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applicability of thermal comfort assessment models in a hospital environment

Ottenheijm, E.M.M.

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E.M.M. Ottenheijm (0828842)
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Author: E.M.M. Ottenheijm (0828842)
Customer: Technical University Eindhoven
Supervisors: Prof. dr. H.S.M Kort
dr. Ir. M.G.L.C. Loomans
Ir. A. Trip
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Summary

Thermal comfort as a parameter of the indoor environment affects both staff and patients, but almost no information or guidelines are given on thermal comfort in health care facilities. There are two commonly used models which assess the thermal comfort of people:

- The Predicted Mean Vote (PMV)
- The Adaptive Thermal Comfort (ATC)

The applicability of these models has not been tested for health care facilities and with the little research that is found on its application in such a setting it is not validated that these models are suitable. Within this graduation project the following research question has been investigated:

‘Are the currently available models for assessing thermal comfort suitable for a hospital setting?’

The goal of this research is to gain more knowledge on the thermal comfort requirements of staff and patients in hospitals and to see if the available models are suitable for a hospital setting. With this knowledge it might be possible to use the models for determining the optimum temperatures in a hospital setting.

In order to answer the research question the predictions of the thermal comfort models are compared to the perception of staff members and patients of three hospital wards from two hospitals (two cardiology wards and one rehabilitation ward). Because of the clear seasonal differences in the Dutch climate, the perception of users and predictions of models have been compared in several seasons of the year.

The perception of the staff members and patients of the wards has been obtained from questionnaires about the indoor climate and the hospital environment. The predictions have been made from climate data, which were obtained from observations and indoor climate measurements. Within these models several combinations of activity and clothing level have been taken into account.

From this research it can be concluded that the PMV and ATC model do not always give a correct prediction on the perception of the users. The PMV predictions of the patients are between 33%-100% in accordance with the perception of the patients and between 0-100% for staff members. The ATC model gives a correct prediction of the patients (in 5/7 measurements) and for staff members.

The model predicts the percentage of dissatisfied people of staff members to be above 25%, which is in accordance with the perception of the staff members in 6/7 measurements, but the specific amount of uncomfortable staff members cannot be determined with the model.

The PMV model might be possible to use in hospitals if the model is applied in a room in which a steady-state situation can be created (in which users have a stable activity and clothing level in a stable climate). In order to see if the ATC model can be used to determine the optimum indoor temperatures of the staff members in hospitals additional research is needed in which the indoor temperatures are varied within the comfort class boundaries.
It is also recommended that some further research is done:

- To the location of the measurement equipment in a room because this can influence the obtained values. The optimum location should be determined without the equipment being an obstacle for the hospital users. As an alternative, it can be considered to do short term measurements (20min) to determine the climate data.

- To the applicability of models in which the individual characteristics of a person are being taken into account. For example the biophysical model of B. Kingma et al. [12], because this model can be used to determine the optimum thermal conditions for single-patients rooms.

- To determine if the users perceive the thermal climate differently with different heating systems and if different type of patients perceive the thermal climate differently. This needs to be done by comparing several heating systems or patients while the climate conditions and the adaptability possibilities are equal.

Finally, the questionnaires should be improved to obtain more information about the location, activity and clothing level of hospital users.
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1 Introduction

Nowadays, there is a growing interest in the role of the built environment as a part of the non-pharmacological treatment of patients. In studies on healing environment, the effects of the physical environment on the healing process and well-being have proved to be increasingly relevant for patients, their families and for the healthcare staff. Many different aspects have been investigated in these studies, but the effect of thermal comfort is not included [1]. From the results of the literature study done previous to this research [2] it can be found that thermal comfort as a parameter of indoor environment affects both staff and patients. A thermal comfortable environment helps to stabilize the emotional moods of patients and affects the working conditions, well-being, safety and health of the hospital staff [3].

For several building types thermal comfort criteria are given in the following guidelines [4,5]:

- NEN-EN-ISO 7730:2005 (EU)
- NEN-EN 15251:2007 (EU)
- ISO74 version 7 (NL)

In these guidelines no thermal comfort criteria are specifically given for health care facilities. In the Netherlands the infection prevention group (WIP) can define restriction and demands on the environmental conditions in health care facilities, but thermal comfort restrictions have only been defined for operating rooms and are mainly towards air quality [6].

Because there is no information on the actual thermal comfort conditions in health care facilities and on whether or not these conditions are in accordance with the desires of the users of these facilities, it is questionable whether there is any need at all to improve the thermal comfort.

Several models exist for assessing the thermal comfort based on objective data, the two commonly used models are:

- The Predicted Mean Vote (PMV)
- The Adaptive Thermal Comfort (ATC)

The PMV model predicts the thermal comfort of people (feeling too cold or too hot) based on their clothing level, activity level and the indoor climate while the ATC method predicts the percentage of people that are uncomfortable with the indoor thermal environment based on the indoor and running mean outdoor temperature.

The results of the PMV model and the ATC model were compared in a study done by Van der Linden et al [7]. Their study showed that, with the correct input in a climate as the Netherlands, the PMV method gives the same results for thermal comfort as gained with the ATC method. The available models have been designed for office buildings and with the little research that has been found on their application in health care facilities it is not validated that these models are suitable in such a setting[2].
Research question and goal
From the literature study it was concluded that thermal comfort is important in health care facilities but still more research is needed. Because there are no specific rules or guidelines on the temperature in hospitals this study focusses on the possibility to use thermal comfort assessment models, PMV and ATC, as a tool to predict which temperatures should be used in a hospital setting in order to maintain a thermally comfortable environment. Within this graduation project the following research question will be investigated:

‘Are the currently available models for assessing thermal comfort suitable for a hospital setting?'

The goal of this research is to gain more knowledge on the thermal comfort requirements of staff and patients in hospitals and to see if the available models are suitable for a hospital setting. With this knowledge it might be possible to use the models for determining the optimum temperatures in a hospital setting.

From the literature study [2] done previous to this research it can be found that people perceive thermal comfort differently depending on their gender and age, also weight and the use of medicine influence the thermal comfort perception of a person. But because the mentioned PMV and ATC thermal comfort models do not take individual aspects into account, the applicability of a new biophysical model that does take these personal characteristics into account has been also assessed.

Report structure
This first chapter introduces the research topic and the second chapter explains the method to answer the research question. The results are shown in the third chapter and in chapter four these results are discussed. In addition to the results of this research into two models, the applicability of the biophysical model is discussed. The report ends with a conclusion and some recommendations. The annexes can be found in a separate report.
2 Method

In order to be able to use the thermal comfort assessment models as a method to predict the optimum temperature for a hospital setting the predictions need to be validated first. The models predict the amount of people who are uncomfortable with a certain temperature (ATC model) or how people are feeling with a certain indoor climate (PMV model). Their validation is done via comparing the predictions with the actual perception of the users on the thermal environment.

