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Thermal comfort in a ship cabin

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SUMMARY

The aim of this study was to examine the thermal comfort in the cabin environment of a ship. A mock-up cabin was built in the Turku University of Applied Sciences' (TUAS, Finland) HVAC laboratory. The indoor condition was planned and implemented based on the design values found in the standard: the supply airflow rate was $Q=21$ l/s, the room temperature was $T=22$ °C. Three clothing ensembles, and two activity levels were used in thermal manikin measurements. The predicted mean vote, predicted percentage of dissatisfied, and the equivalent temperature were measured. This study highlights the importance of clothing ensemble, activity level and heat load from the external wall on thermal comfort. The results can be used in the planning and development of the thermal environment in a cabin, and other hotel environments with a warm external wall.

KEYWORDS

Thermal comfort; Clothing insulation; Activity level; Thermal manikin; Equivalent temperature

INTRODUCTION

A good indoor environment conditions are an important factor supporting recreation in cruise ship cabins and hotels. User satisfaction is important also for shipowners. There is a lot of research data on thermal comfort in buildings, but only limited information is available on the thermal comfort in cabins.

Thermal environment affects occupants' comfort and wellbeing (Parsons 2003; de Dear et al., 2013; Maula et al., 2016; Dimitroulopoulou et al., 2023). Thermal environment includes air temperature, air speed, and air relative humidity. The mean value of thermal sensation votes of a large group of people can be estimated based on the heat balance model of the human body. This is called the predicted mean vote (PMV) model (ISO 7730, 2005). The model uses the 7-point thermal sensation scale: Cold (-3), Cool (-2), Slightly cool (-1), Neutral (0), Slightly warm (1), Warm (2), and Hot (3). The predicted percentage dissatisfied (PPD) can be determined as a function of PMV (ISO 7730, 2005).

Humans do not sense the temperature alone, but the energy loss from the body. The equivalent temperature (t_{eq}) is the integrated effect of air temperature, mean radiant temperature and air speed. It is defined as "the temperature of an imaginary enclosure

with the mean radiant temperature equal to air temperature and still air in which a person has the same heat exchange by convection and radiation as in the actual conditions” (Nilsson and Holmér, 2003). The equivalent temperature can be calculated with equation 1:

$$t_{eq} = t_s - \frac{R+C}{h_r-h_c} \quad (1)$$

where t_s is the surface temperature (°C), R is radiation heat exchange (W/m²), C is convective heat exchange (W/m²), h_r is radiation heat transfer coefficient (W/m²°C), and h_c is convective heat transfer coefficient (W/m² °C).

The equivalent temperature can be measured with thermal manikin. A heated thermal manikin imitates thermal behaviour of human body. It is used to evaluate thermal comfort, and to measure thermal insulation of clothing. Evaluated thermal comfort parameters include equivalent temperature (t_{eq}), predicted mean vote (PMV), and predicted percentage dissatisfied (PPD).

The fresh supply airflow rate of a cabin is driven by the exhaust airflow needed in the cabins private sanitary room. ISO 7547 (2002) gives the design conditions for a ship cabin. According to the standard, the exhaust airflow in a private sanitary rooms (shower or w.c.) shall be 20L/s or a minimum of 10 air changes per hour, whichever gives the highest value. The sanitary room of a cabin is rather small, about 5 m³, which leads to the use of 20 L/S as exhaust airflow. The sanitary room should be at lower pressure than rest of the cabin. Therefore, 21 L/s is typically used for the cabins' fresh supply airflow rate.

Circulated room air is used for air conditioning. Room air is cooled in a cooling coil and then it is returned into the cabin together with the fresh supply air. This increases the total amount of supply air coming from the air distribution systems to the cabin, and the speed of air movement in cabin areas. Increased air speed can potentially lead to thermal discomfort and draught problems.

The aim of this study is to examine the thermal comfort in a cabin environment. The focus is on how the activity level and clothing insulation affects thermal comfort in cabins.

METHODS

Thermal manikin

Measurements were done with a female thermal manikin Pernille (PT Teknik, Denmark). Movable junctions in neck, shoulder, hip, and knees allow adjustment of the posture simulate real sitting or lying person. The metabolic rate of different activity levels can be provided to the manikin.

