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Understanding thermal comfort perception of nurses in a hospital ward work environment

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ABSTRACT

In indoor comfort research, thermal comfort of care-professionals in hospital environment is a little explored topic. To address this gap, a mixed methods study, with the nursing staff in hospital wards acting as participants, was undertaken. Responses were collected during three weeks in the summer (n = 89), and four weeks in the autumn (n = 43). Analysis of the subjective feedback from nurses and the measured indoor thermal conditions revealed that the existent thermal conditions (varying between 20 and 25 °C) caused a slightly warm thermal sensation on the ASHRAE seven point scale. This led to a slightly unacceptable thermal comfort and a slightly obstructed self-appraised work performance. The results also indicated that the optimal thermal sensation for the nurses — suiting their thermal comfort requirements and work performance — would be closer to 'slightly cool' than neutral. Using a design approach of dividing the hospital ward into separate thermal zones, with different set-points for respectively patient and care-professionals' comfort, would seem to be the ideal solution that contributes positively to the work environment and, at the same time, creates avenues for energy conservation.

1. Introduction

Hospitals are designed with hygiene and safety as the main parameters, often making thermal comfort a secondary concern [1,2]. Several studies conducted to examine thermal comfort in hospitals have focused on the situation in operating rooms and on patients [3–9]. Field studies in hospital wards, focusing on the caretakers, are less common [2,10,11]. Patients are likely to have different thermal requirements from the caretakers due to their health related effects, difference in clothing levels, and markedly different activity levels [10]. However, this does not often make it to design considerations. The implications could be twofold: less attention paid to difference in thermal comfort needs of patients vis-a-vis caretakers and less attention paid to the effect of thermal comfort on the work performance of the caretakers.

At the same time, thermal comfort research and corresponding standards [12,13] have primarily focused on comfort of occupants during steady state whereas the nursing staff have to continuously move around and are, on an average, a lot more active than typical office personnel. Multiple experiments, regarding occupants in transitional situations, both spatial and temporal, have been executed in laboratory settings [14–16]. Studies in field settings, involving actual occupants, are rare [17,18]. Some such studies have indicated the importance of the prior location's thermal conditions and that the gradual attuning to their current thermal conditions may require occupants nearly 20 min [18,19].

This work was hence organised as a pilot exercise in addressing the research gap regarding thermal comfort studies involving care-professionals in hospitals and their thermal comfort perception through their active work schedule. The intention was to better understand the thermal perception and thermal comfort requirements of nurses during their work hours and how their thermal perception possibly impacts their work performance. It is expected that these results can be used as starting ground for future research, as well as stimulating recognition of thermal comfort requirements of nursing staff during design stage of hospital wards.

The case study was taken up in two wards of a hospital. Based on the methods developed through a previous study [18], the current field investigation was organised and the aspects that needed to be considered for occupants moving across different thermal conditions were decided upon. Parameters focused on were clothing levels, activity levels, and the thermal conditions encountered by the nurses.

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Fig. 1. Floor plan of the wards, east and west, where the study was undertaken. A–H: locations of the 8 Rotronic sensors. 1–3: locations of the 3 indoor climate measurement stands (ICMS).

2. Methods

The study was executed in two wards of a hospital in the Netherlands, from July 11th till July 29th (summer) and October 7th till November 11th (autumn), 2016. During the study, objective and subjective data were obtained to determine thermal comfort perception of the nursing staff. The two measurement periods were so chosen as to have representative observations from summer and autumn season. A floor plan of the wards has been provided in Fig. 1. The middle of the V-shape separates the east and west oriented wards. Each ward consists of six one-person, six two-person, and four six-person patient rooms. All patient rooms are located near the perimeter. The reception, medicine room, staircase and staff rooms, such as meeting room and chief's office, are positioned towards the core of the building, keeping them ~8 m away from the building envelope. All the rooms in the wards that nurses had to move across due to work requirements, were monitored: patient rooms, reception, meeting room, break room, and medicine room.

2.1. Study participants

The target group in this research was the nursing staff. The focus was on their thermal comfort perception and its perceived influence on their work. As gathered from the hospital administration, there had been generic complaints from the nursing staff regarding the indoor environment causing warm discomfort. The general demographic of the participating nurses has been summarized in Table 1, along with the thermal conditions they faced during these investigations.

The distance between the hospital entrance and the ward is a ~ 5 minutes walk. When the nurses come in for their shift, they stop in the changing room in the basement to put on their uniforms. So, from entering into the building to entering into the ward, they had to spend upwards of 30 min. Due to this time gap, the direct effect of outdoor–indoor transitions was excluded since past studies showed that this effect lasts about 20 min [18,19]. Throughout the year, the nursing staff is obligated to wear the same work clothing, shown in Fig. 2, with the choice for an additional vest (represented along with the uniform). More clothing may be worn as long as it does not constitute the outermost layer. This is for reasons of uniformity and hygiene. Fig. 3a) represents the nurses' work schedule, indicating the typical transitions they made during their shift, as gathered from the head nurse.

Table 1
Demographics and general thermal conditions.

		Summer	Autumn
Demographics		**Responses**	
Total	N	89	43
Age	Mo [perc]	21-30 [75.3]	21-30 [53.5]
Gender	Mo [perc]	Female [64.0]	Female [76.7]
Work length	Mo [perc]	>3 months [92.8]	>3 months [87.8]
Work shift	Day	49 [66.2]	14 [32.6]
(n [perc])	Evening	16 [21.6]	20 [46.5]
	Night	9 [12.2]	9 [20.9]
Outdoor conditions			
T_{out} (°C)	M [SD]	18.7 [4.0]	9.7 [3.5]
	Max.	32.2	18.7
	Min.	8.4	−0.4
RH (%)	M [SD]	78 [15]	86 [11]
Solar radiation (J/cm^2)	M [SD]	74 [87]	26 [43]
Indoor conditions			
$T_{air;shiftmean}$			
$T_{air;in}$ (°C)	Day	23.5[0.7]	22.4[0.7]
(M [SD])	Evening	23.6[0.8]	22.5[0.7]
	Night	23.2[0.7]	22.3[0.8]
RH (%)	Day	54.1[2.5]	40.3[2.7]
(M [SD])	Evening	52.5[2.9]	40.3[2.4]
	Night	54.1[2.6]	38.9[2.6]

2.2. Objective measurement of indoor thermal conditions

Objective indoor environmental measurements were performed and surveys were conducted in three phases: during summer, during autumn, and a set of preliminary measurements. Measurement data was collected at several positions in the wards. These positions were determined during preliminary measurements.

