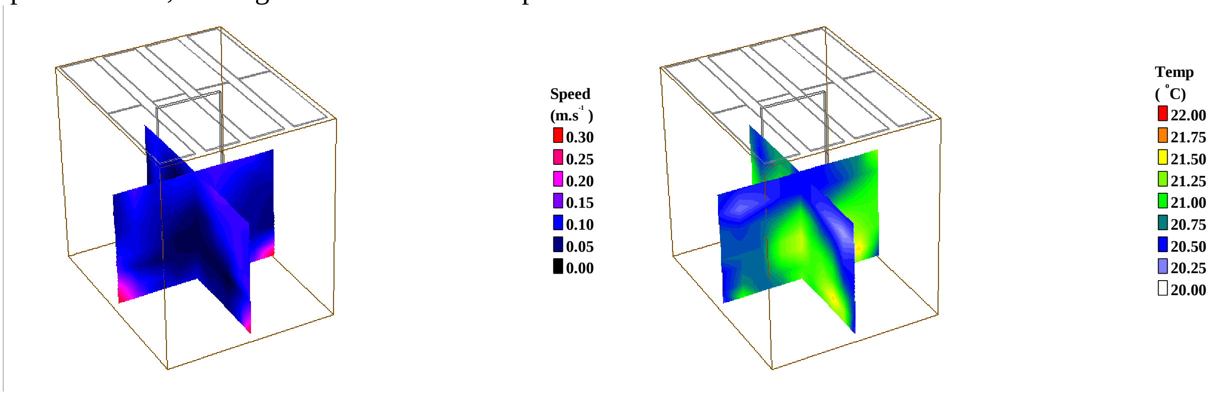
3 Results and discussion

Prior to conducting experiments the room leakage and pressure drop over the ceiling supply tiles measured at different fan speeds. This was used to calculate the theoretical downflow speed as shown in Table 1.

Fan speed	ΔP	Flow-leakage	Theoretical speed
Hz	(Pa)	$l.s^{-1}$	$m.s^{-1}$
19.8	22.49	1410	0.25
33.0	32.55	2013	0.35
45.0	40.75	2498	0.44

Table 1 Fan speeds-Air speed in room

Initial tests were carried out with a perimeter extract and a fan speed of 19.8 Hz (approximately 0.25 m.s-1). Anemometry results (Figure 2) showed that at the lowest fan speed (enough to achieve a theoretical 0.20 $m.s^{-1}$ at bed level) the air was not flowing uniformly downwards, but coalescing, leaving areas in the room with an insufficient air velocity (<0.05 $m.s^{-1}$). The air did not achieve a speed of 0.2 $m.s^{-1}$ anywhere in the room at occupied level (0-1.8 m) except where it accelerated near the extract. As shown in Table 1, to achieve uniform down flow, it was necessary to increase the fan speed to 33Hz, although the theoretical fan speed would have been 19.8 Hz.