Clothing insulation and activity level

Three different clothing ensembles were used in this study (figure 1). The thermal manikin was either sitting in a couch or lying in a bed. All tested clothing ensembles included the effect of a couch or a bed. Figure 2 shows the positions of the manikin during measurements. The measured clothing insulation values, and the used activity levels are shown in table 1.

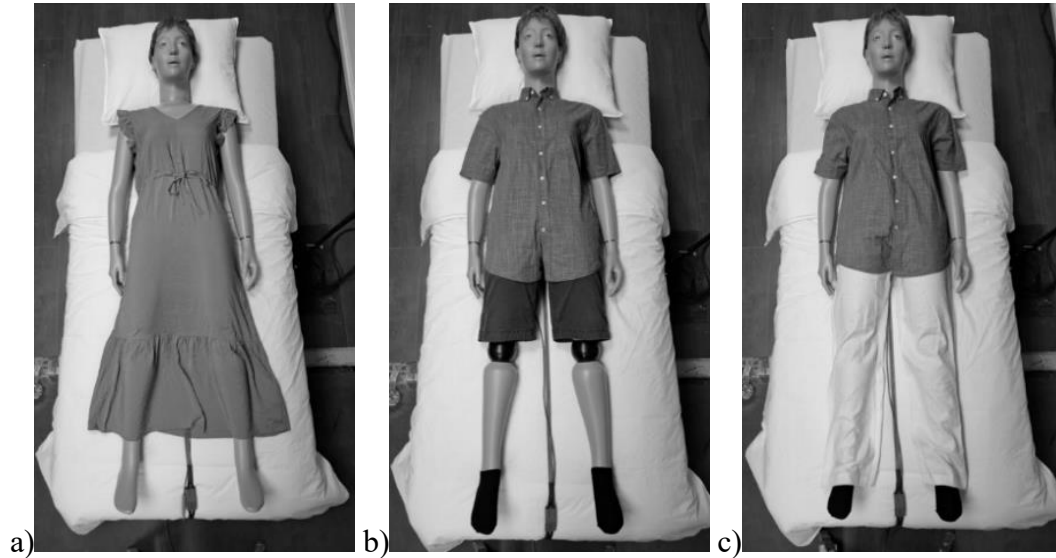


Figure 1. The clothing ensembles used in this study: a) long dress, b) shorts, shirt and socs, and c) pants, shirt and socs. All tested clothing ensembles included underpants and bra.

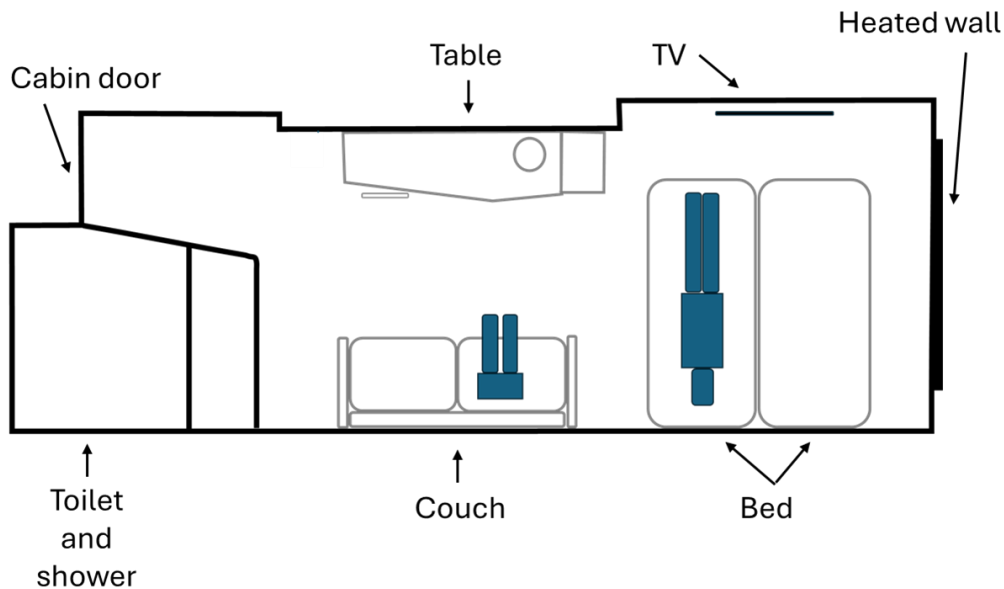


Figure 2. The layout of the cabin (floor area 6.9 m * 2.6 m, and height 2.1 m) and positions of the thermal manikin. The thermal manikin was either sitting in the couch or lying in the bed.

