Reducing patient to patient airborne exposure in patient and isolation rooms with two patients

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Abstract. Airborne transmission in hospital patient rooms may take place both in patient healthcare worker (HCW) interaction, but also between patients sharing the same room. A protective flow concept with dynamic airflow control, individual thermal environment and protective task airflow pattern has been developed and its efficiency in reducing HCW exposure risk as well as the thermal acceptance been verified in the previous stages of research for both patient and isolation rooms.

In the recent study the concept performance has been studied in a room with two patient beds both with individual protective flow arrangement. The research question was, whether the protective flow concept provided enhanced protection on patient to patient exposure compared to traditional mixing ventilation. The research was conducted for both normal patient room and isolation room situations.

The protective ventilation was able to keep the normalized concentration below 0.72 near exposed patient's head in all four test conditions. It prevented the tracer gas to spread evenly to the patient room. The best protection, concentration clearly below 0.5 for the exposed patient was reached with the elevated airflow rate and having the curtain between patient beds.

1 Introduction

Recent Covid pandemic has raised the public understanding on how significant role airborne transmission plays in transmission of infectious microbes. Transmission in hospital patient rooms may take place both in patient healthcare worker (HCW) interaction, but also between patients sharing the same room.

Even if the single patient rooms have become much more common in new hospitals there still are many with multiple patient bedrooms as well. The Covid pandemic has also raised a new need for multi-patient rooms with isolation need to environment, when several Covid patients were treated in common intensive care rooms.

An especial exposure situation would be in multi-patient ward, when medical treatment is provided to one of the patients, while others present in the same room.

1.1 Previous research

The significance of the HCW exposure and especially elevated exposure risk in close interaction has been addressed by Koskela et al. [1] A protective flow concept with dynamic airflow control, individual thermal environment and protective task airflow pattern has been developed and its efficiency in reducing exposure risk been verified in the previous stage of research by full scale laboratory experiments for both patient and isolation rooms. At the second stage of research the thermal acceptance of task ventilation approach was studied using human subject experiments. [2]

During Covid pandemic multiple surveys reported patient-to-patient infections in non-Covid wards of patients, who were exposed to index patients with an infection acquired prior to admission. As an example, Wenlock et al reported more than 20% infection rate among 575 exposed patients in their cohort study. [3]

Previous studies have reported concentration distribution of contamination in one patient room with mixing ventilation with ceiling exhaust [1] and patient to patient exposure risk in distributed air supply with ceiling exhaust [4]. As can be seen in Figure 1. The contaminant distribution in one patient room is uniform in the room except close to patient.

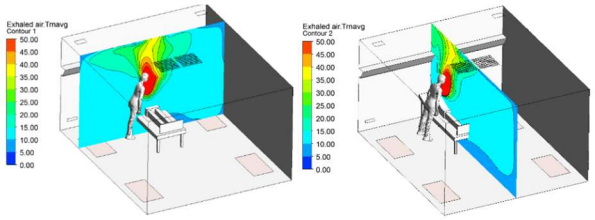

Fig 1. Contaminant distribution within one patient room with mixing air distribution and ceiling exhaust. [1]

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Qian et al studied distributed, partly localized ventilation combined with variable exhaust locations. [4] The measurement set-up is shown in Figure 2. In this study the inhaled concentration of the patient closest to the source patient exceeded the average exhaust condition.

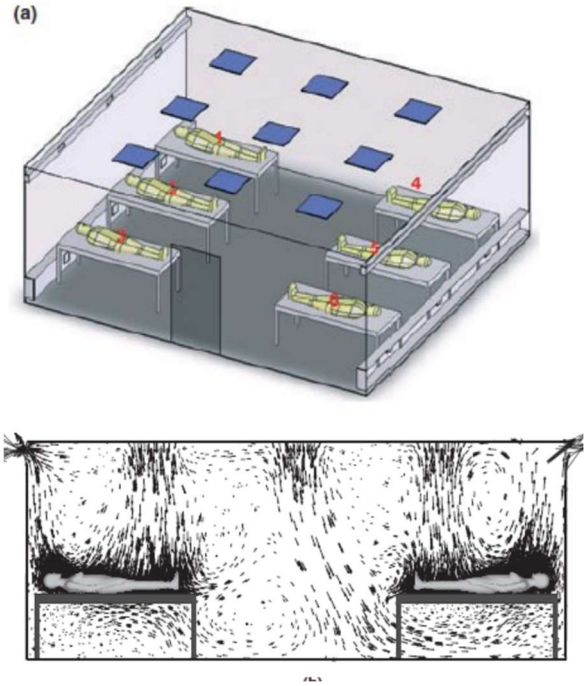

Fig 2. Measurement set up of Qian et al study. [4]

In both [1] and [4] the results also showed that location of the exhaust openings have also influence on the contaminant distribution.

