Interaction of thermal plumes from a patient wound with mixing and laminar airflow at different room temperatures in two operating rooms at St. Olav's hospital

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Abstract: This study investigated the interaction of the thermal plumes (TP) of the patient´s wound with two different room temperatures, 21°C and 23°C in two operating rooms with mixing (MV) and laminar airflow (LAF)at St. Olav's hospital. The indoor environment parameters such as temperature, air velocity, and turbulence intensity were measured for the investigation of the thermal plume (TP) over the patient's wound with an interrogation area of 100 cm (height) × 60 cm (width). The higher turbulence intensity appeared along the vertical direction with mixing ventilation. In the case of laminar airflow, the high turbulence intensity zone is located in the horizontal direction around the patient's wound which indicates suppression of the buoyancy effect by the downward laminar airflow.

Keywords: Thermal plume, ventilation, operating rooms, air velocity

Introduction

Clean air in operation rooms (ORs) prevents surgical site infections (SSI) [1], which refer to infection at the skin, tissue, or organ level within 30 to 90 days of surgery [2]. Air currents and human movement in the surgical room can relocate the squames and bacteria-carrying particles (BCPs) towards the sterilised area [3], [4]. Studies have demonstrated that BCPs can be also spread around the surgical area due to thermal plumes and contaminate the surgical site [9]. Interaction between the skin of the human body and surrounding air creates a temperature gradient where the convective boundary layer (CBL) around the surfaces of the human body releases a thermal plume (TP) [5][6]. Therefore, thermal plumes (TP) are an energy exchange between the body and its surroundings, causing the air to rise slowly and transporting pollutants with less density than the supply air [7]. The thermal plume (TR) and the convective boundary layer (CBL) of the human body are studied through both numerical and experimental approaches without, and with a breathing manikin in small occupied spaces [5][6][9][9][10], isolation room [4], operating room with mixing, laminar airflow ventilation and their combination [7][11]. The interest to intervene in a significant way to understand the TP and CBL is obvious. Among those studies, there are three main aspects that influence the buoyancy effect of TP and CBL – the different temperatures between the skin and surrounding air, the body position of the manikin, and the velocity of air over the body.

Therefore, understanding the thermal plumes and interaction between different airflows is critical to recognising the airflow pattern in a room and thus the risk of SSI [12]. This study aims to quantify and characterise the impact of two different room temperatures, 21°C and 23°C, on the thermal plume around the patient wound in two different rooms of St. Olav's hospital with mixing (MV) and laminar airflow (LAF).

Experimental set-up

Measurement of temperature, air velocity and turbulence intensity is executed in two operating rooms, MV and LAF with two different room temperatures, 21°C and 23°C, respectively. The operating room with mixing ventilation and 20 ACH has an area of 59.1 m² and a height of 2.9 m while the laminar operating room with 61 ACH has a total area of 56.1 m², of which 11 m² is the rectangular LAF zone, with a room height of 3.08 m.

A female humanoid thermal manikin is 1.7 m tall and located at an operating bed to simulate a patient under stomach surgery. The manikin is covered by the surgical blanket and at the surgical site is cut into the shape of a 20 cm square. The surface temperature of the patient's wound is in the range of 33.5 to 34.5°C measured by the image of the thermal detector Bosch PTD 1 and infrared camera Flir one - iOS.

The sides of the surgical blanket is taped to the manikin as seen in **Figure 2**. The interrogation area of 100cm (height) x 60cm (width) around the wound is measured by seven anemometers SensoAnemo 5100 LSF, 8.5 cm apart, in levels 5, 10, 25, 50, and 100 cm over the wound. Each level is measured for five minutes. Boundary conditions of measurement cases are introduced in the **Table 1**.

Table 1. *Measuring cases.*

Case No.	Type of ventilation [-]	Room temperature [°C]	Supply temperature [°C]	ACH
Case (a)	MV	21	18.9	20
Case (b)	MV	23	23.3	20
Case (c)	LAF	21	21.2	61
Case (d)	LAF	23	22.8	61

Figure 1. In the left, image of the mixing ventilation operating room at St. Olav. In the right, Image of the Laminar airflow operating room at St. Olav Hospital.