Table 1. The measured clothing insulation values of different clothing ensembles (including the furniture), and activity levels used in the thermal comfort measurements.

| | The clothing insulation | | | Activity level (met) |
|-------|-------------------------|----------------------------------|---------------------------------|-------------------------|
| | Long dress (clo) | Shorts, shirt and socks (clo) | Pants, shirt and socks (clo) | |
| Bed | 0.67 | 0.79 | 0.91 | 0.9 |
| Couch | 0.55 | 0.60 | 0.73 | 1.1 |

Experimental design and conditions

The experiment was carried out in the mock-up cabin at the Turku University of Applied Sciences' (TUAS, Finland) HVAC laboratory (figure 2). The mock-up cabin was constructed of real ship cabin elements, and commercially available ventilation and air-conditioning system. The cabin had a total heat load of 33 W/m² which consisted of lights, two thermal manikins, a TV, and a heated exterior wall representing a warm glazed surface. The wall temperature of a heated wall was adjusted to 31 °C.

The supply airflow was $Q = 21$ L/s, circulated room airflow was $Q_c = 30$ L/s, the cabin air temperature was $T = 22$ °C (measured with Dostmann P650+Pt-100 sensor), and the relative humidity was $RH = 17$ % (measured with Vaisala MI70 + HMP75 sensor). The local air speed was $v < 0.1$ m/s (measured with Dantec hot- sphere anemometer). The supply airflow and airflow patterns in the cabin are described in an article by Sivula et al. (2025). The test conditions were planned and implemented based on the design values found in the standards DNV (2021) and ISO 7547 (2002).

The equivalent temperature, the predicted mean vote and the predicted percentage dissatisfied was measured with the thermal manikin to all clothing ensembles and both activity levels. Figure 2 shows the thermal comfort measurement positions. The equivalent temperature is measured continuously from the actual heat loss of the manikin. The predicted mean vote and the predicted percentage dissatisfied are calculated when the manikin has reached a steady state condition.

RESULTS

Table 2 shows the PMV, PPD, and the equivalent temperature for each clothing ensemble and activity level. The PMV was highest with highest clothing values (pants, shirt and socks), and lowest in the bed with long dress. The equivalent temperature is higher in the bed than in the couch in each clothing ensembles.

Table 2. The predicted mean vote (PMV), predicted percentage dissatisfied (PPD), and the equivalent temperature T_{eq} for each clothing ensemble and activity level. The equivalent temperature is the mean value for the whole manikin.

| Activity level | | PMV | PPD (%) | T_{eq} (°C) |
|--------------------|-------------------------|------|---------|---------------|
| 1.1 met (couch) | Long dress | -1.0 | 25 | 22.6 |
| | Shorts, shirt and socks | -0.7 | 15 | 23.2 |
| | Pants, shirt and socks | -0.5 | 10 | 22.9 |
| 0.9 met (bed) | Long dress | -1.3 | 38 | 23.8 |
| | Shorts, shirt and socks | -1.1 | 31 | 23.4 |
| | Pants, shirt and socks | -0.9 | 20 | 23.5 |

DISCUSSION

The purpose was to study how the activity level and clothing insulation affects thermal comfort in cabins. The indoor condition was planned and implemented based on the design values found in the standard ISO 7547 (2002).

The equivalent temperatures were higher in the bed than in the couch. This is due to the heated wall representing a warm glazed surface, since the bed is closer to the heated wall than the couch. Also, the bed acts as an obstacle between the heated wall and the legs of a person sitting in a couch. Long dress had the lowest clothing insulation and also the PMV value was lower with long dress than other clothing ensembles. Similarly, Pants, shorts and socks had the highest clothing insulation, and highest PMV value. The used activity level values were different between the two measurement places, which affected the PMV value.

CONCLUSIONS

The thermal comfort in a cabin environment was studied with thermal manikin. This study highlights the importance of clothing ensemble, activity level and heat load from the exterior wall on thermal comfort. The results can be used in the planning and development of cabins. Although this study was conducted in a cabin, these results can be useful in many kinds of rooms where one wall is a warm external wall. Due to the diversity of affecting physical parameters related to indoor environment or the clothing insulation values, more research in this topic is needed.

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