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Radiant Ceiling Panels Combined with Localized Methods for Improved Thermal Comfort of Both Patient and Medical Staff in Patient Room

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SUMMARY
The objectives were to identify whether ceiling installed radiant heating panels can provide thermal comfort to the occupants in a patient room, and to determine a method for optimal thermal environment to both patient and medical staff simultaneously. The experiments were performed in a climate chamber resembling a single-bed patient room under convective air conditioning alone or combined with the ceiling installed radiant heating panels. Two thermal manikins simulated a patient lying in the bed and a doctor standing next to the patient. Conventional cotton blanket, electric blanket, electric mattress were used to provide local heating for the patient. The effects of the methods were identified by comparing the manikin based equivalent temperatures. The optimal thermal comfort level for both patient and medical staff would obtained when two conventional cotton blankets were used with extra clothing for the patient, at room air temperature adjusted to be comfortable for the doctor.

KEYWORDS
Hospital environment, local heating, radiant heating panels, thermal manikin, equivalent temperature

INTRODUCTION
An optimal thermal environment is important for the quick recovery and comfort of patients and for the working efficiency and comfort of healthcare workers. However, patients and healthcare workers often require different thermal indoor conditions (Skoog et al. 2005; Hashiguchi et al. 2005; Khodakarami et al. 2007). That is caused by the difference in their physical activity levels and physiological states. Therefore, the existing systems and methods designed to provide a uniform thermal environment in hospital rooms fail to provide an optimal thermal environment for both patients and medical staff at the same time.

Radiant heating/cooling systems installed in the ceiling have the potential to reduce draft. Under radiant cooling system, twice as many subjects reported that they did “not feel air flow” compared to those under the case of convective system (Kawakami et al. 2011). However, an optimal control approach for a radiant heating/cooling system still remains to be defined. There are few studies on the thermal comfort of patients in hospital wards under ceiling installed radiant heating panels using human subjects (Smith et al. 1977). Nagano et al. (2001) indicated that installing cooling panels on the ceiling saves energy because the occupants are most comfortable at 27.3°C, which is 1.3°C higher than the maximum temperature of 26 °C recommended for the comfort zone in ASHRAE Handbook. On the other hand, Itoigawa et al. (2007) indicated that lower operative temperature was required to provide thermal comfort for men in a patient room in the case of radiant cooling system compared to the case of convective air conditioning.

The use of individually controlled systems for providing thermal comfort locally at the bed of each patient, while keeping the background thermal environment comfortable for healthcare workers may be one solution to achieve an optimal thermal environment for both patients and healthcare workers at the same time. The objectives of this study were to identify whether the operation of ceiling installed radiant heating panels can provide thermal comfort for occupants in a single-bed hospital patient room, when the air temperature was set to be lower or higher than the temperature comfortable for medical staff, and to determine a method for providing optimal thermal conditions for both patients and medical staff simultaneously. Different local heating methods for the patient were examined with or without the radiant heating system on the ceiling.

METHODS

Experiments were performed in a climate chamber with dimensions of 4.7 × 5.9 × 2.5 m^3 (W × L × H). Low velocity (<0.07 m/s) was achieved by an upward "piston flow" ventilation. A metal frame with wall surfaces covered with vinyl material was constructed with dimensions of 2.4 × 2.8 × 2.3 m^3 (W × L × H) to support the ceiling installed radiant panels used for the experiment. Heated water was continuously supplied to the panels during the experiment to maintain the surface temperature constant. The surface temperature of the ceiling panels was continuously measured at eight points during the experiment. The air temperature (t_a) and operative temperature (t_{op}) were also continuously measured at four heights (0.1, 0.6, 1.1, and 1.7 m) above the floor on a stand located on the right side of the bed; 0.9 m away from the wall (head side of the bed); and 0.3 m away from the bed. The radiant temperature asymmetry (RTA) was measured at 1.1 m above the floor close to the first stand for each experimental condition tested. The relative humidity was kept at approximately 50 % during the experiment.