The purpose of the preliminary measurement — carried out two weeks prior to first survey period, for two days, in multiple locations around both wards — had been to determine presence of thermal non-uniformities, thermal stratification, and to decide on locations where measurements could be conducted to provide a representative view of the ward's thermal conditions. Air temperature and relative humidity (RH) were measured at different locations, based on typical nurses' transition within the ward, using three Rotronic sensors placed on two stands — at 0.6, 1.1, and 1.7 m height — in accordance with ISO 7726 and ASHRAE 129 [20,21]. Results of the preliminary measurements showed air temperature and RH differences, for devices positioned on a particular stand, kept lower than the device accuracies. Therefore, stratification concerns were absent. Measured temperature differed across the patient rooms having different number of beds. Hence measurements were conducted in each room type, based on the number of beds in a room. Furthermore, temperature and humidity were also measured in several patient rooms falling under the same type in order to take into account differences arising due to room orientation.

The final measurement locations have been shown in the floor plan in Fig. 1. Three indoor climate measurement stands (ICMS), image given in Fig. 3 b), positioned in two patient rooms and near the reception, had measurement equipment for air temperature, globe temperature, omni-directional air velocity, RH, and CO_2 concentration. The Rotronic devices measured air temperature and RH. The measurements were taken in accordance with ISO 7726 [20], at a height of 1.1 m, which approximately corresponds to a standing person's centre of gravity. Measurement equipment specification has been provided in Table 2.

Weather data was obtained from the Royal Dutch Meteorological Institute's (KNMI) [22] location “De Bilt”, which was within a 3 km radius of the hospital. Outdoor conditions during the measurements have been summarized in Table 1. Following the survey measurements,

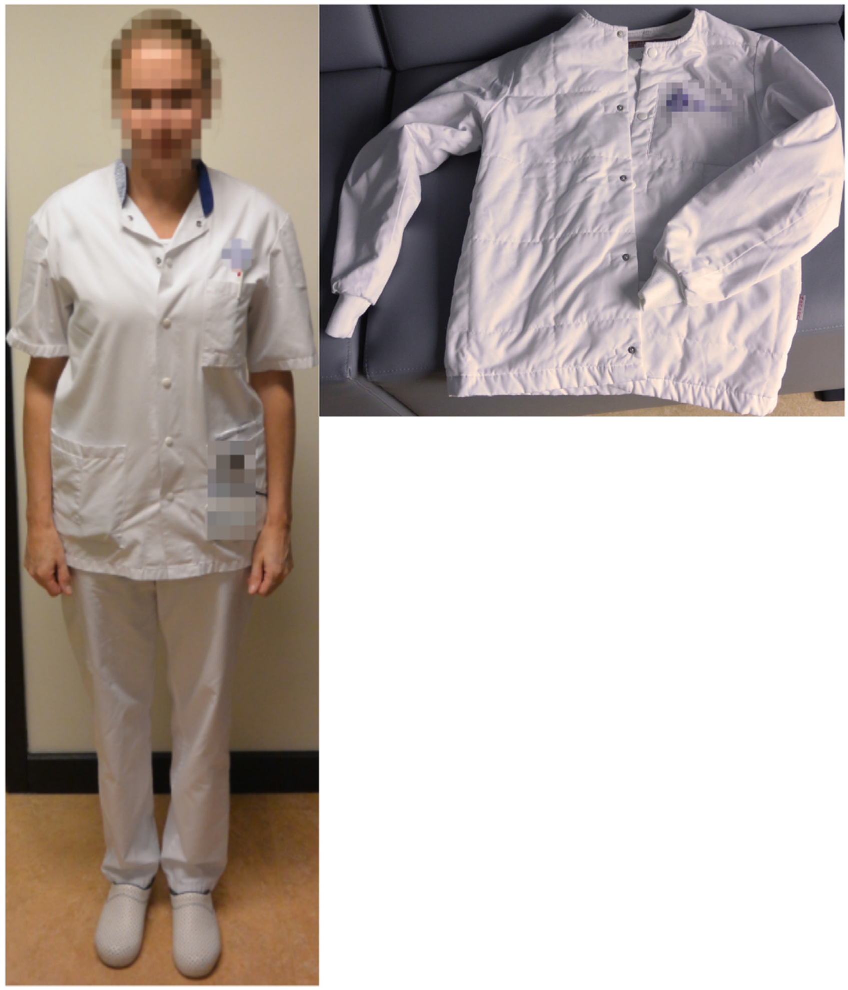

Fig. 2. The obligated work uniform and the additional vest nurses may put on. (Photo by: Manon Derks).

additional measurements of particulate levels in air were conducted using a hand-held, Lighthouse 3016-IAQ particle counter. Measurement settings were chosen as per ISO 21501–4 [23].