2 Research questions

In the recent study the remaining question of whether the protective flow concept would perform in a room with multiple patients has been studied using full scale laboratory experiments. In the recent set-up the room consisted of two patient bed areas both with individual protective flow arrangement.

The research question was, whether the protective flow concept was able to provide enhanced protection on patient to patient exposure compared to traditional mixing ventilation. The research was conducted for both normal patient room and isolation room situations. In both cases two different airflow rates like in earlier studies were used; basic airflow for the situation, where only patients would be present in the room and elevated airflow rate to be used for treatment situation with HCW present. As additional variable was used a curtain between the patients, where both situations with and without curtain was assessed.

3 Current practices in patient rooms

3.1 Patient Wards ventilation

The ventilation rates in patient wards vary quite much between countries and individual hospitals. Quite common range in Europe is between 2 ACH to 4 ACH, but even values up to 6 ACH [5] are recommended. These corresponds in typical 20 m^2 single patient ward to 33 l/s, 67 l/s, and 100 l/s outside airflow rate. The typical reasonings for elevated airflow rate are increased amount of odours from patients, medication provided and the treatments given in wards.

It is also wort noting that even in one patient ward the occupation varies during the day due to treatments and visitors. Thus, the ideal ventilation arrangements in patient ward would enable minimum ventilation rate for sustainable operation but have flexibility for elevated air flow rate and protective performance during varying situations in a ward.

Typical patient ward ventilation system is based on mixing ventilation principle without any special considerations of a specific exposure situations. The maximum cooling load in a typical patient ward is about 500W/patient, which means that an additional room cooling is often needed. This is often provided by chilled beams or radiant panels.

3.2 Isolation Room ventilation

A commonly used ventilation rate in European isolation rooms is 12 ACH. Defining the airflow rate-based ACH is arbitrary because the target of ventilation is to reduce the infection risk caused by a source, which is not depending on the room size. In infection isolation room the source is the patient. In the recent Nordic guideline for hospital ventilation the necessary ventilation rate is defined based on the patient source strength by using patients breathing rate as source. [6] In this way it is possible to determine the targeted protection degree / dilution rate in an isolation room with a patient. With a typical breathing rate of a sedentary person, 15 l/min to reach 1:1000 dilution rate (average, based on complete mixing) a 200 l/s ventilation rate would be required. This air flow rate corresponds to 12 ACH in a 60m^3 room, but ACH would be different in rooms with different size as the ventilation rate should be kept the same to meet the dilution criteria.

The isolation room ventilation system is typically designed to use only outside air apply mixing ventilation principle and thus assuming that the contamination is equal all over the space. In some protective isolation applications, such as burns patient wards, also protective zone ventilation principle is applied. But in such use case the ventilation rate used is much higher.

4 Protective flow concept

The basic principle of the designed protective airflow system is presented in Figure 3. [7] It is based on the use of parallel air streams supplying air towards patient bed that are created by two adjustable supply air diffusers located on both sides of the patient bed.

Fig. 3– Protective airflow system concept, patient room. [7]

During the development phase the airflow and temperature parameters have been optimized to provide both optimal protection and comfort conditions.

The same system principle has been applied for both normal ward and isolation room resulting in two variants of the system based on the different boundary conditions.

The patient ward system is based on two inward jets that are integrated with a radiant panel to provide necessary cooling and personal comfort control, like presented in Figure 3. The dynamic airflow is applied to be able to provide sustainable operation for patient only situations and active protective mode for patient treatment with HCW present.

The isolation room system has slightly different airflow principle; due to high airflow additional airflow patterns are directed towards sidewalls as shown in Figure 4.[7] The isolation room system has also dynamic operation principle to allow sustainable operation, when room is used for normal patients and activating enhanced protective mode for either isolation or treatment situations.