There are several different types of users within a hospital:
- Patients, out-patient clinic or patients who stay for one or more days.
- Staff members, for example nursing staff, doctors and supporting staff.
- Visitors

Within this research the focus has been on patients who are at least 1 day at a hospital ward and the nursing staff members (users). The nursing staff members have been selected because they are spending most of their time on one single ward. The type of heating/cooling system and type of patients are not taken into account in these models, but their influence has to be considered in the comparison between prediction and actual perception.

Research location

In this research three wards from two hospitals have been included. Both hospitals are located in the Netherlands, they have been selected because they are built in roughly the same period and are both labeled as healing environment hospitals. The research took place in two hospitals because in a study done by J. Khodakarami et al [3] it was concluded that although there have been several researches to thermal comfort in hospitals but that each study only investigated one hospital and one type of user which limited the usability of the results for a broader group of hospital users.

Within this research the three hospital wards that were used have been selected based on their staff's cooperation and to have different patient groups. In both hospitals the research has been performed on a cardiology ward and in one of the hospitals the research also took place on the rehabilitation ward.

Table 2.1 shows some characteristics of the hospitals and wards that have been taken into account. The hospital with two wards included in the research is called hospital A and the hospital with only a cardiology ward is called hospital B, annex 1 gives more information about the specific hospitals.

Research Period

In the Netherlands the outdoor temperature changes throughout the year due to seasonal influences. In order to see if the outdoor temperature influences the thermal comfort perception of the users of the hospitals the research in hospital A has been done in several periods according to figure 2.1. The chosen research periods are selected based on the availability of the ward. In each period the research has covered one whole week.

![Figure 2.1 Research periods of the three hospital ward.](image)
2.1 Perception of hospital users - Questionnaires

The opinion of the nursing staff and patients has been obtained from questionnaires. The questionnaires that were used in this research are an adapted version of the questionnaires made by J. Ekbom [8]. Those questions were used because their research is similar to this research and the results can therefore be compared. Within the questionnaire the questions did not only address how people experienced the different climate aspects of their environment but also how they perceived their rooms (staff rooms / patient rooms). Annex 2 shows the questionnaires that have been used in this research and it also shows the questionnaire of J. Ekbom. The most important adjustment that has been made in the questionnaires is the scale, all the answers can be indicated at a seven-point scale in order to create consistency. The seven-point scale has been chosen because this is the same scale as the thermal sensation scale.

The questionnaires and information letters were distributed among staff and patients with the approval of the hospitals patients counsel. Both staff and patients were asked to fill in the questionnaires multiple times because the questionnaires address the users’ opinion on the environment on a specific moment and the environment conditions and perception can change over time. The number of responses of the questionnaire depends on the informed consent and freedom to participate of the staff members and on how many patients are willing to participate.

Analyzing the questionnaires

Figure 2.2 shows the three questions of the questionnaires about the temperature. The results of these questions show the perception, actual mean vote (AMV) and actual percentage dissatisfied (APD), of the staff and patients on the thermal environment. The results of the other questions from the questionnaires have also been reviewed to see if there were certain aspects of the climate or environment which users are uncomfortable with.
In order to compare the results of the questionnaires with the predictions of the thermal comfort models the scales needed to be made equal. The PMV model predicts how people feel on a 7-point scale from -3(too cold) till +3 (too hot). The ATC model predicts how much people are uncomfortable with the environment on a 2-point scale: comfortable or uncomfortable. Table 2.2 shows the translation of the results of the questionnaires into a scale from 1 till 7, being different for each question about the temperature:

1. The first question ‘How do you experience the temperature at this moment?’ will be used to determine the percentage of people that were comfortable with the temperature at that moment. From these results the actual percentage dissatisfied (APD) people can be obtained which can be compared to the results of the ATC model, this can be seen in table 2.2 question 1. For example a person fills in a score of 4 on the questionnaire which means that they are comfortable with the thermal environment.

2. The second question addresses how people perceive the temperature. The question has been answered on a 7-point scale from bad till good. The results of the question will be compared to the results of the PMV model which runs from too cold till too hot, this can be done in two different options:
   a. It is unknown if a person, when perceiving the temperature as bad means to too cold or too hot. The 7-point scale of the questionnaire has been translated into a 4-point-scale comparable to the PMV scale, this can be seen in table 2.2 under question 2 option a. For example a person fills in a score of 5 on the questionnaires which means that this person perceives it slightly bad, it is unknown if they are too cold or too hot, the score of the AMV will then be +1 or -1 according to the PMV scale.
   b. The 7 point scale of the answer to the question can also be interpreted differently which gives a second option to translate the results of the questionnaire, see table 2.2 under question 2 option b. The scale can be interpreted as a score of 4 being neutral and not perceiving the temperature as extremely good or bad. For this approach the results from 4 till 7 on the question were considered as neutral. For example a person fills in a score of 5 which means that they are feeling somewhat better as neutral which means a score of 0 on a PMV scale.

To determine which of the options for translating the results of the second question into a PMV scale is the correct one, the results of this question are compared to the results of the third question and the option with the best fit with the results of the third question is considered as the correct one.
3. In the third question people have been asked how they would prefer the temperature to be at that moment. The result of this question will be translated into the actual mean vote (AMV) which can be compared to the predictions of the PMV model. The questions are answered on a 7-point scale from preferring to be cooler or warmer, this is opposite of the PMV scale from feeling too cold or too hot. Table 2.2 question 3 shows the translation of the questionnaire results to a PMV scale. For example a score of 6 means that a person prefers to feel warmer which on the PMV scale means that they are feeling too cold.