2.3. Subjective data

Subjective thermal comfort data was collected using question sets in Dutch. Previous research [18] had shown the important parameters to be regarded for ascertaining thermal perception of occupants moving across thermal zones. A sample of the questions, translated into English, have been provided in Supporting information (Supplementary Figure 1). These survey questions were formulated based on those findings. It had three parts: demographics, current and previous events, and thermal perception and comfort questions. Information about current

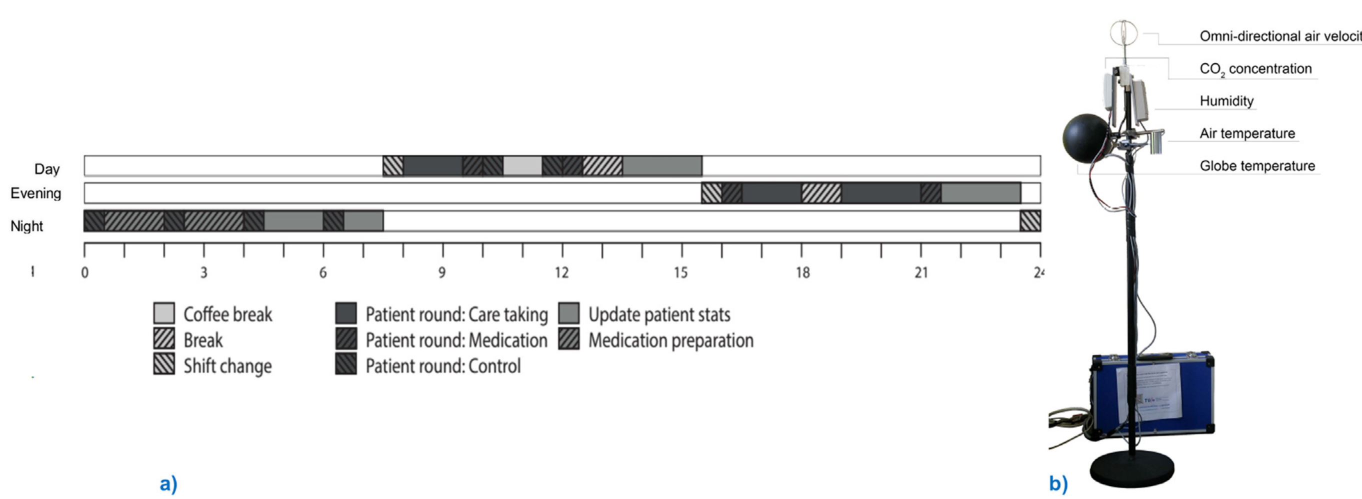

Fig. 3. a) Nurses' work schedule as indicated by the head nurse b) An image of the indoor climate measurement stand (ICMS).

Table 2
Specifications of the equipments used for measurements during the survey.

Device	Model	Specifications
ICMS		
RH/CO_2 Sensor, E + E Elektronik	EE80 series	RH[10–90%, ±3%] & CO_2 [0–2000 ppm, ± 50 *ppm*]
Omnidirectional anemometer SensoAnemo transducer	HT-412	v_{air} [0.05–1 m/s, ±0.02 m/s±1%]
Black globe thermometer	Black sphere with	Globe temperature [−5–40°C, ±0.1°C]
Temperature sensor	U-type NTC thermistor NTC thermistor U-Type	Air temperature [−5–40°C, ±0.1°C]
Temperature and humidity sensors — 9 in numbers		
	Rotronic	Air temperature [0–50°C, ±0.3°C] Humidity [10–90%, ±3%]

and previous events was necessary to link the correct measuring equipment with participant location. Surveys were filled in by the participants at time-points of their choosing during their shift. The break room, an easily accessible location without work obstructions or chances of inconveniencing patients, was chosen to provide the survey sheets. The nurses could also drop off filled survey sheets in a collection box at the same location.

There were three questions regarding thermal comfort perception: (i) thermal sensation vote (TSV) on the seven point ASHRAE thermal sensation scale, (ii) thermal acceptance vote (TAV) on a six point Likert scale of "Very acceptable" (1) [Acceptable, Slightly acceptable, Slightly unacceptable, Unacceptable] to "Very unacceptable" (6), and (iii) self-assessed work performance (SAWP), again on a six point Likert scale of "Very obstructing" (1) [Obstructing, Slightly obstructing, Slightly conducive, Conducive] to "Very conducive" (6). The SAWP question was based on a similar question examining performance among office employees, from the questionnaire of the University of California's Centre of Environmental Design Research, Berkeley [24]. However, instead of a seven point answering scheme, we choose to have a six point scheme so that respondents had to choose either the Obstructive or the Conducive side of the scale. This step was taken based on the response structure suggested for questions of satisfaction in indoor environment surveys [25] also having six point scheme to ensure respondents do not just pick the middle/neutral option and make a decision one way or the other.

2.4. Data analysis

For statistical analysis, the objective data and subjective responses had to be compiled together. A MATLAB-script was used to connect the filled in current and previous location in the survey with the corresponding device; time-stamp of the filled in survey was used to select the appropriate measurement data. Measurement data was averaged over 10 min and the data of the 10 min value closest to the survey time-stamp was utilised. Thus, thermal sensation questions (TSV and TAV) were linked to each participant's specific current and previous room conditions. Outdoor temperature data was linked to the compiled set in terms of daily mean temperatures. This analysis presumed that the nurses were reasonably accurate in recording the time they took the survey.

The following aspects were primary targets of the current investigations, the respective null hypotheses being differences or correlations were non-existent:

- Variation of thermal conditions across the spaces commonly used by the nurses.
- Correlations between air temperature and nurses' thermal perception (TSV and TAV)
- Correlation between TSV and TAV
- Relating thermal perception to SAWP

Statistical tests were conducted at a 5% significance level ($\alpha = 0.05$). Pearson product moment correlation was used to examine possible correlations. Based on if distributions were normal or not (determined using Shapiro-Wilk test), *t*-test or Wilcoxon rank tests were used to examine significant differences. The study being a pilot case, did not always provide a desirable size of sample space and the analysis often relied on assumptions. Despite this, we have tried to cover different possible perspectives in the analysis and maintain the due rigours so as to be useful for future similar works. Statistical analysis utilised IBM SPSS Statistics 22.