Results

Velocity field

Figure 3 represents the velocity results of four scenarios, where cases, (a) and (b), refer to MV and cases (c) and (d) represent LAF. The thermal plume for the case (a), has the highest velocity at 10 cm above the wound. The thermal plume's velocity decreases with increasing distance from the wound and mixes with the

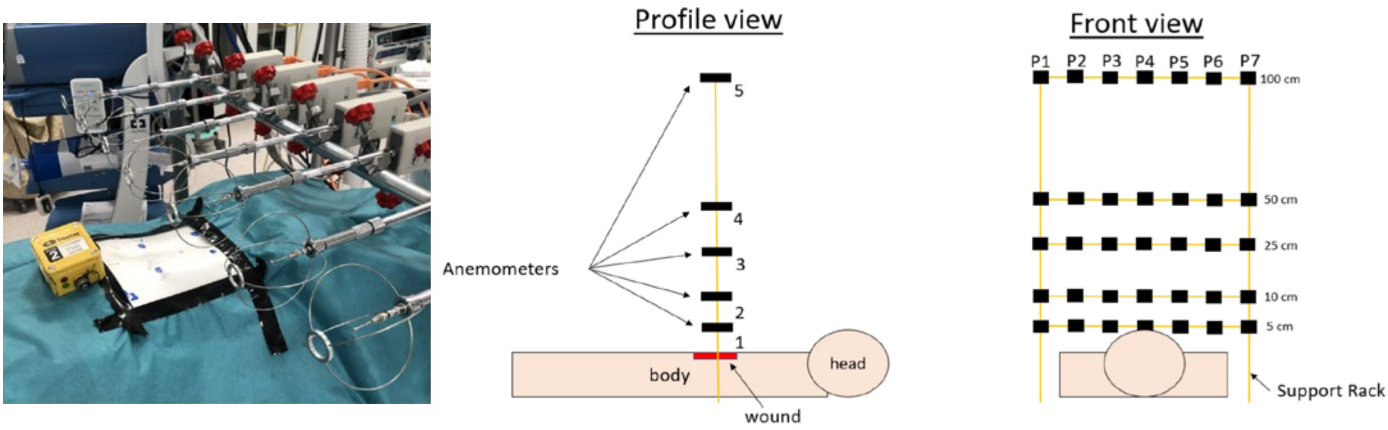

Figure 2. In the left, illustration of anemometers measurement and size of surgical wound. In the right, scheme of measuring points.