<table>
<thead>
<tr>
<th>Results questionnaires</th>
<th>Question 1</th>
<th>Question 2</th>
<th>Question 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Option a</td>
<td>Option b</td>
</tr>
<tr>
<td>1</td>
<td>Uncomfortable</td>
<td>+3 or -3</td>
<td>+3 or -3</td>
</tr>
<tr>
<td>2</td>
<td>Uncomfortable</td>
<td>+3 or -3</td>
<td>+2 or -2</td>
</tr>
<tr>
<td>3</td>
<td>Uncomfortable</td>
<td>+2 or -2</td>
<td>+1 or -1</td>
</tr>
<tr>
<td>4</td>
<td>Comfortable</td>
<td>+2 or -2</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Comfortable</td>
<td>+1 or -1</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>Comfortable</td>
<td>+1 or -1</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>Comfortable</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### 2.2 Thermal comfort models – ATC and PMV

In the ATC model the maximum amount of dissatisfied people can be predicted based on the inside temperature and the running mean outdoor temperature. The PMV model predicts how people feel about their thermal environment based on the inside air temperature, mean radiant temperature, relative humidity, air velocity, clothing level and activity level[9]. The data for the models have been obtained during the research periods by measurements and observations:

- Measurement of inside climate data
- Outside temperature obtained from weather station
- Observation of clothing level
- Observation and measurement of activity level

**Inside climate data**

The inside temperature is needed for both ATC and PMV model. The inside temperature and the other climate aspects needed for the PMV model were determined by measuring the climate of the hospital ward during one week in each measurement period according to figure 2.1. Table 2.3 shows the measurement equipment and the sample frequencies of the measurement data. The climate data have been obtained with three climate poles (see figure 2.3) of which two have been placed in patient rooms and one in the staff room. In order to perceive an idea on how the temperature is distributed throughout the ward, 10 small Temperature/Relative-Humidity sensors (see figure 2.4) have been distributed. Figures 2.5, 2.6 and 2.7 show the floor plans of the hospital wards and the locations of the measurement equipment. The enlarged floor plans can be found in the measurement plan in annex 3.
Outside temperature

In the ATC model also the running mean outdoor temperature is needed to determine the percentage of comfortable people. The running mean outdoor temperature has been determined from the outdoor temperature from seven days before the measurements according to the ISSO 74 [9]. The outside temperatures were obtained from the nearest weather station of the national weather institute (KNMI). Annex 4 shows the outside temperatures during the measurement periods. From the results in annex 4 it can be concluded that there were seasonal differences in temperature between the first (1.8°C) and last measurements (14.9°C) and that the outdoor temperatures, during the measurements, are comparable with the averaged outdoor temperatures of the years 1981 till 2000.

Table 2.3 Measurement equipment, sample frequency and accuracy.

<table>
<thead>
<tr>
<th>Type</th>
<th>Unit</th>
<th>Sample frequency</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor air temperature</td>
<td>T-sens 399/412</td>
<td>°C</td>
<td>2 min</td>
</tr>
<tr>
<td>Radiate temperature</td>
<td>T-sens 399/412</td>
<td>°C</td>
<td>2 min</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>Humitter 50U</td>
<td>%</td>
<td>2 min</td>
</tr>
<tr>
<td>Air velocity</td>
<td>SensoAnemo 5132SF</td>
<td>m/s</td>
<td>2 min</td>
</tr>
<tr>
<td>T-RH sensor</td>
<td>Escort Junior: T/RH data logger</td>
<td>°C</td>
<td>3 min</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>SensewearPro3</td>
<td>%</td>
<td>3 min</td>
</tr>
</tbody>
</table>

Clothing level

The clothing level that is needed for the PMV has been determined based on observations. The staff members are wearing the same outfit throughout the year while patients can adjust their clothing level to their own desire. Table 2.4 shows the clothing levels that have been used in the PMV model, calculation for these values can be found in annex 5. Only one clothing situation for staff members is taken into account while for patients 6 clothing situations are distinguished, based on their location (in bed or in a chair) a maximum and minimum clothing level insulation is calculated including the insulation level of the chair and bed.

Table 2.4. Determined clothing levels [clo] of staff and patient, which is equal in all of the research periods. 1 clo is equal to 0.155K*m²/W.

<table>
<thead>
<tr>
<th>Patient [clo]</th>
<th>Staff [clo]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chair</td>
<td>Bed</td>
</tr>
<tr>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>0.65</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Figure 2.4. T-RH sensor
Figure 2.5 Floor plan hospital A cardiology ward

Figure 2.6 Floor plan hospital A rehabilitation ward

Figure 2.7 Floor plan hospital B cardiology ward
Activity level
The activity level of the patients has been determined by observations and controlled with the results from the questionnaires, from these results the activity level of patients is divided into day and night. In order to determine the activity level of the staff a measurement device, Sensewear Pro3, was used (see figure 2.8). In each research period some staff members, who were selected on a voluntarily basis, were asked to wear the Sensewear on the back of their right upper arm during their entire shift. The results of the Sensewear measurements can be found in annex 6, and some of these results are shown in figure 2.9. From the Sensewear results three different activity levels (approximately the minimum, average and maximum activity level) have been derived which were used to calculate the PMV. Table 2.5 shows the activity levels of staff and patient that have been used in the models.

![Figure 2.8. Sensewear](image)

Figure 2.8. Sensewear

![Figure 2.9. Measured activity level of nine staff members during different shifts. In which HA-cardiology means Hospital A cardiology ward.](image)

Figure 2.9. Measured activity level of nine staff members during different shifts. In which HA-cardiology means Hospital A cardiology ward.

### Table 2.5. Determined activity level of staff and patient in each of the research periods in W/m². In which H:A ward C 1 means Hospital A cardiology ward research period 1.

<table>
<thead>
<tr>
<th>Ward</th>
<th>Patient [W/m²]</th>
<th>Staff [W/m²]</th>
<th>Day</th>
<th>Night</th>
<th>Min</th>
<th>Average</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>H:A ward C1</td>
<td>58</td>
<td>46</td>
<td>70</td>
<td>116</td>
<td>174</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H:A ward C2</td>
<td>58</td>
<td>46</td>
<td>70</td>
<td>116</td>
<td>174</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H:A ward C3</td>
<td>58</td>
<td>46</td>
<td>70</td>
<td>116</td>
<td>174</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H:A ward R1</td>
<td>58</td>
<td>46</td>
<td>70</td>
<td>105</td>
<td>174</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H:A ward R2</td>
<td>58</td>
<td>46</td>
<td>70</td>
<td>105</td>
<td>174</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H:A ward R3</td>
<td>58</td>
<td>46</td>
<td>70</td>
<td>105</td>
<td>174</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H:B ward C</td>
<td>58</td>
<td>46</td>
<td>58</td>
<td>105</td>
<td>174</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Analyzing the adaptive thermal comfort model

The adaptive thermal comfort (ATC) model determines the maximum percentage of dissatisfied people based on the indoor air temperature and the running mean outdoor temperature (RMOT). The results of the model will be compared to the actual percentage of dissatisfied people (APD), derived from the results of the questionnaires.

In the ATC model two building types can be distinguished (α and β) based on the possibility to open windows. Only the users of hospital B can change the inside conditions by opening a window, but because there are no possibilities for different opening positions of the windows it cannot be considered as an adaptable enough window according to ISO 74 [9]. This means that for all of the hospitals wards in this research the β boundaries are used.

The standard comfort class boundaries between which the percentage of dissatisfied people is determined is only valid for people with an activity level up to 81.2 W/m². Because the activity levels of the staff members can be higher than 81.2 W/m² a correction on the boundaries of the ATC comfort classes has been made, the corrected boundaries are determined with ISO 74 [9]. Figure 2.10 shows the ATC ‘standard’ boundaries (solid lines) and corrected boundaries for a metabolism of 116 W/m² (dashed lines) which is the maximum activity level that can be corrected and used in the ATC model.