The work performance scale was: '1' very obstructing, '2' obstructing, '3' slightly obstructing, '4' slightly conducive, '5' conducive, '6' very conducive. The six point scale lead naturally to a binary work performance scale for further analysis using logit models. All votes of 1 till 3 indicated a 'work obstruction' and votes of 4 till 6 indicated 'work conducive' on the binary scale. To correlate this binary work performance indicator, logit regression was used. Logit of a probability value 'p' can be expressed as below:

$$\text{logit}(p) = \ln\left(\frac{p}{1-p}\right) \quad (1)$$

Logit regression was used to ascertain the effect of thermal perception on the probability of the nursing staff experiencing work obstruction or finding the thermal conditions to be work conducive. This model assumes a linear relation between the logarithm of the ratio of probabilities of the binary response based on the independent variable or predictor [26]. Here, the response frequencies for work obstructions were put up against the total observed responses, to yield a probability 'p' for work obstruction. Occupant thermal perception (TSV or TAV) acted as the predictor for the regression.

3. Results

3.1. Objective indoor measurement data

As shown in Fig. 4 a), a significant difference in indoor air temperature can be observed when comparing across seasons and ward orientation (East and West ward). Similar to the indoor air temperature, a significant difference was found for RH and absolute humidity (AH) between seasons and ward orientation, as can be seen in Fig. 4 b), indicating thermal conditions in the wards were not uniform. Also of import are the extreme temperature values recorded during summer, for both wards, Fig. 4 a). Though they represent a small fraction of the measured data, yet, such extremes can be particularly distressful for the patients, who shared more or less the same space as the care professionals.

Since the ward orientation had an influence on the indoor air temperature and humidity, the engagement between survey data and objective measurement data needed to be ward specific, that is, room orientation needed to be taken into account when compiling the data. Indoor AH corresponded closely to the outdoor conditions, apart from a slight time lag. Though the indoor air temperature also depended on the outdoor conditions, since the air is heated/cooled, the dependence was much weaker.

3.2. Combined analysis of objective and subjective measurement data

During the survey period, a total of 132 responses were gathered

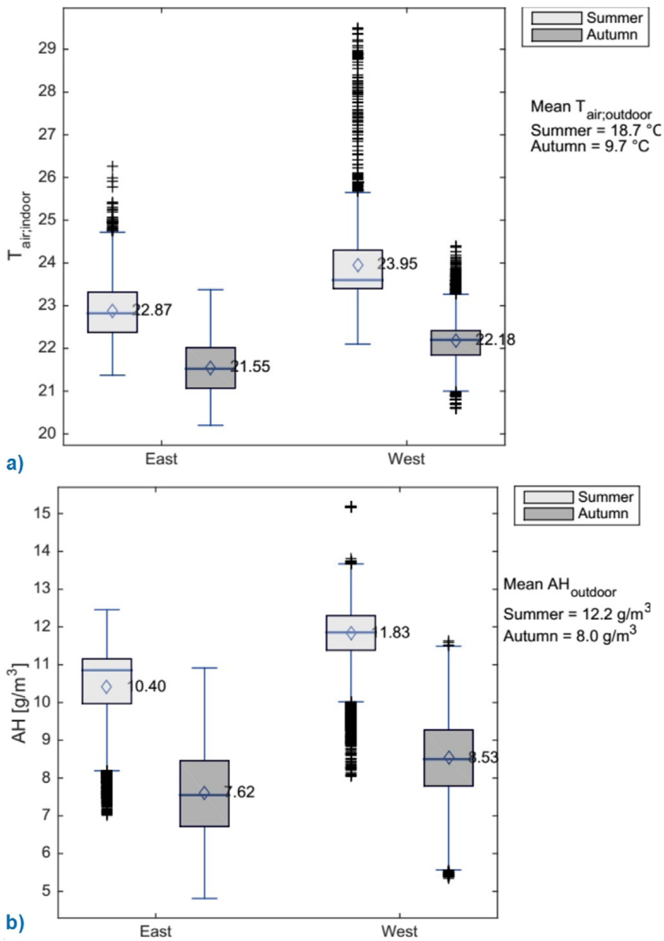

Fig. 4. Boxplots of objective indoor measurement data in patient rooms, divided by ward orientation and seasons a) Indoor air temperature b) Indoor absolute humidity.

from the nursing staff, 89 during summer measurements and 43 during autumn measurements. Unless indicated otherwise, the following mentioned results used the entire data set (N = 132).

The subjective responses regarding thermal comfort perception have been summarized in Table 3. As may be seen, a seasonal difference in TSV, TAV, and self-assessed work performance (SAWP) was found. The TSV and TAV were significantly larger during summer, which represents respectively a higher warm discomfort and a higher unacceptability. Similarly, SAWP was significantly lower during summer, indicating more hindrance from the thermal environment. Overall, thermal comfort and related work productivity during summer were voted worse than during autumn. Taking the whole data set together revealed a slightly unacceptable thermal comfort and a slightly obstructed work productivity, with the thermal sensation being on side of warm discomfort.

Table 3
Seasonal differences for thermal comfort perception.