A bed was placed in the middle of the inner chamber with the head side touching one of the walls. The bed had a mattress covered with a thin cotton sheet, a quilt enveloped in light cotton bed lining, and a feather pillow. Two thermal manikins closely resembling the complex body shape of an average Scandinavian woman of 1.7 m height were placed in the inner chamber. One of the thermal manikins was used to simulate a patient lying in the bed. Its body consisted of 23 body segments. The other thermal manikin was used to simulate a doctor standing on the left side of the bed at a distance of 0.3 m. Its body consisted of 17 body segments. The segments were separately controlled to maintain the surface temperature equal to the skin temperature of a person in a state of thermal comfort. The dry heat loss and surface temperature of each segment measured with the manikins were used to determine the equivalent temperature (t_{eq}) which was defined as the temperature of a uniform enclosure in which a thermal manikin with realistic skin surface temperatures would lose heat at the same rate as it would in the actual environment (Tanabe et al. 1994) The manikins were calibrated prior to the experiments. The patient manikin was dressed in typical hospital pajamas with a basic clothing insulation of 1.0 Clo (obtained from the experiment, with the manikin on the bed). The doctor manikin was dressed in typical healthcare worker clothing consisting of a T-shirt, apron with short sleeves, trousers, socks, and sneakers with a basic clothing insulation of 1.1 Clo (obtained from the reference case mentioned below). Figure1 shows the experimental set-up.

Two reference cases (RC_{20} and RC_{24}) were studied at room air temperatures of 20 °C and 24 °C: considered to be thermally comfortable for the medical staff, and the patients lying on the bed and covered with one conventional cotton blanket, respectively. These air temperatures were determined prior to the experiment, based on Predicted Mean Vote (PMV) within the comfort range (-0.5 to 0.5). The experiment consisted of two main conditions:

Convective Air Conditioning Cases (CACC) at a set room air temperature of 20 °C, and *Radiant Heating Cases* (RHC) at a set room air temperature of 18 °C combined with the radiant panels operated in heating mode. Under each condition, different local heating methods for the patient were used: *one conventional Cotton Blanket* (1CB); *two conventional Cotton Blankets* (2CB); *Electric Blanket* (EB) with seven heat-power levels. In all studied cases, the EB was placed over the patient manikin; *Electric Mattress* (EM) divided into an upper and lower part. Each of these parts could function in low, middle, and high power modes independently. The combinations used of upper/lower parts of EM were Low/High for CACC and Low/Low for RHC. The EM placed below the patient manikin was used with one CB placed over the patient manikin (CB & EM).

Figure 1. Experimental set up

The experimental procedure was as follows: the chamber target temperature was set, the manikins were switched on, and the devices used for local heating were switched on. The ceiling installed radiant panels were operated only during RHC. The thermal environment in the chamber was initially controlled with respect to the doctor's comfort level (the heat loss measured for studied conditions were close to that measured for RC_{20}): for the CACC, the room air temperature was same as that in RC_{20}, and no system was used to heat/cool the doctor manikin. During RHC, the supplied water temperature in the ceiling installed radiant panels was controlled at 47.9-48.6 °C and constantly monitored.

RESULTS

1 Thermal Environment

Figure 2 shows the operative temperature and the air temperature under every studied condition. For RCs and CACC, t_{op} and t_a were very close to each other as well as to the target chamber air temperature. In contrast, t_{op} and t_a for RHC at high heights (1.1 and 1.7 m) were higher than those measured at low heights (0.1 and 0.6 m) because of the heated ceiling. Vertical air temperature difference between 0.1 m and 1.7 m was below 1.0 K for RC and CACC and 2.7 K for RHC; these results meet ASHRAE 55-2010 recommendations of maximum 3 K. The radiant temperature asymmetry between the ceiling and floor was around 8.5 K for RHC, whereas it was below 0.5 K for RC and CACC. The RTA for RHC was higher than that recommended in ASHRAE 55-2010, and the percentage dissatisfied (PD) caused by RTA resulted in 15 %. The surface temperature of the ceiling panels was 21–22 °C for RC and CACC and 30.4–32.9 °C for RHC.