Analyzing the Predicted Mean Vote

Because of the variation in clothing and activity level several combinations have been implemented in the PMV model. With these combinations it can be seen between which PMV scores the staff members will score due to changing activity level and what the effect is of changing the clothing level for patients. Because the PMV model predicts how people feel, the results have been compared to the results of the AMV which were determined from the questions on how users perceive the temperature and how they would prefer the temperature to be.

<table>
<thead>
<tr>
<th>Activity according to questionnaire</th>
<th>Original activity level according to the questionnaires</th>
<th>Activity level 58 W/m² till 174 W/m².</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lying</td>
<td>±46 W/m²</td>
<td>±46 W/m²</td>
</tr>
<tr>
<td>Sitting – Passive</td>
<td>±58 W/m²</td>
<td>±58 W/m²</td>
</tr>
<tr>
<td>Sitting – Active</td>
<td>±58 W/m²</td>
<td>±58 W/m²</td>
</tr>
<tr>
<td>Sitting – Relaxed</td>
<td>±58 W/m²</td>
<td>±58 W/m²</td>
</tr>
<tr>
<td>Standing – Work</td>
<td>±116 W/m²</td>
<td>±116 W/m²</td>
</tr>
<tr>
<td>Standing – muscle work 1</td>
<td>±116 W/m²</td>
<td>±174 W/m²</td>
</tr>
<tr>
<td>Standing – muscle work 2</td>
<td>±116 W/m²</td>
<td>±174 W/m²</td>
</tr>
</tbody>
</table>
In order to understand if the predictions of the PMV are correct for each activity level, the predictions of the PMV have been compared to the AMV results of the staff members with the corresponding activity levels. In the questionnaires the staff members were asked to fill in their activity level of the last hour up till activities of 116 W/m$^2$. From the Sensewear measurements it can be found that the activity level of the staff members is up to 174 W/m$^2$, see figure 2.9. Because the measured activity level is higher than asked in the questionnaires there are two options to compare the PMV predictions with the AMV results: the results of the activity level can be used on the original scale as in the questionnaires (till 116 W/m$^2$) or they can be corrected into a assumed range up till 174 W/m$^2$ which fits the measured activity levels, see table 2.6.
3 Results

This chapter shows the results of the measured data (3.1), the results of the questionnaires (3.2) and the results of the implementation of the measured data in the ATC (3.3) and the PMV (3.4) model. Paragraph 3.5 shows comparisons of the results of the questionnaires with the ATC and PMV results.

3.1 Measured data

During each research period several climate parameters have been measured. Figures 3.1 till 3.3 show the measured temperatures with the climate poles in two patient rooms and in one staff room, these are typical examples. The other measured temperatures and climate data can be found in annex 7. An overview of the results of the other measured data can be found in table 3.1.

The patients of the cardiology ward of hospital A have the opportunity to adapt their room temperature, this means that the measured temperature can be different for the measured rooms (figure 3.1). The patient room temperatures in the other wards cannot be changed by the patients, it can be seen that the room temperatures are very similar in each room (Figure 3.2 and 3.3). The staff lounge of hospital B has several peaks which are caused by the possibility to open the window.

![Figure 3.1. Measured temperature in hospital A on the cardiology ward in the control room and in two patient rooms. (a) measurement 1, (b) measurement 2, (c) measurement 3.](image-url)
Figure 3.2. Measured temperature in hospital A on the rehabilitation ward in the common room and in two patient rooms. (a) measurement 1, (b) measurement 2, (c) measurement 3.

Figure 3.3. Measured temperature in hospital B on the cardiology ward in the staff lounge and in two patient rooms.

Table 3.1. Average measured climate data for Hospital A cardiology ward (HA:ward C), rehabilitation ward (HA:ward R) and the cardiology ward of hospital B (HB:ward C).

<table>
<thead>
<tr>
<th></th>
<th>HA: ward C</th>
<th>HA: ward R</th>
<th>HB: ward C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient rooms</td>
<td>20-24°C</td>
<td>20-24°C</td>
<td>20.5-25°C</td>
</tr>
<tr>
<td>Staff rooms</td>
<td>21-23°C (night-day)</td>
<td>22-24°C (night-day)</td>
<td>Depending on window</td>
</tr>
<tr>
<td>Medicine room</td>
<td>-</td>
<td>21-23°C (night-day)</td>
<td>21-22°C</td>
</tr>
<tr>
<td><strong>Relative humidity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ward</td>
<td>35-45%</td>
<td>45-50%</td>
<td>20%-60%</td>
</tr>
<tr>
<td><strong>Radiant temperature</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient rooms</td>
<td>20-24°C</td>
<td>20-24°C (night-day)</td>
<td>20.5-25°C</td>
</tr>
<tr>
<td>Staff rooms</td>
<td>21-23°C (night-day)</td>
<td>22-24°C (night-day)</td>
<td>20-24°C</td>
</tr>
<tr>
<td><strong>air velocity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows closed</td>
<td>&lt;0.05 m/s</td>
<td>&lt;0.05 m/s</td>
<td>&lt;0.05 m/s</td>
</tr>
<tr>
<td>Windows open</td>
<td>-</td>
<td>-</td>
<td>Up till 0.15 m/s</td>
</tr>
</tbody>
</table>
3.2 Results questionnaires – Actual Mean vote

The opinion of the hospital users on their environment has been obtained with questionnaires. A total of amount of 160 questionnaires were filled in by staff members and 63 questionnaires were filled in by patients. Figure 3.4 shows the amount of received questionnaires for each measurement period. The questionnaires were distributed several times to the same staff and patients, due to the anonymous questionnaires it is not possible to determine the number of individual participants.

In this report only the results of the questions about temperature are shown, the results of the questions about the other climate aspects and hospital facilities can be found in annex 8. From the results in annex 8 it can be concluded that the patients are quite positive and feeling comfortable. The staff members of hospital A want the temperature and the air quality to change while the staff members of hospital B are more neutral. Another difference is that the amount of daylight the staff members of hospital A perceive is not enough according to the results of the questionnaires, this is due to the location of the staff rooms and the layout of the ward.

With three questions about the temperature the perception of the users (AMV and APD) can be determined, the results of the three questions have been analyzed according to table 2.2 in order to compare the results to the PMV and ATC predictions.