	M [SD]	Rank	Significance
TSV	1.2[1.4]		
Summer	1.6[1.1]	76.54	$U = 1020$,
Autumn	0.2[1.7]	45.72	$p < .001$
TAV	3.8[1.3]		
Summer	4.0[1.3]	73.89	$U = 1256$,
Autumn	3.2[1.2]	51.21	$p = .001$
SAWP	2.7[1.1]		
Summer	2.5[1.1]	58.73	$U = 1222$,
Autumn	3.1[1.0]	82.58	$p < .001$

3.2.1. Thermal sensation vote

The air temperature from participant's current location ($T_{air;current}$) and TSV had a significant correlation (r = 0.46, p < 0.001). Linear regression analysis for temperature and TSV provides the relation as shown in Eqn. (2). This correlation leads to a neutral temperature of 21.8 °C (temperature obtained by substituting neutral TSV in the equation). Additionally, a moderate correlation between TSV and air temperature from participant's previous location was also found (r= 0.37, $p < 0.001$).

$$TSV = 0.68 \cdot T_{air;current} - 14.81;\ R^2 = 0.215,\ p< 0.001 \quad (2)$$

As the TSV values of ± 1 correspond to Slightly Warm and Slightly Cool, assuming the temperature conditions corresponding to these TSV values imply comfortable or only slightly inconveniencing thermal conditions, using Eqn. (2), a temperature range of [20.3, 23.3] is arrived at. None of the votes given when air temperature was ≥24 °C were on the cool side of the thermal sensation scale.

3.2.2. Thermal acceptance vote

A significant correlation between TAV and $T_{air;current}$ was found (r = 0.35) though it was not as strong as the one between TSV and $T_{air;current}$. The corresponding regression relation is shown in Eqn. (3). Due to the range of temperature recorded during the survey, the relation has a linear nature. For lower temperature ranges, it is believed that the correlation would have a quadratic nature. As may be observed from the two relations — Eqns. (2) and (3) — warmer conditions led both to warmer thermal sensation and lowering of thermal acceptability.

$$TAV = 0.47 \cdot T_{air;current} - 7.08;\ R^2 = 0.12,\ p< 0.001 \quad (3)$$

Calculating percentage of respondents dissatisfied (PD) as those who vote on the dissatisfied half of the TAV scale, a significant correlation (r = 0.74, p< 0.001) was found between PD and mean air temperature of each shift ($T_{air;shiftmean}$). The correlation from the linear regression analysis has been provided in Eqn. (4) (R^2 = 0.55), while the scatter plot of the points has been given in Fig. 6. Since the indoor temperature range experienced in this study was between 21 and 25 °C, the correlation between PD and $T_{air;shiftmean}$ showed a linear nature. It is hypothesised that if thermal comfort data for a cooler environment were included, the correlation could have a quadratic nature.

$$PD = 27.637 \cdot T_{air;shiftmean} - 592.095 \quad (4)$$

A significant correlation (r = 0.62, p < 0.001) was found between TSV and TAV. Based on the scatter plot of TSV and TAV, depicted in Fig. 5, a quadratic relation was deemed appropriate between the two quantities. The correlation has been provided in Eqn. (5). The optimal

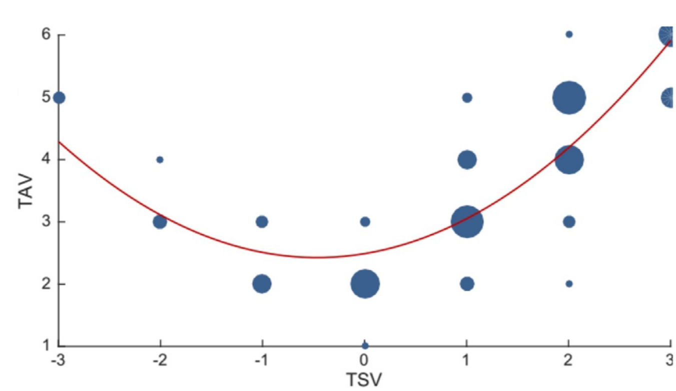

Fig. 5. Scatterplot of TSV against TAV, along with the regression line.

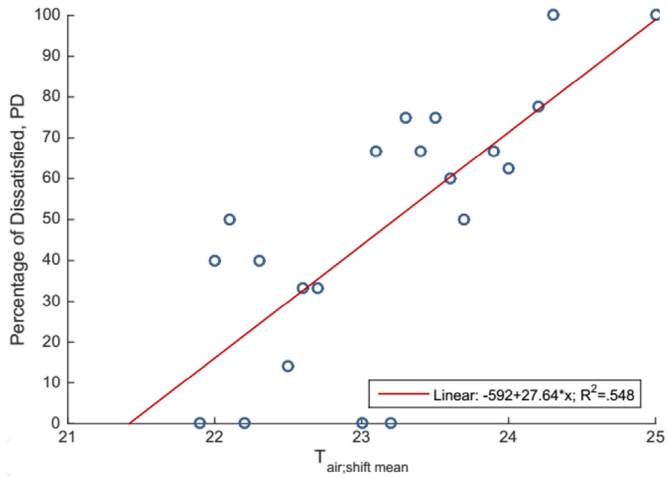

Fig. 6. Scatterplot of $T_{air;shiftmean}$ against PD, along with the regression line.

TSV, minima of the regression line, lies just on the cooler side of the TSV scale. This indicated the nursing staff preferred the thermal environment to be slightly cool for working conditions to be acceptable.

$$TAV = 0.29 \cdot TSV^2 + 0.27 \cdot TSV + 2.49;\ R^2 = 0.73,\ p < 0.001 \quad (5)$$

This nature was also reflected in the relation between TSV and PD. Since there could be only seven data points, in this study, for the TSV–PD correlation and the Pearson product moment correlation between the two quantities was not significant (p = 0.696), we have not provided a plot of the result. But the trend indicated a wider range of TSV for 80% satisfaction: – 2 to 1, compared to the commonly adhered range of – 1 to 1. So, referring back to the analysis presented in Section 3.2.1, based on Eqn. (2) and an 80% satisfaction corresponding to TSV of – 2 to 1, the temperature zone for comfort of the nurses would be [18.8, 23.3]°C.