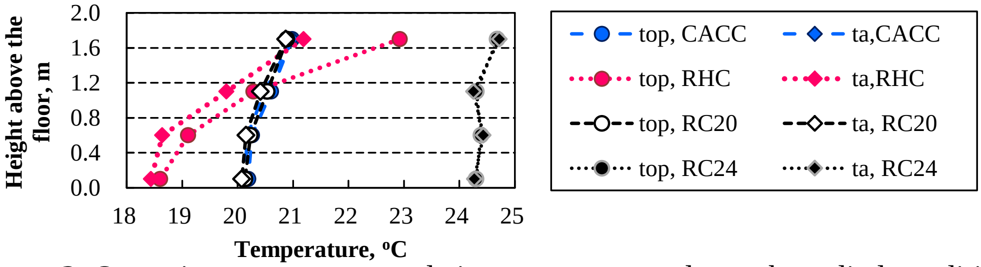

Figure 2. Operative temperature and air temperature under each studied condition

2 Manikin Measurements

The difference (Δt_{eq}) between the equivalent temperatures determined for the reference cases (RC_{20} for doctor and RC_{24} for patient) and all studied conditions was used to assess each studied thermal environments. Δt_{eq} shows by how many degrees cooler or warmer each studied environment was perceived compared to the environment at the reference temperature. With regards to the doctor, Δt_{eq} for all body segments was less than ±0.5 K for CACC and less than ±2.0 K for RHC; Δt_{eq} for whole body was less than ±0.1 K for CACC and between -0.8 K and -0.6 K for RHC. Based on the patient's Δt_{eq} for whole body, the EB placed over the body resulted in a thermal environment closest to the reference case for both CACC and RHC. EM placed below the patient manikin combined with a CB placed over the patient manikin (CB & EM) also resulted in a thermal environment close to the reference case for CACC and RHC. However, CB & EM showed quite elevated values for the equivalent temperature for some body parts, such as low legs, back side, and back of patient. (Figure 3 and 4)