How do you experience the temperature?
The results of the question ‘How do you experience the temperature’ have been translated to a percentage of people who are comfortable and uncomfortable (APD) with the temperature. Figure 3.5 and 3.6 show the results of this question. It can be seen that the staff members of the rehabilitation ward in hospital A are mostly uncomfortable (>70%) while at the cardiology wards in both hospital A and B the results are reversed. Also the patients of the rehabilitation ward of hospital A are less comfortable with the temperature compared to the cardiology patients.
How do you perceive the temperature?

Staff members and patients were asked how they perceived the temperature at a certain moment on a 7-point scale from bad to good. The results of the questionnaires, the actual mean vote (AMV), have been translated into a 4-point scale in order to compare to the predicted mean vote (PMV) model according to table 2.2. The figures 3.7 till 3.10 show the results of the AMV on the PMV scale, the original AMV scores can be found in annex 8. The translation of the results of the questionnaire has been done in two different methods, figures 3.7 and 3.8 show the results of the first method (2a in table 2.2) and figures 3.9 and 3.10 show the results of the second method (2b in table 2.2).

Figure 3.7. AMV staff. Results of question how staff members perceive the temperature, translated to PMV scale according to the first method (2a of table 2.2). In which H:A ward C-1 is hospital A cardiology ward measurement 1.

Figure 3.8. AMV patients. Results of question how staff members perceive the temperature, translated to PMV scale according to the first method (2a of table 2.2). In which H:A ward C-1 is hospital A cardiology ward measurement 1.

Figure 3.9. AMV staff. Results of question how staff members perceive the temperature, translated to PMV scale according to the first method (2b of table 2.2). In which H:A ward C-1 is hospital A cardiology ward measurement 1.

Figure 3.10. AMV patients. Results of question how staff members perceive the temperature, translated to PMV scale according to the first method (2b of table 2.2). In which H:A ward C-1 is hospital A cardiology ward measurement 1.
How would you like the temperature to be right now? The results of the question ‘How would you like the temperature to be right now?’ have been translated into PMV results which are assumed to be equal to the question ‘How do you feel at this moment?’, this is done according to table 2.2. The results of this question show the AMV on a PMV scale in order to compared to the results of the PMV (Figure 3.11 and 3.12). It can be seen that the results of the patients are quite evenly distributed through all of the wards while this is not the case with results of the staff members. The staff members of hospital A cardiology ward are feeling too cold, staff members of the rehabilitation ward hospital A are feeling too hot and the staff members of the cardiology ward in hospital B are feeling neutral-slightly hot.

**3.3 Adaptive thermal comfort model**

The results of the adaptive thermal comfort model (ATC) are shown in figure 3.13, this figure shows the total result of the research periods. The ATC model of each measured room can be found in annex 9. It shows that most of the time the results of hospital A are between the ‘standard’ B-class boundaries (81.2W/m²) which means a maximum of 10 % of the people should be dissatisfied. It also means that when people have an activity level above 116W/m² the amount of dissatisfied people will be more than 25% (according to the dashed lines). Hospital B and measurement 3 of the cardiology ward hospital A have most, due to the higher RMOT, within both standard and corrected boundary lines.

![Figure 3.11. AMV score on a PMV scale of staff members on how they prefer the temperature to be. In which H:A ward C-1 is hospital A cardiology ward measurement 1.](image1)

![Figure 3.12. AMV score on a PMV scale of patients on how they prefer the temperature to be. In which H:A ward C-1 is hospital A cardiology ward measurement 1.](image2)

![Figure 3.13. Adaptive thermal comfort model of all of the measurements. In which H:A ward C-1 is hospital A cardiology ward measurement 1.](image3)
3.4 Predicted mean vote model

The PMV results are quite stable over the measured rooms and research periods, this is because the indoor climate condition are also quite stable throughout the research periods. Because of the stable indoor environment the total PMV boundaries for all rooms are shown in figures 3.14 till 3.18 (HA:C1 means hospital A cardiology measurement 1). Annex 10 shows the PMV for each measured location. Figures 3.14 till 3.16 show the PMV of patients (with minimum and maximum clothing) in a chair, in their bed during day and in bed during night. Figure 3.17 and 3.18 show the PMV results of the staff members in staff rooms, with three different activity levels taken into account, and in the room of the patient with an average activity level of 116W/m².

Figure 3.14. PMV of patients at night with different clothing levels. Left is minimum clothing level and right maximum clothing level according to table 2.4.

Figure 3.15. PMV of patient sitting in a chair. In the PMV also the different clothing levels are taken into account but this cannot be seen because the results are partly equal.

Figure 3.16. PMV of patients on bed during the day. In the PMV also the different clothing levels are taken into account but this cannot be seen because the results are partly equal.

Figure 3.17. PMV of staff members in staff rooms at three different activity levels. Left is at minimum activity level, in the middle the average and right the maximum activity level.

Figure 3.18. PMV of staff in patient room on average activity of 116 W/m² (2Met) for hospital A and 105 W/m² (1.8 Met) for hospital B.
3.5 Total

The results of the ATC model and the PMV model are compared to the results of the questionnaires in order to determine if the models give a prediction which is in accordance with the perception of the users. The comparisons are shown in this chapter.

ATC model

Table 3.2 shows the results of the actual percentage of dissatisfied people (APD) and the results of the ATC model. In this table the ATC results of all of the measured rooms are taken into account because there is no difference in indoor temperatures, which mean that the ATC is similar in all of the rooms. The patient results show that two out of the seven ATC calculations do not give the same prediction of the amount of patients who are uncomfortable according to the APD. The results of the staff members show that at the standard boundaries (≤81.2 W/m²) the predicted amount of dissatisfied staff member is not in accordance with the APD while at the corrected boundaries (116 W/m²) they are. The ATC model can only predict that the amount of dissatisfied people is larger than 25% in 6 of the 7 staff measurements, this is because the results of the staff members are outside of the corrected boundaries (figure 3.13).

<table>
<thead>
<tr>
<th></th>
<th>Patients % dissatisfied</th>
<th>Staff % dissatisfied</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>APD</td>
<td>ATC≤81.2 W/m²</td>
</tr>
<tr>
<td>H:A ward C1</td>
<td>0.0</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>H:A ward C2</td>
<td>0.0</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>H:A ward C3</td>
<td>0.0</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>H:A ward R1</td>
<td>21.4</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>H:A ward R2</td>
<td>33.3</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>H:A ward R3</td>
<td>0.0</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>H:B ward C</td>
<td>0.0</td>
<td>&lt;10%</td>
</tr>
</tbody>
</table>

PMV model

Patients

Figure 3.19 shows the percentage of the patients who gave an actual mean vote (AMV) score which is in accordance with the PMV results, within the range of both maximum and minimum clothing level. Within the figure a distinction is made between the bed and chair situation because from the questionnaires it is not clear where patients are located within their rooms. The total distribution of the scores can be found in annex 11.