3.3. Self-assessed work performance

3.3.1. Work performance and TSV

The 6-point SAWP correlation to TSV was significant and negative (r = −0.41, p<0.001). A quadratic fit between TSV and SAWP presented a better R_2 value than the linear fit (0.29 for the quadratic fit vs 0.16 for the linear fit) and hence this curve has been presented in Fig. 7 a). The maxima point of this curve lies on the cooler side of the TSV scale (Fig. 7 a)). However due to responses regarding work performance being predominantly on the 'Obstructive' side, even the maxima point of work performance in the TSV-SAWP curve lies closer to the Work Obstructed portion of the SAWP scale.

In Fig. 7 b), the curves respectively represent correlation between TSV and logit transform of the probability of 'Work Obstruction' and 'Work Conduciveness'. The point of intersection of the two curves thus represents TSV where SAWP is equally likely to be on the positive and negative side, implying a point of equilibrium. This point on the TSV scale is close to the optima found for the TSV-SAWP correlation curve in Fig. 7 a). The logistic regression model was statistically significant ($\chi^2(5) = 510.113$, $p < 0.001$).

3.3.2. Work performance and TAV

The same approach was used to correlate SAWP with TAV. The results of both regression analyses are shown in Fig. 8. Work performance (6-scale) showed a significant, negative correlation with TAV (r= −0.518, $p < 0.001$). Here, a linear regression ($R^2 = 0.27$) provides nearly as good a fit as a quadratic one ($R^2 = 0.28$). Hence we have provided only the linear fit in Fig. 8 a). As can be seen in Fig. 8 a), the point of work performance turning from Conducive to Obstructive (Work performance = 3.5) lies around a TAV of 2, i.e., 'Acceptable'.

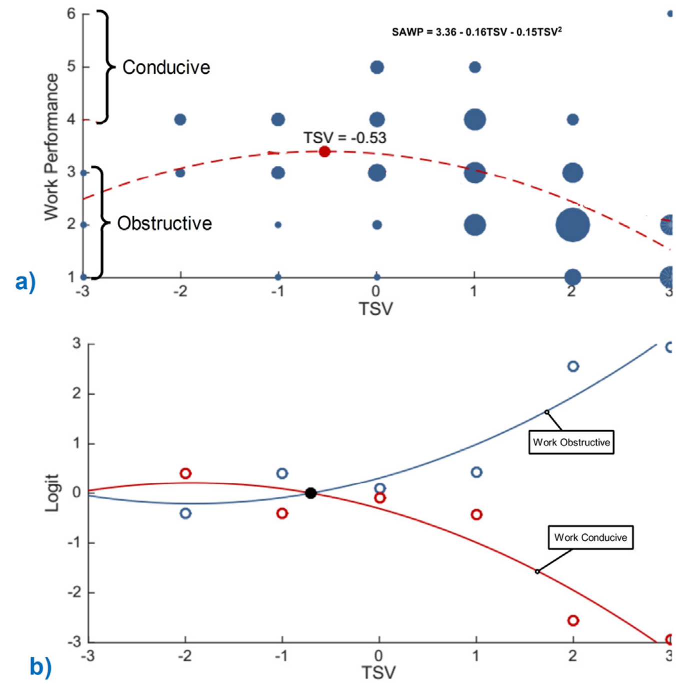

Fig. 7. Correlating TSV and SAWP a) TSV and the 6-scale SAWP b) TSV and logit transformed values of the probability of work obstruction and work conduciveness on the 2-point SAWP scale.

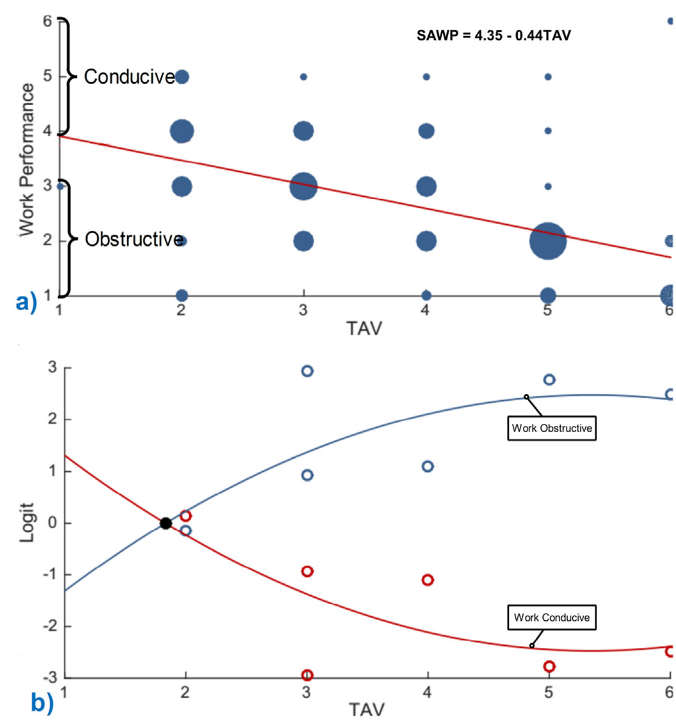

Fig. 8. Correlating TAV and SAWP a) TAV and the 6-scale SAWP b) TAV and 2-scale SAWP, logit transformed responses.

For the binary work performance indicator, the logistic regression model with TAV was not statistically significant at a 5% level ($\chi^2(5) = 10.010$, $p = .075$). We do represent the regression lines in Fig. 8 b). Their intersection indicated the turning point of SAWP — equal probability of the feelings of obstruction and conduciveness — around a TAV of 2, i.e., 'Acceptable'. The non-significance of the correlation does weaken this conclusion.