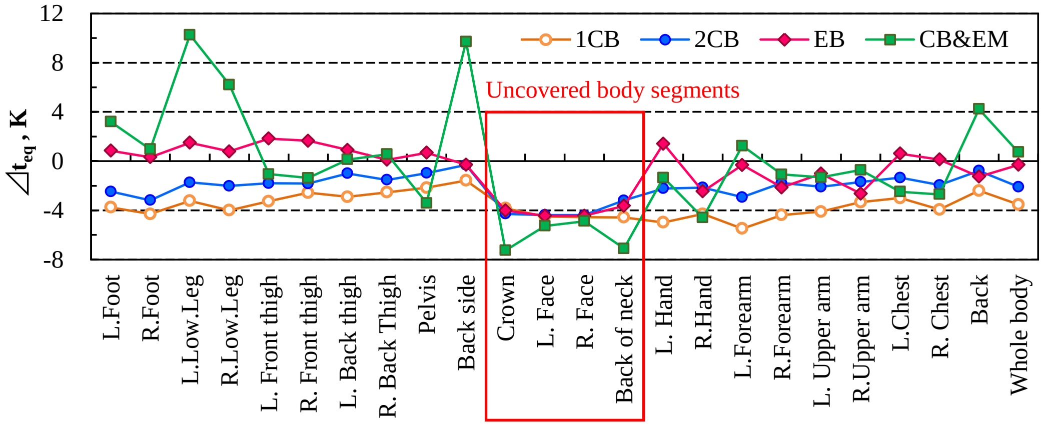

Figure 3. Patient's Δt_{eq} for CACC: room air temperature set to 20 °C

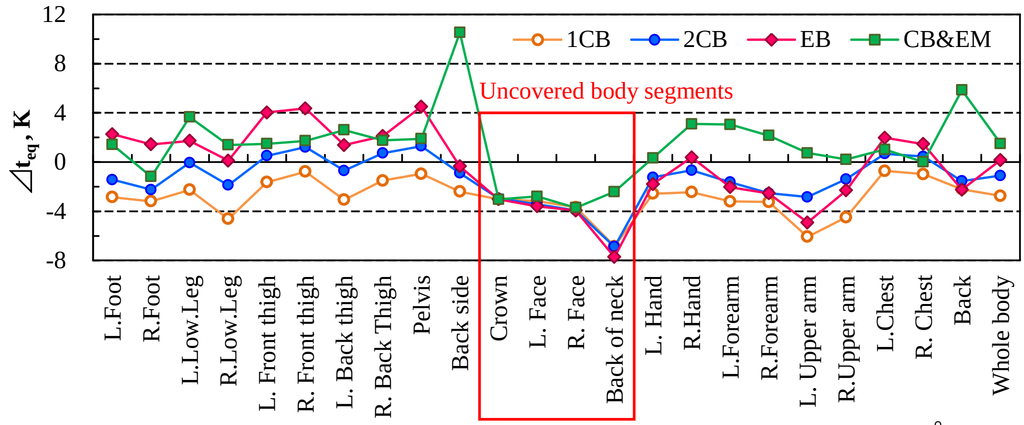

Figure 4. Patient's Δt_{eq} for RHC: room air temperature set to 18 °C

The difference between the equivalent temperatures determined for the conditions under study with and without operation of the ceiling installed radiant heating panels was calculated to show the effect of the radiant heating panels on the thermal perception of the occupants. For the lying patient, the effect of the radiant heating panels on body parts covered with clothing or the conventional cotton blanket was less than when the same body parts were uncovered. The equivalent temperature for whole body when the dressed patient was covered with 1CB decreased by 4.0 K compared to when the patient was naked (Figure 5). For the standing doctor manikin, the effect of the radiant heating panels on the body parts covered with clothing was less than when the same body parts were uncovered. The equivalent temperature for whole body of the dressed doctor decreased by 1.0 K compared to when the doctor was naked (Figure 6). The ceiling installed radiant heating panels affected the lying manikin on the bed much more than the standing manikin (Figure 5 and 6).

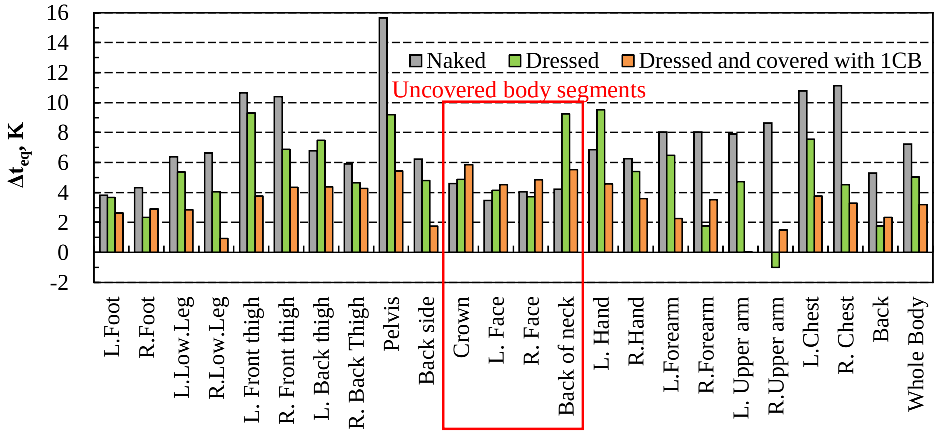

Figure 5. Effect of the radiant heating panels on the patient manikin lying on the bed