Fig. 4 – Protective airflow system concept, Isolation room. [7]

5 Methods

For the experiment, a full-scale mock-up simulating a simplified hospital patient room with two beds was built into the Turku University of Applied Sciences' HVAC laboratory. The supply air was distributed through four multi-diffuser units (one on each side of both patient beds). Diffuser units had three front panels of which two had nozzles for adjustable air distribution and the third was sealed (no air flow through it). The exhaust locations were chosen to be distributed to study supply only influence. The mean exhaust concentration was used as a benchmark to fully mixed situation in this steady state study. The experiment had four test conditions:

1) Supply airflow rate Q_1=30 l/s per patient (typical ventilation rate in a patient room) and two nozzle rows,
2) Supply airflow rate Q_2=70 l/s per patient (ventilation rate in patient room during treatment situation) and two nozzle rows,
3) Supply airflow rate Q_3=70 l/s per patient (ventilation rate in isolation room that is used as patient room) and four nozzle rows, and
4) Supply airflow rate Q_4=200 l/s per patient (ventilation rate in isolation room) and four nozzle rows.

Figure 5 shows the layout of the patient room and positions of inlets and outlets. Airflow rates of each inlet and outlet in all conditions are shown in Table 1. Each condition was measured with and without hospital curtain dividing the space. The mean supply air temperature was 20.5 °C, the mean room air temperature was 21.8 °C, and the mean relative humidity was 34 %.

Airflow rates were measured with micromanometer (Swema 3000, Swema, Sweden). Supply and exhaust temperatures were measured with Dostmann P650 instrument and 271A sensor (±0.03 °C accuracy). Room air temperature and relative humidity was measured with Miran DSL logger (accuracy T ±0.3 °C, RH ±1.8 %).

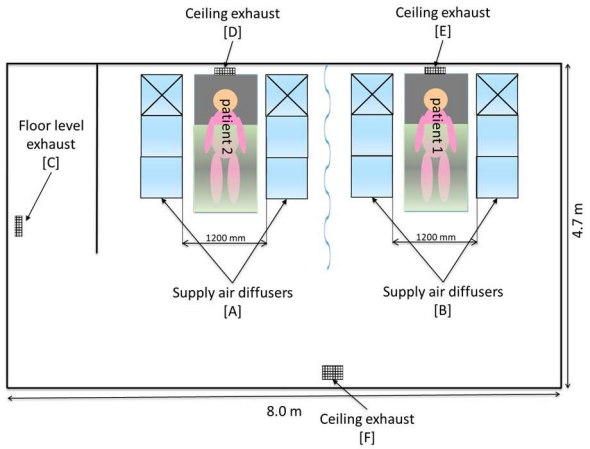

Fig. 5. The layout of the patient room and positions of inlets and outlets. The blue wavy line shows the position of the curtain when it was used between patient beds.

Table 1. Airflow rates of each inlet and outlet, and the total airflow rates in all tested conditions. +/- sign indicates the direction of the airflow (+inlet, -outlet). Inlet B had always the same airflow rate as inlet A, Outlet C had always the airflow rate of -30 l/s, and D and E -15 l/s each.

Test cond.	A [l/s]	F [l/s]	SUM, inlets [l/s]	SUM, outlets [l/s]
1	+30	0	+60	-60
2	+70	-80	+140	-140
3	+70	-80	+140	-140
4	+200	-340	+400	-400

Tracer gas measurements were conducted to quantitatively assess the exposure of the patient 2 to the patient 1 exhaled air (Figure 1). Sulphur hexafluoride (SF6) was distributed with tube (diameter 0.009 m) through patient 1 nose to simulate the spreading of airborne infections. The outflow from nose consisted of 0.15 l/min raw SF6 mixed with 10 l/min fresh air. The exhaled air of the patient 1 (a mixture of SF6 and fresh air) was heated to 50 °C to compensate for the density difference between SF6 and air. The tracer gas concentration was measured from the exhausts and from next to patient 2 head. The sampling was carried out with a multi-gas analyzer (Gasera One Pulse, Gasera Oy, Finland). The background concentration was measured before and after the experiment. After the tracer supply was turned on, it was waited for an hour to reach steady state conditions before measuring the exhaust concentrations. Then the actual exposure of patient 2 was monitored for an hour. After the patient 2 exposure monitoring was over, the exhaust concentrations were again monitored for half an hour each. The sampling interval was about 20 s. As a result, an average of concentration near exposed patient 2 head, an average of concentration in exhaust air, and normalized concentration (i.e., divided with average exhaust concentration) are shown.

6 Results

The mean tracer gas concentration in all exhausts and next to patient 2 (exposed) head is shown in Table 2 together with the normalized concentration. As expected, the tracer gas concentration in the exhaust decreased with increased airflow rate. The normalized concentration was lowest in the condition 4, which had the highest airflow rate. Changing the amount of active nozzle rows (test conditions 2 and 3) did not affect the normalized concentration when the curtain was not used (pulled next to the wall), but when the curtain was between the patient beds, the normalized concentration was higher in condition 3 having greater amount of active nozzle rows. In all tested conditions, the normalized concentration was lower when the curtain was between the patient beds than when it was pulled next to the wall.