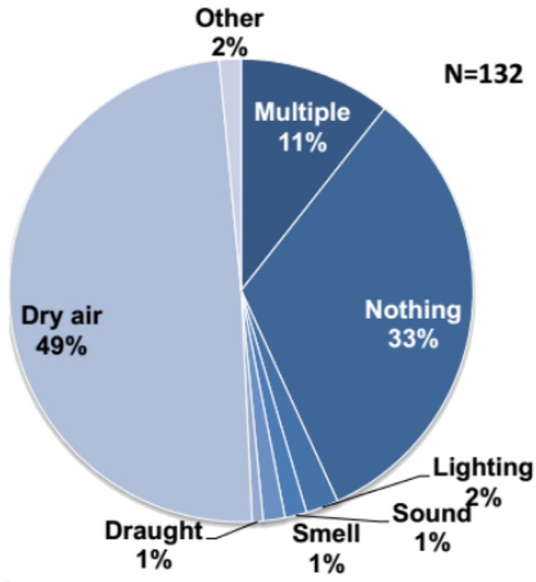

Fig. 9. Distribution of non-thermal complaints, as a fraction of the total number of responses received over the entire survey.

3.3.3. *Other possible negative influences on work performance*

To appreciate aspects of indoor comfort sensation, other possible negative influences on the work performance (complaints) were asked for in the survey. A pie chart of the fractions of other complaints, besides thermal, is shown in Fig. 9. During both survey periods, the nature of these distributions were similar. The most frequent complaint was the experiencing of dryness in indoor air (Freq. = 49%). But, as may be seen in Fig. 4 b), the RH always kept within acceptable range, 30–70%, for comfort [27].

Next, the influence of the dry air experience on thermal comfort and work performance was examined. For this examination, the data set was divided into two groups: participants who expressed dry air complaints and participants who did not. No significant difference between the two groups was found for TSV ($p = 0.84$), TAV ($p = 0.23$), and the 6-scale SAWP ($p = 0.47$).

4. Discussions

In response to changes in their thermal environment, occupants can adapt and restore their comfort level. Such adaptation has been categorized in three groups: behavioural, physiological, and psychological [28]. The influence of the physiological adjustments (long-term adaptation to climate) is rather limited for this situation [29]. Herein, the focus is on psychological adaptations since the participants are focused on their work and need to be constantly mobile, not sparing enough time to respond with behavioural actions. Further limiting behavioural adaptations was the fact that their work clothing was obligated and little to no adjustments were accepted. Only a minimal spread in clo-value (M [SD] = 0.48[0.04]) was present and hence clothing insulation levels were not analysed further.

Research in a laboratory setting, exploring work productivity aspects, have their advantages but the findings from controlled laboratory settings may not be translated to field settings without proper validation. Methods utilised in the current study, which was an exploratory effort, can be useful for developing future research into the thermal profile of nursing staff in hospital wards. Further investigations into the possibilities for objective work performance is desired, as described in Sec. 4.3. At the same time, other options for executing the subjective survey would need to explored since towards the end of the survey period, survey fatigue was noticed. For obtaining larger number of responses, measurements would need to be conducted across multiple wards so as to involve more number of participants. In this regard, equipment availability may pose a limitation. The usage of digital survey, through a smart phone app, may also be explored. The app could also provide intermittent feedback to the participants in order to encourage participation. Nonetheless, work obstructions or inconveniences for patients should always be prevented. For this purpose, consultation and cooperation with the head nurse and responsible administrative members was undertaken prior to and during the survey and is highly recommended for future such studies. Also, in order to obtain data across all possible thermal conditions in these wards, measurements throughout the year and/or at different hospitals would be desirable, considering seasons and ward orientation had an influence on the indoor temperature and humidity.

Surveys were filled in by the nurses at their chosen moment. When analysing the responses, it was found that most of the responses, during both Summer and Autumn, were filled out between 9:00 and 12 noon. To examine if this disproportionate number of responses during a particular period affected the overall results, the correlations between TSV and TAV were compared for responses from different time periods. The survey responses are divided based on the time-stamp of the survey: a “popular time”-group and an “unpopular time”-group. These groups are compared with the whole data set. For all the groups, a significant correlation was found, as can be seen in Table 4. Next, the corresponding regressions were calculated and are shown in Fig. 10. As can be seen, all three regression lines are nearly coincident.

The “popular time”-group involved TSVs in the range of −1 to 3. This distribution over just part of the scale explains the almost linear regression line. It still covers the right side of the quadratic line from the complete data. Regression line of the “unpopular time”-group is almost similar to the regression of the whole data set. Further, the “popular” and “unpopular” groups did not show a significant difference for TSV, TAV or 6-scaled SAWP (p-values of 0.18, 0.71, and 0.96 respectively). Hence, it may be concluded that the “popular time”-group does not inordinately dominate the overall results and the entire data set may be used. At the same time, by using the whole data set, a broader temperature range can be examined.

4.1. *Thermal comfort of nursing staff*

Analysis of the nurses' subjective responses showed that the current thermal settings on the hospital wards, varying between 20 and 25 °C, cause a slightly unacceptable thermal perception, a slight warm discomfort, and a slightly obstructed SAWP. Optimal TSV was indicated to be on the cooler side of the scale. A thermal sensation of ‘slightly cool’ might be thus be a more appropriate aim in indoor conditioning for care-professionals’ work performance.

Based on the regression equations, the indicated neutral temperature was 21.8 °C. In the work of [11], a mean air temperature of 21.5 °C during summer was accompanied by a mean TSV of −0.5 for the nursing staff and during winter a mean air temperature of 21.8 °C and a mean TSV of −0.7 was observed [10,11]. On the other hand, in the work of [30], a mean TSV of 1.053 was recorded for the medical staff with mean air temperature around 23 °C [30]. These results are similar to those from the current study where the mean air temperature was 23.3 °C, leading to a mean TSV of 1.12. The results from previous researchers support our finding that temperatures extending all the way to 25 °C can result in warm discomfort and that optimal TSV for the

Table 4
Pearson correlation between TSV and TAV.