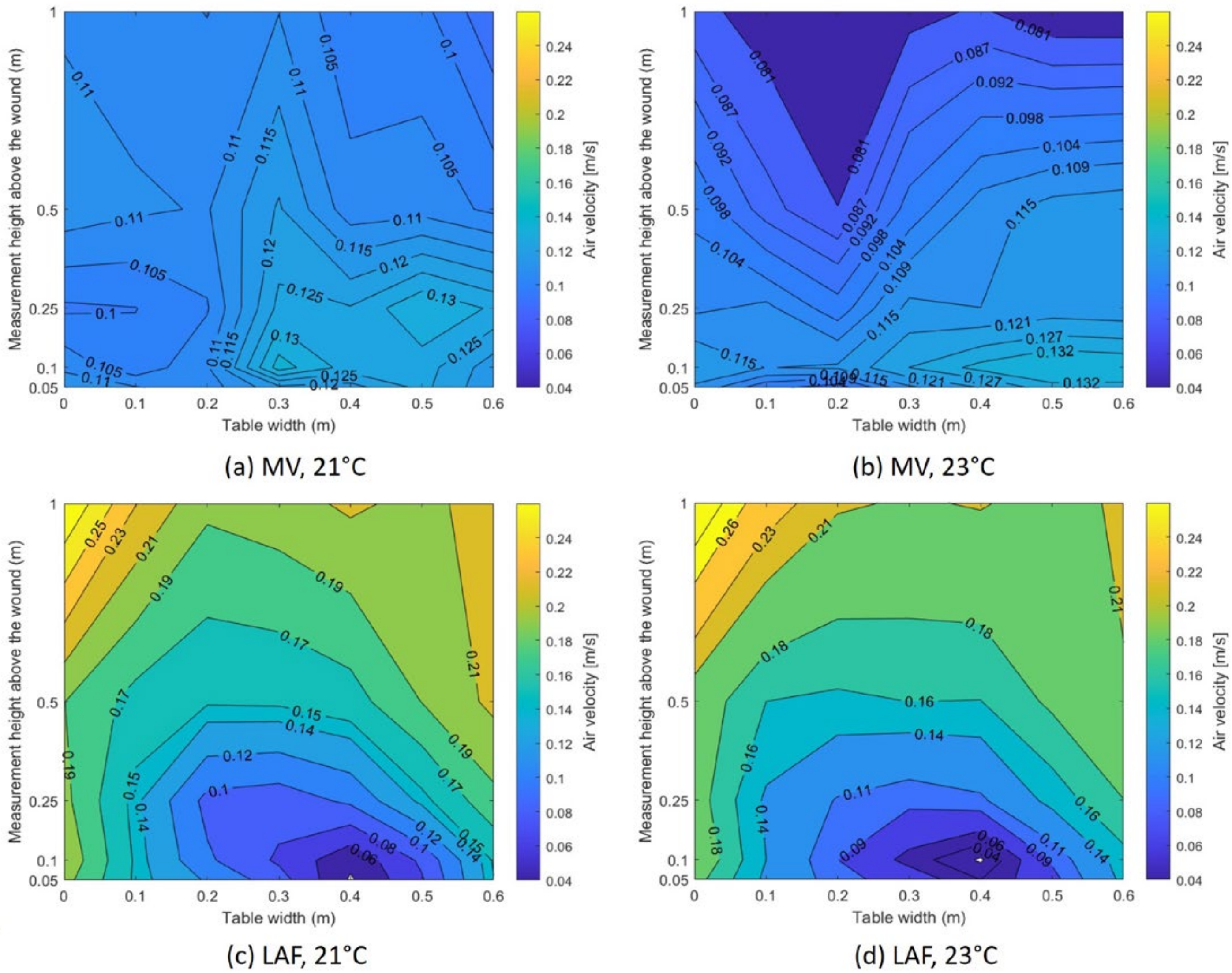

Figure 3. Velocity profile of the patient´s thermal plume of mixing ventilation (a), (b) and laminar airflow (c) and (d).

room air, which is caused by the gradual weakening of the buoyancy effect, respectively. For the case (b) the velocity is lower in the vertical direction than the horizontal direction, which is also proven by temperature stratification in **Figure 5**. In case (c) a higher velocity gradient occurs within 50 cm over the patient's wound than in case (d), which is caused by higher interaction of thermal plume by LAF. In the case (d), due to the lower temperature difference and density difference between laminar airflow and thermal plume, their interaction is observed closer to the wound.

Turbulence intensity and temperature field

Turbulent intensity and temperature are also observed for all four scenarios, case (a), (b), (c) and (d) which are shown in **Figure 4** and **Figure 5**, respectively. Due to higher room temperature in this case (b) by 2°C, **Figure 4** shows that a weaker buoyancy effect occurs, and the thermal plume expands in a horizontal direction. In both LAF cases (c) and (d), laminar airflow is dominated against the buoyancy effect of the thermal plume, respectively. In **Figure 4**, the maximum values of turbulence intensity are observed in the LAF of 40% of cases (c) (d), which are very close to the patient's wound. However, cases of MV (a) and (b) indicate an overall higher gradient of turbulence intensity in the horizontal and vertical directions. In case (a) on both sides is occurs locations with TI up to 23% cause a rising thermal plume, which is possibly observed in the centre of the temperature field. In case (b) is observed area in the vertical direction on the left side and in the upper part of TI up to 30%. This is caused by the expansion of the thermal plume in the horizontal direction and low velocities over the thermal plume which is also observed by stratification on the temperature field. As is mentioned in the previous chapter, case (c) has higher TI above and around the surgical wound than case (d) due to the higher interaction of the thermal plume with LAF.