Figure 3.19 Percentage AMV results of patients in accordance with the PMV. HA:C1 is hospital A cardiology measurement 1.
**Staff**

Figure 3.20 and 3.21 show the percentage of the staff AMV results which are in accordance with the results of the PMV separated into activity level. Via two different methods the activity level of the staff members can be determined from the questionnaires, see table 2.6. Figure 3.20 shows the results of the original activity levels according to the questionnaires (up till activity levels of 116W/m²) and figure 3.21 shows the results when translating the activity levels of the questionnaires to the maximum activity level (up till 174W/m²). Annex 11 shows the table to calculate the percentages.

![Figure 3.20](image1.png)

*Figure 3.20. Percentage of staff AMV which are in accordance with the PMV score of activity levels based on questionnaires. Activity levels till 116W/m². H:A ward C-1 is hospital A cardiology measurement 1.*

![Figure 3.21](image2.png)

*Figure 3.21. Percentage of staff AMV which are in accordance with the PMV score of activity levels corrected for activities up till 174W/m². H:A ward C-1 is hospital A cardiology measurement 1.*
### 4 Discussion

This chapter discusses the results that were presented in the previous chapter. First the measured data will be discussed, then the results of the questionnaires, the results of the ATC in comparison with the perception of the users, the PMV in comparison with the perception of the users and in the end some general discussion points and comparisons with other researches.

### 4.1 Measured data

The figures 3.1 till 3.3 show some of the measured temperatures and table 3.1 shows the average measured climate data for each hospital ward. From the measured data of hospital A (cardiology ward and rehabilitation ward) it can be found that the indoor thermal conditions are quite equal over time (20°C - 24°C), only the patients of the cardiology ward of hospital A can change their room temperatures +3°C or -3°C in relation to the set-up. In hospital B it can be seen that the operable windows can have a large influence on the indoor temperatures (normal 20°C - 25°C and due to window +3°C or -3°C).

From table 3.3, comparing the measured data of all of the wards, it can be found that the climate conditions in the patient rooms of the different wards are quite similar. In the staff rooms there is a difference between the rehabilitation ward and the cardiology wards, the air temperature of the rehabilitation ward in hospital A is 1°C higher than that of the cardiology wards. The measured data are different from the temperature set-points as shown in table 2.1, the rehabilitation ward of hospital A should have a lower air temperature as the cardiology ward in hospital A.

Because the measurement equipment was located in the corner of the rooms, in order to prevent it from being an obstacle for staff and patients, the measured data can slightly deviate from the actual climate in the middle of the room. This is especially the case for the measured air velocities, which have been measured to be very low <0.05m/s. This is not in accordance with the perception of the patients and their visitors who complain about the high air velocity on the other side of the room.

### 4.2 Questionnaires

The measurements of the climate data took place in a part of the rooms of the hospital wards (see figure 3.5 till 3.7). Because the indoor temperature in all of the measured rooms is quite similar it is assumed that the other rooms, in which the temperature has not been measured, have also the same indoor temperatures. This means that all the results of the questionnaires can be used to compare with the measured data instead of only the questionnaires received from the measured rooms. The results of the questions on the temperature are shown in figures 3.5 till 3.12.

Three questions about the temperature are incorporated in the questionnaires to determine the opinion of the users, how they experience, perceive and prefer the temperature to be. The translation of the results of the questionnaires has been done according to table 2.2. The results of the second question (perceive) have been translated to a scale which can be used to compare to the PMV model in two different ways. By comparing the result of the second question ‘How do you perceive the temperature?’ to the results of the last question ‘How would you prefer the temperature to be?’ it could be found that the first option (see table 2.2 question 2a) is the correct translation, this is because the results of the first option for the second question are similar to the results of the third question which is also on a PMV scale.
The results of the three questions, figure 3.5 till 3.12, have been analyzed by comparing them to each other and to the measured indoor conditions. Figure 3.5 and 3.11 show that the staff members of the rehabilitation ward (H:A ward R) are very uncomfortable with the indoor temperatures and prefer the temperature to be much cooler. The cardiology staff members of both hospitals are very comfortable with the temperature but still the staff members of cardiology hospital A prefer a slightly warmer environment.

The patients of the cardiology wards are also more comfortable compared to the patients of the rehabilitation ward (figure 3.6 and 3.12). The difference in patient response might be caused by the amount of influence they have on the temperature while having a same indoor thermal climate. Because, according to the ISSO 74 [9] people accept higher temperatures when they can influence them. The patients of the rehabilitation ward have no influence on the temperature while at the cardiology ward of hospital A the temperature can be changed +3° or -3° C and in hospital B the windows can be opened.

The obtained amount of questionnaires, as can be found in figure 3.4, might not be representative for the total group of staff members and patients on the researched wards. It is not possible to determine which percentage of staff members and patients participated in this research because the questionnaires were distributed multiple times and were filled in anonymously. Up till 3 times patients were asked to fill in the questionnaire and the staff members had the questionnaires available during each shift. Another important aspect in reviewing the results is that the questionnaires might not always be filled in correctly. In the questionnaires people are asked to give their opinion of the environment on that specific moment, but based on the received questionnaires, it can be seen that people fill in the questionnaires more generally. For example, the questions about the daylight are also answered even though there was no daylight available at that time of the day. This means that there are two possibilities to analyze the questionnaires: the perception on thermal comfort on a certain moment or an average perception. Because of the stable thermal indoor environments both methods to analyze the questionnaires give the same results.

4.3 ATC model and comparison with APD

The results of the ATC model in figure 3.13 show that in the standard situation, for activity levels below or equal to 81.2W/m², the combination indoor temperature and running mean outdoor temperature (RMOT) is between the B-class boundaries. This means that only a maximum of 10% of the people is predicted to be uncomfortable. For people with an activity level of 116W/m² the corrected boundary lines need to be used. In the heating season (hospital A cardiology and rehabilitation ward measurements 1 and 2), in more than 87% of the time, people with an activity level of 116W/m² are predicted to be uncomfortable. In the non-heating season (measurements 3 of hospital A and the measurement of hospital B) 7% of hospital A cardiology, 80% of the rehabilitation and 45% of the cardiology hospital B users are predicted to be uncomfortable with the temperature at an activity level of 116W/m². The high percentage of uncomfortable users for the rehabilitation ward in the non-heating season is due to the lower indoor temperatures compared to the other wards.
The staff members have different activity levels throughout the day, this was measured with the Sensewear Pro3. Table 4.1 shows the percentages of the time that the staff members are between certain activity levels, this is determined based on 10 shifts of the cardiology wards and 13 shifts of the rehabilitation ward. In 40% of the time the activity level is measured in the day shift, 40% in the evening shift and 20% during the night shift. From this table it can be found that >75% of the time the staff members have an activity level higher than 81.2W/m$^2$ and 35% of the time the activity level is even higher than 116W/m$^2$.