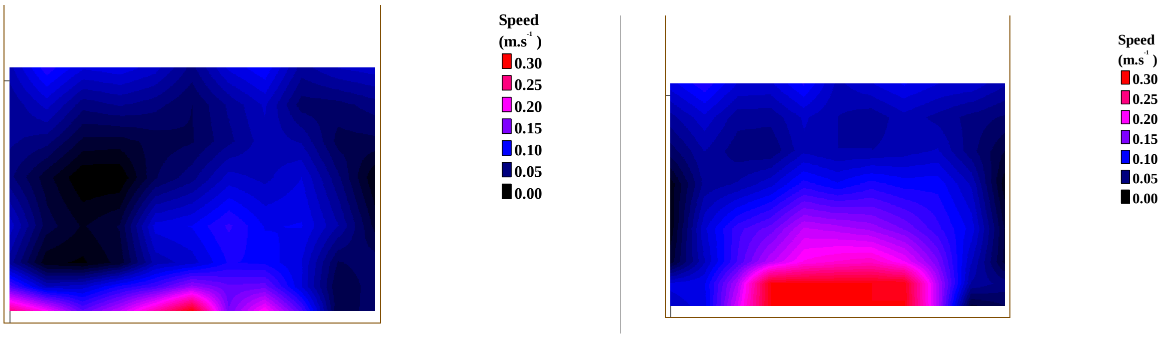
(a) Speed (b) Temperature

Figure 2 Test 02, empty room anemometry results at 19.8Hz

Results showed that it was not sufficient with the push effect of the supply from the ceiling, it was also necessary to pull the air from the extract (floor) side. With this intention, several extract configurations were tested: a perimeter extract round the room, tartan floor (the floor tiles were extract grilles themselves -with full floor tiles and 50% open tiles set up in a chess board pattern) central extract (with four 50% tiles in the center of the room). Additional tests also examined a pedestal extract (with a perforated box/pedestal underneath the bed), and a bed extract which pulled air from the sides of the bed into the floor void. Figure 3 shows results from anemometory tests to compare tartan and central extract locations. It can be seen that central extract configuration improves the flow field in the centre of the room, minimizing areas of low flow. Subsequent tests showed this worked very well in accelerating the flow above the bed, and smoke tests used to visualize the air coming from the patient showed that any “breath” (not coughs) released by the patient was effectively removed by the extract and not reaching the staff.

	Height	Test 10 19.8 Hz				Test 11 33 Hz				Test 13 45 Hz			
	(m)	ave	max	min	stdev	ave	max	min	stdev	ave	max	min	stdev
Average speed (m.s^{-1})	2.70	0.07	0.11	0.02	0.034	0.23	0.44	0.07	0.066	0.37	0.64	0.11	0.095
	2.55	0.05	0.08	0.02	0.016	0.20	0.41	0.05	0.064	0.35	0.61	0.10	0.099
	2.40	0.03	0.05	0.02	0.008	0.18	0.35	0.06	0.055	0.33	0.48	0.12	0.089
	2.25	0.01	0.05	0.00	0.011	0.16	0.28	0.08	0.043	0.32	0.43	0.14	0.087
	2.10	0.03	0.07	0.02	0.015	0.16	0.26	0.10	0.036	0.29	0.40	0.15	0.059
	1.95	0.03	0.09	0.01	0.018	0.15	0.28	0.09	0.038	0.28	0.36	0.15	0.050
	1.80	0.03	0.10	0.01	0.020	0.15	0.29	0.06	0.039	0.26	0.35	0.15	0.042
	1.65	0.03	0.12	-0.01	0.028	0.16	0.29	0.02	0.038	0.26	0.36	0.14	0.041
Average temperature (°C)	2.70	20.7	21.0	20.4	0.195	20.4	20.7	20.3	0.096	20.6	20.8	20.4	0.075
	2.55	20.8	21.2	20.6	0.171	20.6	20.8	20.4	0.087	20.8	21.0	20.6	0.131
	2.40	20.8	21.6	20.4	0.263	20.3	20.8	20.2	0.108	20.5	20.8	20.3	0.057
	2.25	20.9	21.2	20.6	0.196	20.5	21.1	20.3	0.116	20.7	20.9	20.4	0.086
	2.10	21.0	21.2	20.6	0.171	20.6	20.9	20.3	0.105	20.7	20.9	20.5	0.074
	1.95	20.9	21.2	20.5	0.197	20.5	20.7	20.3	0.120	20.7	20.9	20.5	0.092
	1.80	21.0	21.3	20.7	0.156	20.6	20.8	20.4	0.107	20.8	20.9	20.5	0.071
	1.65	20.9	21.2	20.5	0.168	20.6	20.9	20.4	0.116	20.8	20.9	20.6	0.084

Table 2 Speed and temperature by height in the empty room at three fan speeds.



(a) Tartan extract (b) Central extract

Figure 3 Tests 08 and 09, empty room, investigating extract location.

The introduction of a bed effectively reduced the distance the air had to travel downwards, therefore increasing the air speed above the bed. Despite this, smoke tests showed that when heat loads were introduced (DIN men –to simulate staff, patient and equipment) the plume was making the air flow upwards. Anemometry results in Figure 4 also show the low flow above the bed due to the thermal plume from the DIN man counteracting the downflow.