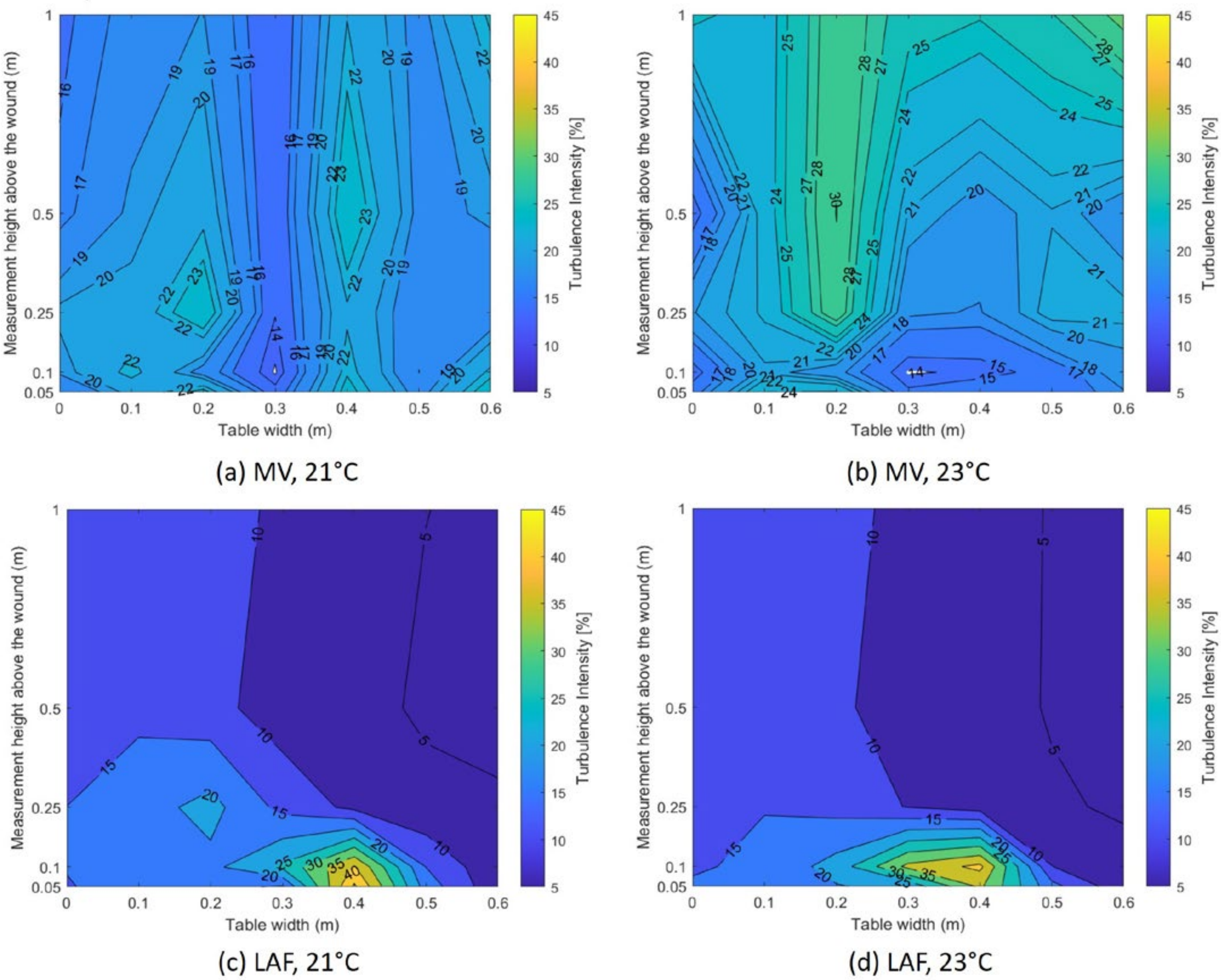

Figure 4. Turbulence intensity profile of the patient´s thermal plume of mixing ventilation (a), (b) and laminar airflow (c) and (d).

Conclusion

This study shows an experimental investigation of the interaction of thermal plumes with mixing and laminar airflow over a patient´s wound at two room temperatures, 21°C and 23°C. By comparing the results of air velocity, temperature, and turbulence intensity of four cases for MV (a), (b) and for LAF (c), (d), the conclusions are summarised as follows:

a) In the cases with a room temperature of 23°C, (b) and (d) observed the expansion of the thermal plume in the horizontal direction, while with a room temperature of 21°C thermal plume directly expanded in the vertical direction.

b) In the case of laminar airflow, a higher room temperature, 23°C, indicates lower turbulence intensity over the patient's wound and surroundings.

c) In the case of mixing ventilation, a lower temperature, 21°C, indicates lower turbulence intensity over the patient's wound and surroundings.