	Sample size	Pearson correlation coefficient	p-value
Popular fill in time	50	.552	$p < .001$
Unpopular fill in time	67	.844	$p < .001$
Whole data set	132	.624	$p < .001$

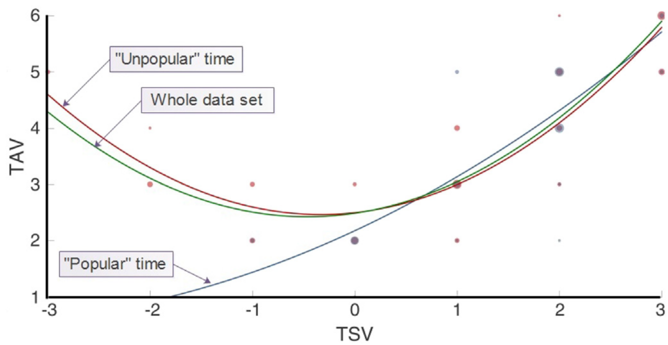

Fig. 10. Scatterplot and regression lines of TSV vs. TAV for the "popular", "unpopular", and whole data set.

nursing staff lies on the cooler side of the thermal sensation scale.

4.2. Complaints of dry indoor air

As stated in Sec. 3.3.3 RH values were within acceptable range, 30–70%, for thermal comfort [27]. Still there were many responses with complaints about dry air. There is always a possibility that "dry air"-complaints may have resulted from eye, nose, or throat irritation caused by particulate matter in the environment rather than low humidity [31,32]. Therefore, additional measurement was performed to determine levels of particulate matter in the air. The results confirmed to ISO class 8, according to ISO 21501–4 [23], which represents a regular indoor public space. This measurement was not in complete accordance with ISO 14644–1 [33], since the standard is for clean room classification and the wards were open, public spaces. Still the recommended sample time and sample volume from ISO 14644–1 were used during the measurement.

Since particle counts did not exceed the limits of ISO class 8, it would be unlikely that particulate matter in air would be causing the "dry air"-complaints. The nurses could be more sensitive to particulates due to their more active schedule. Although CO_2 levels were only measured at locations with an ICMS, the three measurement locations indicated CO_2 to be within recommended range (≤800 ppm). That would suggest the ventilation levels were sufficient to handle levels of typical indoor pollutants, thus excluding them from being the possible source of dry air complaints.

An explanation could be the frequent use of hygienic, alcoholic hand gels, which can result in skin irritation caused by dryness of the skin [34]. This might influence the participants' overall humidity sensation. The "dry air"-complaints might also be due to an expectancy factor among the nurses. The measurement period covered only part of the year and hence, occurrence of durations of low humidity during rest of the year may not be completely excluded. A slightly dry environment during heating period can still cause dry air complaints. This may have influenced expectation of nurses so that the dry air perception is expressed during this study period. Since no significant difference was found for TSV, TAV, and SAWP for responses with and without dry air complaints, the dry air perception is not likely to have influenced the other conclusions from this work.

4.3. Work performance indicator

The used work performance indicator in this study was self-estimated. As indicated from several previous works, self-estimated work performance may be giving an underestimation compared to objectively measured performance when the thermal work environment was deteriorated and an overestimation when the thermal work environment was improved [35–38]. While self-estimated work performance may not be a reliable indicator, objective measurements of work performance in field experiments, on a day-to-day basis, are much more difficult to conduct [35]. This was true for the current work as well, where an objective assessment could have presented work obstruction for the staff and inconvenience for patients. Hence, SAWP was considered to be an optimal approach, following discussions with the head nurse and representatives from the nurses. Depending on the work schedule and willingness of participants, future studies may also consider a work performance estimation from one-on-one interviews and Csikszentmihalyi's experience sampling method, involving a performance records diary. Since SAWP indicator may over- or underestimate the actual work performance, only the overall pattern indicated may be used instead of the individual, absolute values. Recently, efforts towards clarifying objective and uniform performance measures of care-professionals in hospitals has been receiving renewed focus [39] and attention to patient outcomes, process measures, complaints etc. may provide more suitable answers for performance appraisal.

4.4. Recommendations and implications for practice

Hospitals are trying to help patients to recover and heal as quickly as possible, under optimal circumstances and with excellent staff. One approach for this is the Planetree design approach [40] or by building so called "healing environment" hospitals. Evidence for benefits to the staff due to the healing environment approach is however limited [41].

Patients being mostly in a sedentary state prefer a neutral temperature higher than that of the nursing staff [10,42]. Thus, it would be useful to further investigate zonal settings of thermal conditions so as to benefit both groups. Zones where patients' needs do not have to be taken into account, e.g. the hallway on the ward, would be suitable candidates for lower temperature set-points. Results from the current work suggest that this should lead to a more comfortable work environment for the nursing staff. The lowered set-points could also have some positive implications for hospital energy use in heating dominated climates. The creation of a new thermal profile for the nursing staff is advised, where the implementation of the ward's design temperature (21–24 °C, [43]) should be restricted to patient rooms while other locations are conditioned with comfort of the care-professionals in mind.

5. Conclusions

The study revealed that current thermal settings in the hospital ward are liable to cause a warm thermal sensation among the nursing staff. This consequently led to a slightly unacceptable thermal comfort perception and compromised work performance. The analysis points towards an optimal TSV within the cooler side of the thermal sensation scale, both for work performance and comfort. These findings point strongly to the need for developing thermal comfort guidelines oriented specifically towards health care professionals.

To meet needs of thermal comfort of both the patients and nursing staff, different conditioning set-points for different zones can be the most straightforward solution. This could also have beneficial aspects for overall energy usage. It is important to keep in mind that the thermal requirements of staff working in hospitals are quite different from that of employees in typical office spaces. This needs to make its way into design guidelines for hospitals. Further studies would help this purpose while the current work intended to present suitable avenues of investigation by providing the results of this pilot study.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.buildenv.2018.05.039

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