The final set of experiments explored approaches for enhancing the downflow. A local supply ventilation ring was installed above the bed above the occupied space. Despite the higher-speed curtain of air provided by the ring, the downflow at 19.8 Hz still was not enough to overcome the plume due to the heat loads. A fan speed of 33Hz (0.35m.s^{-1}) was still necessary to counteract the effects of the plume in a patient and nurse. Finally the ring was moved to the side of the bed (see figure 5). Smoke tests demonstrated that the ring in this position aided the plume from the patient downwards. Results also showed that even at the highest supply fan speed, a person blocking the air pattern could block the downflow and breathe in contaminated air from the patient. Therefore, a halo system was envisaged, consisting of a mask and a ventilation method over the nurse's head which will blow air downwards the face of the nurse. This system proved effective in preventing contaminated air from reaching the face of the mannequin-nurse when it was lying over the patient.

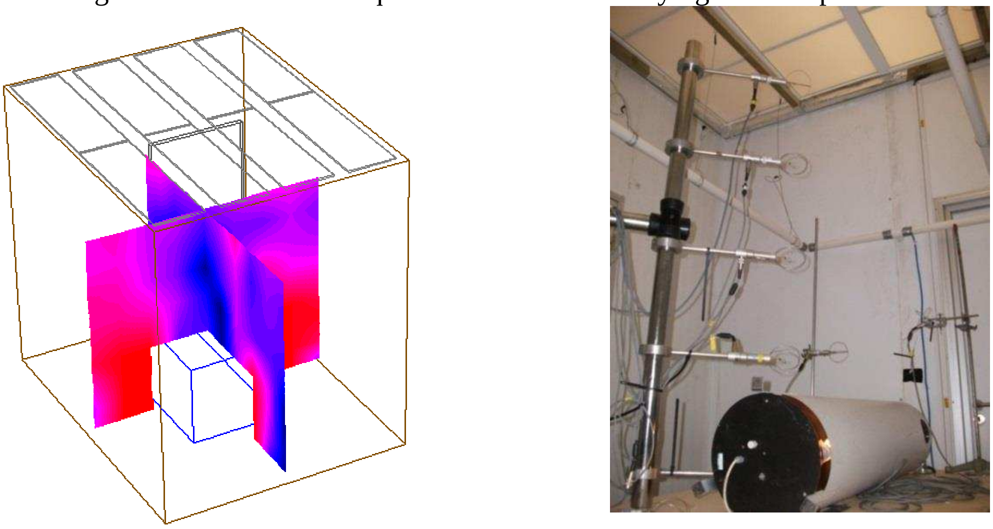


Figure 4 Anemometry results with patient and nurse heatloads, central extract 33 Hz supply fan. Cantilever anemometry pole measuring above DIN-man

4 Conclusions

This design for a CL4 isolation room was intended so that the tent (enclosure over and around the patient's bed) could be eliminated to provide easier access to the patient from the hospital staff. To achieve a uniform downflow and an air speed of 0.20 m.s^{-1} at bed level, and to overcome the plume (upwards) of heatloads in the room (patient, staff, equipment) it was necessary to increase the speed of the fans to a supply design of 0.35 m.s^{-1} (both set ups included the losses from airtightness). It was also necessary to modify the floor extract to create a push (supply) pull (extract) effect on the room, to avoid very low speed areas (or air going upwards). A pedestal extract and a ventilation ring proved to increase the air speed around and above the bed, reducing the risk of infection. The ability of the downflow system to overcome thermal plumes arising from simulated people and equipment was demonstrated. Heatloads remain a challenge and future work should consider ways of reducing or minimizing the effects of people and equipment within a CL4 protected zone.

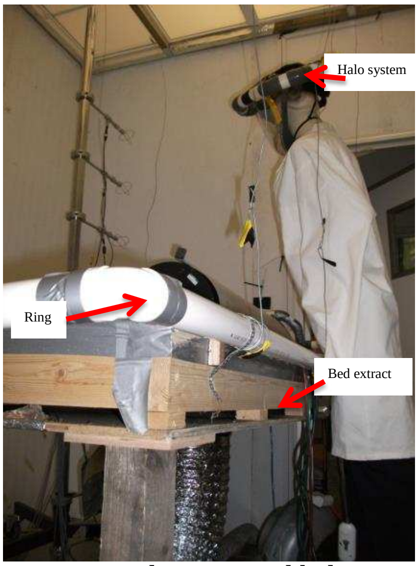


Figure 5 Bed extract and halo system

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