<table>
<thead>
<tr>
<th>Hospital A – cardiology ward</th>
<th>≤81.2 W/m$^2$</th>
<th>&gt;81.2 W/m$^2$ ≤116W/m$^2$</th>
<th>&gt;116W/m$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospital A – rehabilitation ward</td>
<td>26%</td>
<td>38%</td>
<td>36%</td>
</tr>
<tr>
<td>Hospital B – cardiology ward</td>
<td>25%</td>
<td>41%</td>
<td>34%</td>
</tr>
</tbody>
</table>

The ATC predictions are compared to the perception of the users obtained from the questionnaire (APD), table 3.2. From this table it can be found that for the patients the ATC model does not predict the correct amount of dissatisfied people in case of the rehabilitation ward, more patients are uncomfortable than predicted. The deviating prediction of the ATC model compared with the APD, can be caused by the lack of adaptability for the rehabilitation patients compared to those in the cardiology wards. It is also possible that the patients are still feeling warm from the physical therapy, which happened on another location in the hospital and caused a temporary higher activity level.

The predicted percentage of dissatisfied staff is shown in table 3.2 for an activity level below 81.2W/m$^2$ and of 116W/m$^2$. The results show that the prediction for activity levels of 116W/m$^2$ is in 6/7 measurements is in accordance with the results of the questionnaire (APD). Although the prediction corresponds to the APD, it does not give a specific idea on how many people are uncomfortable or which percentage of people with an even higher activity is feeling dissatisfied.

### 4.4 PMV model and comparison with the AMV

The predicted mean vote (PMV) has been determined for all of the rooms. However, the air velocity and radiant temperature are only measured in the rooms with the climate poles as a measurement set-up, but because of the equal internal conditions the average air velocity of the measured rooms have also been used in the PMV models of the non-measured rooms. The measured air temperatures have been used to determine the radiant temperature because based on the data from the climate pole it can be seen that the radiant and air temperature are quite similar ±0.25°C.

Figure 3.14 till 3.18 show the PMV ranges for each measurement period. The results show that depending on the clothing level and the location of the patient (on a chair or in bed) the PMV predicts that the patient feels between slightly cold and slightly warm during the day. During the night the patients are predicted to feel too hot, especially with the maximum clothing level. The PMV predictions of the staff member depend on the activity level, the staff members are predicted to be most neutral when the activity level is slightly below the average activity level of 116W/m$^2$. With a higher activity level the staff members are predicted to be hot and with a lower activity level they are cold according to the PMV predictions.
The percentage of the AMV results which are in accordance with the PMV results are shown in figures 3.19 till 3.21. These percentages are obtained from comparing the PMV predictions to that of the AMV. In order to compare the PMV with the AMV the scale needs to be made equal by rounding the numbers of the PMV predictions with the half round up method, for example the PMV score of 0.5 till 1.4 are rounded into 1.

The PMV-AMV results of the patients can be found in figure 3.19 in which the percentage of AMV which is in accordance with the PMV is shown for the bed and chair location, the influence of the different clothing levels can also be found in figure 4.1. The results show that more than 54-88% of the cardiology predictions on the thermal climate are in accordance with the AMV of the patients. The predicted PMV for the rehabilitation ward is around between 33-100% in accordance with the perception of the patients. This difference is caused by the perception of the patients, in the rehabilitation wards they perceive the temperature more extreme (3.11 and 3.12), and is not caused by the climate conditions which are similar in all of the wards (fig 3.14 till 3.16).

Figures 3.20 and 3.21 show the percentages in which the PMV is in accordance with the AMV for the staff members separated into activity level. The PMV-AMV relationship can also be found in figures 4.2 and 4.3. The activity level has been determined from the questionnaires by direct interpretation of the activities to activity level (up till 116W/m²) and with a corrected range of assumed activity levels up till 174W/m², see table 2.6. The results of direct interpretation (figure 3.20) show that only in the range of PMV predictions which are in accordance with the AMV are between 0 - 83%. The results of the corrected range of activity levels (figure 3.21) show that the range is between 0 - 100% in which the prediction is in accordance with the AMV. The large amount of predictions which are not in accordance with the AMV can be caused by the determination of activity levels. In the questionnaires the staff members were asked to fill in the activity level of the last hour, but it is not certain in what way that influences the perception of thermal comfort when they are actually filling in the questionnaire (and have a low activity level).
From the comparison of the PMV predictions with the perception of the users (AMV) it can be found that the PMV is more in accordance with the perception in case of the patients compared to the staff members. This is because the PMV model is a steady-state model which fits with the stable conditions of the patients but is less applicable on the staff members. The deviation of the PMV prediction with the perception of the patients is caused by the unknown clothing insulation. The use of the PMV model in a hospital should be applied only in steady-state rooms in which the activity level of the users is quite stable.

4.5 General discussion

Type of patients
In this research three hospital wards have been taken into account in which 2 types of patients can be distinguished, cardiology patients and rehabilitation patients. The activity level and clothing level of both types of patients are the same in the research. Due to the similar clothing and activity level the predicted perception of the temperature is similar for the wards while the thermal comfort perception obtained with the questionnaires is different. The patients of the rehabilitation ward are more uncomfortable with the thermal environment and are feeling warmer compared to the patients of the cardiology wards. The adaptability can influence the thermal comfort perception because on the rehabilitation ward there is no influence on the temperature but also the medicine use and health of the patient influences the perception [10]. In order to determine if the type of patient causes the difference in thermal comfort perception a research needs to be done in which both the adaptability possibilities and internal conditions are equal.

Heating systems
The hospitals and ward that have been taken into account in this research all have a different heating and cooling system. The cardiology ward of hospital A uses air heating, the rehabilitation ward uses radiators and in hospital B concrete core activation is used to heat and cool the building. Although there are different heating systems the indoor temperatures of the wards are quite comparable (table 3.1). However, the results of the questionnaires show that the perception of the staff members on the thermal climate is different in all of the wards (figures 3.5 till 3.12). The staff members of hospital A cardiology ward perceive it as slightly cold, the cardiology staff of hospital B is quite neutral about the temperature and the rehabilitation staff of hospital A perceives it as very warm and uncomfortable. These differences can be caused by the heating systems. A study done by L. Schellen et al [11] about the influence of thermal sensation under non-uniform environments show that under non-uniform conditions the perception of the users is lower (feeling colder) than predicted with model. This can explain the difference between the cardiology wards because the air heating is applied from some points in a room which might not be creating a uniform environment. Also the adaptability of the users can influence the perception of thermal comfort, and because in this study the adaptability was different in all of the wards further research into the different heating systems in a hospital is needed.
Comparison with research of J. Skoog [8]
In this research an adapted version of the questionnaires designed by J. Skoog et al [8] were used. They studied the thermal environment of Swedish hospitals during summer and winter. In their study it was found that staff and patients cannot be seen as one coherent group of users because of the difference in activity level and clothing level. In this research a distinction is made between these groups of users and from the results of this research it can also be seen that there is a difference in perception of the thermal climate. The patients are more positive and comfortable with the environment compared to staff members, this can also be found in their research.
5 Alternative to ATC and PMV model – Biophysical model

The PMV and ATC model predict the perception of users on the temperature based on the climate conditions in a room and not on individual differences between people. From the literature study [9] done previous to this research it can be found that people perceive thermal comfort differently depending on their gender and age, also weight and medicine use influence the thermal comfort perception of a person.