d) Laminar airflow has higher turbulence intensity within 25 cm over the wound than mixing ventilation, while the turbulence intensity with mixing ventilation varies in both vertical and horizontal directions. ■

References

Please find the complete list of references in the html-version at https://www.rehva.eu/rehva-journal

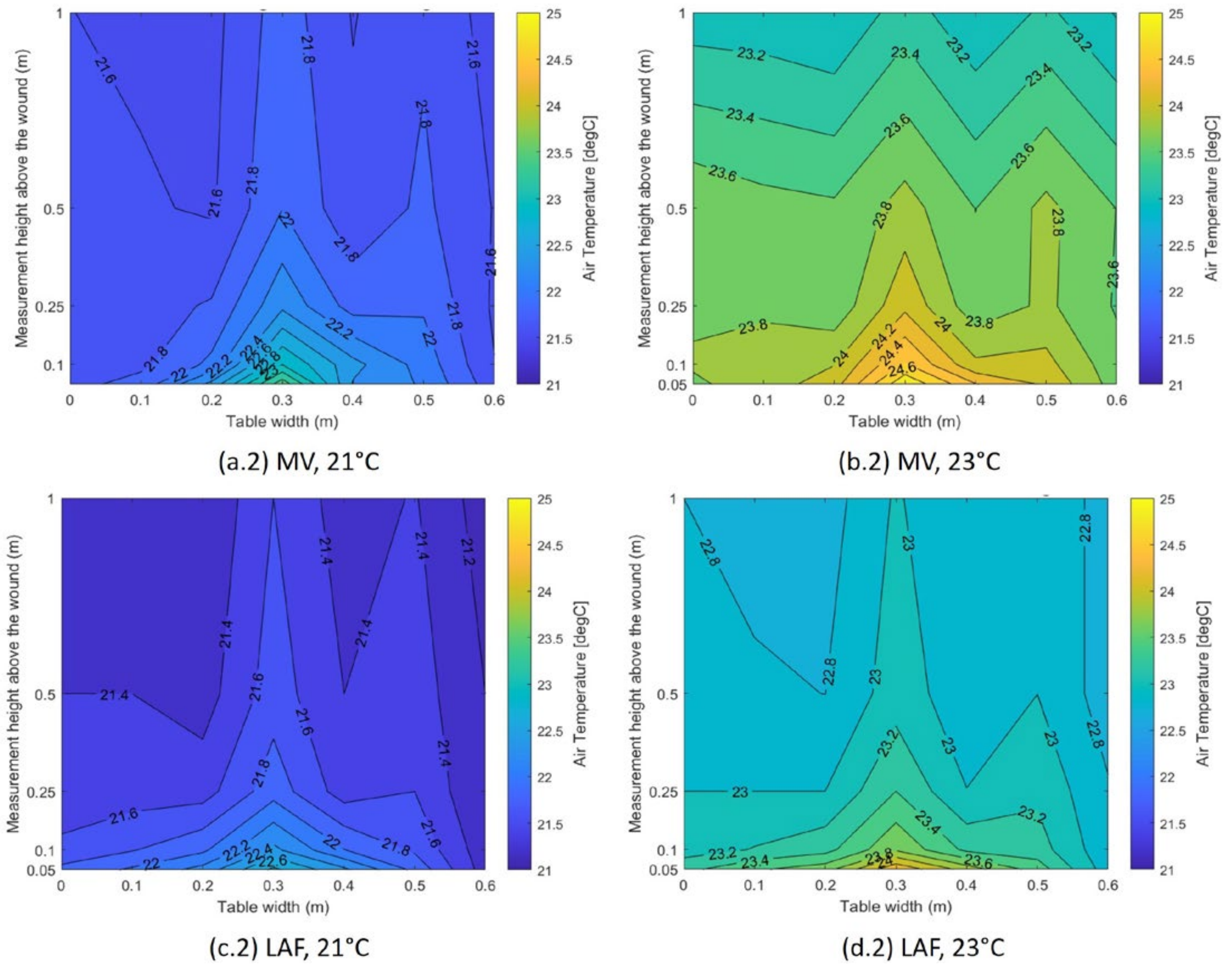

Figure 5. Temperature profile of the patient´s thermal plume of mixing ventilation (a), (b) and laminar airflow (c) and (d).