Table 2. The mean values and standard deviations (in brackets) of the tracer gas SF6 concentrations (ppm) measured from next to patient 2 (exposed) head and from all exhausts, and the normalized* concentration for patient 2 (exposed). The column named Noz. shows the amount of active nozzle rows. The column named Curt. describes weather the curtain was between the patient beds (Yes) or pulled next to the wall (No).

Test cond.	Noz.	Curt.	Patient 2 (exposed)	Exhaust (all)	Patient 2*
1	2	No	23.8 (3.8)	34.4 (10.6)	0.69
		Yes	22.5 (1.5)	35.0 (10.8)	0.64
2	2	No	9.9 (1.1)	14.1 (3.7)	0.70
		Yes	**6.8 (0.8)**	**14.8 (6.2)**	**0.46**
3	4	No	10.1 (1.3)	14.4 (8.1)	0.71
		Yes	9.3 (0.8)	14.2 (8.1)	0.65
4	4	No	3.5 (0.5)	5.9 (5.0)	0.59
		Yes	**2.0 (0.3)**	**5.3 (4.4)**	**0.39**

*Normalized with (i.e., divided by) average exhaust concentration

The normalized concentrations for each exhaust are shown in Table 3. Table 3 shows that the protective ventilation was able to prevent the tracer gas to spread evenly to the patient room. Exhausts D (patient 2) and C (toilet), which are closest exhausts to patient 2 (exposed), had lower normalized concentrations than exhausts E (patient 1) and F (opposite wall). This was seen in all test conditions with and without curtains, except in test condition 4 with no curtains, where the normalized concentration in exhaust E (patient 1) was highest and exhaust F (opposite wall) had similar value than exhausts C (toilet) and D (patient 2).

Table 3. The normalized* tracer gas concentration in each exhaust. The column named Noz. shows the amount of active nozzle rows. The column named Curt. describes weather the curtain was between the patient beds (Yes) or pulled next to the wall (No). Toilet exhaust C was at floor level. The other exhausts (D: patient 2, exposed; E: patient 1, source; and F: opposite wall) were in the ceiling. Exhaust F (Opposite wall) was not used in test condition 1.

Test cond.	Noz.	Curt.	C*	D (patient 2)*	E*	F *
1	2	No	0.82	0.83	1.34	-
		Yes	0.89	0.75	1.34	-
2	2	No	0.68	0.97	1.26	1.11
		Yes	0.52	0.67	1.35	1.38
3	4	No	0.63	0.65	1.87	0.84
		Yes	0.71	0.59	1.84	0.84
4	4	No	0.46	0.61	2.39	0.56
		Yes	0.35	0.40	2.29	0.89

*Normalized with (i.e., divided by) average exhaust concentration

7 Practical interpretation of the results

Below notions may be drawn to highlight the practical implications of the results:

Protective flow concept provides enhanced protection against in-ward exposure between patients, 30% as a minimum, in all situations.

The bolded test condition **2Y** represent treatment situation, which is the most critical exposure situation in a patient room. When using protective flow temporarily with enhanced airflow, 1.3 times the basic airflow rate, it is possible to reduce the exposure risk by a factor of 5 (35/6.8) compared to traditional ventilation system with fixed airflow rate and mixing ventilation. Such a functionality would enable reaching high degree of protection without penalty in energy consumption.

In multi- patient isolation room, test condition **4Y**, the protective airflow reduced exposure by 2.5 times compared to traditional mixing ventilation used in [1].

8 Conclusions

The protective ventilation was able to keep the normalized concentration below 0.72 near exposed patient's head in all four test conditions. It prevented the tracer gas from spreading evenly to the patient room.
The best protection for the exposed patient was found with the highest airflow rate representing an isolation room. In the patient room it was possible to decrease exposure risk by increased airflow rate during active protective mode.
Having the curtain between patient beds, which is a common situation in multi-patient wards, provided additional protection for the exposed patient. This especially, when active protective flow operation mode was in use in both normal patient room and isolation room situations.
The exhaust concentrations varied expectedly so that highest concentration was found close to source and the lowest close to protected patient. Thus, it may be that the total performance could be further enhanced with the more strategical location of the exhausts.

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