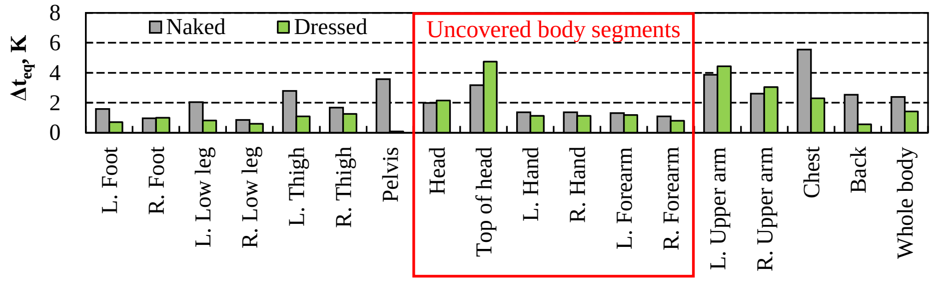

Figure 6. Effect of the radiant heating panels on the standing doctor manikin

DISCUSSION

The results revealed that some methods for local heating at the bed can provide the patient with a thermal environment close to the reference level when the background room air temperature is set to provide optimal thermal environment for the doctor. However, non-uniformity in the local heat loss from the body parts existed when some electric devices were used for local heating of the patient. This may lead to local thermal discomfort for patients even though the equivalent temperature of the whole body may be close to the reference level. In contrast, the cotton blanket conditions, with 1CB and 2CB, resulted in lower change in the heat transfer of the body compared to the tested electric devices (EB and EM), but provided a much more thermally uniform micro environment at the bed. In particular, the equivalent temperature of the whole body for the case with 2CB under RHC, when the radiant heating panels were operational, was very close to the reference case with room air temperature of 24 °C. If more insulation (reducing the heat loss) is provided, through the use of socks and cardigan, to the body segments whose t_{eq} is lower than the reference case (feet and arms), the case with 2CB would be the optimal method for making the lying patient comfortable. Adding another cotton blanket could be assumed to provide additional insulation to the existing 2CB; however, the effect of adding second blanket on the heat loss from the body was lower than that when providing the first blanket. Furthermore, Sessler et al. (1993) reported that increasing the number of covering blanket from one to three only slightly reduced the heat loss. Also, three or more blankets could be heavy and not very comfortable (prevent free movement) for the patients.

The results showed that the ceiling installed radiant heating panels can provide a thermal environment close to the reference level for both patients and medical staff in a hospital room where the set air temperature was lower than that of the reference case (with 2 K for the staff and 6 K for the patient). The radiant heating panels affect the lying manikin more than the standing manikin, although covering the manikin with a cotton blanket significantly reduced the effect of the radiant heating panels. Therefore, radiant heating panels are more effective than increasing the room air temperature of patient rooms for patients who cannot use local heating methods such as blankets, due to their medical treatment procedures or physical conditions. Raising the air temperature over a wide range may lead to thermal discomfort for the medical staff as well. Also, the use of patient bed incorporated methods for thermal comfort or ceiling installed radiant heating/cooling can provide higher flexibility of the hospital ventilation and conditioning units: the supply temperature of conditioned air will be the same in all patient areas and by those local means the required temperature can be achieved based on the recommendations in ASHRAE. This strategy will also allow for individual patient and staff preferences. When the radiant heating panels were operated, the radiant temperature asymmetry was higher than that recommended, although the vertical air distribution was within ASHRAE 55-2010 standards. More research, including experiments using human subjects, are needed to evaluate the thermal comfort for a lying and standing person under ceiling installed radiant heating panels in operation.

CONCLUSION

The optimal way to achieve thermal comfort for both patient and medical staff simultaneously would be to use two conventional cotton blankets with extra clothing for a patient in a room set to be thermally comfortable for the doctor/medical staff. The ceiling installed radiant heating panels affect the lying person more than the standing person, although the cotton blanket covering the lying manikin substantially reduces the effect of the radiant heating panels. The use of the radiant heating panel system may prove to be an effective way to control the hospital ward thermal environment.

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