As an alternative for the PMV and ATC model a biophysical model has been taken into account. This biophysical model is designed by B. Kingma et al [12] and predicts the temperatures in which a person, based on their characteristics, is in the thermal neutral zone. The thermal neutral zone (TNZ) is the range of ambient (air) temperatures in which a subject can maintain their heat balance without additional heat production (shivering) or additional heat loss (sweat). In the biophysical model the TNZ is determined based on several individual characteristics. This is done by calculating the exact amount of heat production based on the activity level and the body surface area of a person. Figure 5.1 shows the TNZ for a person dressed in business suit and with a heat production associated with light office work obtained by the research of B. Kingma et a [12].

Method

In order to determine if the biophysical model gives an accurate prediction of the preferred ambient temperatures the results of the model have been compared to the results of the questionnaires. For the implementation of the model the activity level and personal characteristics (weight, length and age) are needed, these data have been obtained from the Sensewear measurements (see chapter 2.2).

Table 5.1 Results Biophysical model, ambient temperature in order to create a TNZ, for 3 staff member and their perception on the thermal conditions (current time of questionnaire) based on the questionnaires.

<table>
<thead>
<tr>
<th></th>
<th>Staff member 1</th>
<th>Staff member 2</th>
<th>Staff member 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement</td>
<td>H:B</td>
<td>H:A R-2</td>
<td>H:A R-1</td>
</tr>
<tr>
<td>Activity level</td>
<td>87W/m²</td>
<td>74.4W/m²</td>
<td>87W/m²</td>
</tr>
<tr>
<td>T_{ambient, in situation}</td>
<td>23°C</td>
<td>23°C</td>
<td>23°C</td>
</tr>
<tr>
<td>T_{ambient, according to TNZ}</td>
<td>20°C -21°C</td>
<td>22°C -23°C</td>
<td>20°C -21°C</td>
</tr>
<tr>
<td>Temperature experience (APD)</td>
<td>Comfortable (5)</td>
<td>Comfortable (6)</td>
<td>uncomfortable (3)</td>
</tr>
<tr>
<td>Temperature preference (AMV)</td>
<td>slightly cooler (-1)</td>
<td>neutral (0)</td>
<td>cooler (-2)</td>
</tr>
</tbody>
</table>

Figure 5.1. TNZ of a person dressed in a business suit and a heat production of light office work. The TNZ shows the combination of mean skin temperatures and ambient temperatures in which the body heat production is stable (in a core temperature between 36 and 38 °C). In which NST = thermogenesis by non-shivering and SH = shivering. [12]
Results
Table 5.1 shows the results of the biophysical model, which were obtained from calculations in Excel, and the corresponding questionnaire results. The calculations can be found in annex 12. There are 33 shifts in which a staff member has worn the Sensewear to determine their activity level, seven of these staff members also filled in a questionnaire. Because, currently, the biophysical model is designed for low activity levels only three combinations of Sensewear measurement and questionnaire could be used.

Discussion
From the results it can be seen that the ambient (air) temperature, in which the staff member would be thermally neutral according to the biophysical model, is different from the temperature in the real situation. The calculated TNZ temperatures are more comparable with the AMV of the three staff members that were taken into account. For example, the staff member of situation 1 prefers the temperature to be cooler, which is also in accordance with the biophysical that predicts that staff member 1 is neutral at a lower temperature.

Conclusion
The results show that the preferred ambient (air) temperature according to the biophysical model is in accordance with the preferred temperature of the staff members. This shows that the model predicts the right preferred ambient temperature, based on the small group of 3 staff members, on an individual base. The applicability of this biophysical model in hospital rooms with more than one user is difficult due to the fact that the model predicts the ambient temperature based on a person’s characteristics, this can be different for each person.

The applicability of this model for staff members is hard because of the variable activity levels of the staff members, this means that for every activity the prediction needs to be adjusted to that activity level, and the current model is not yet developed for higher activity levels.

In order to use this current model in a hospital environment, a user needs to be selected who has a stable activity level and has the possibility to change the temperatures. This means that for single-patient rooms this model could be used. Since for each patient the optimum temperatures need to be determined and this can be time-consuming, the optimum location for this model would be on an intensive care ward in which the optimum temperatures can contribute to improve the recovery of the patient.
Conclusion and recommendations

Conclusion

The goal of this research was to determine whether the current available models for assessing thermal comfort are suitable for a hospital setting and can be used as a tool to improve the thermal comfort of the staff and patients. Within this research the following research question was answered:

‘Are the current available models for assessing thermal comfort suitable for a hospital setting?’

In order to answer the research question the results of two models, the predicted mean vote model (PMV) and adaptive thermal comfort model (ATC), have been compared to the opinion of the hospital users. The models have been used to predict the thermal comfort at three wards of two hospitals. From this research the following conclusions can be made:

- The PMV model takes the clothing level and activity level into account, but due to the fluctuations in both clothing and activity level the PMV needs to be determined based on maximum and minimum values. With the most common boundaries taken into account the results of the research show that the range in which the PMV predictions match are between 33-100% for the patients and between 0-100% for staff members depending on the measurement location.

- The ATC model predicts how many people are uncomfortable with the temperature based on the indoor and running mean outdoor temperature. The results of the ATC are not always in accordance with the opinion of the patients, this is the case for patients of the rehabilitation ward who might be more active than predicted. The results of the ATC model for the staff members at an average activity level are in 6/7 measurements in accordance with the perception of the staff members. However, from this research it cannot be said that the ATC model can be used to predict the amount of uncomfortable staff members because results only show that more than 25% of the staff members is uncomfortable but is does not give a precise prediction.

- Not only the clothing level and activity level influence the perception of the thermal comfort, also individual aspects as body surface area, age and gender influence the thermal comfort [9]. An option for predicting the optimum temperatures on an individual base could be the biophysical model by B. Kingma et al [13], and this model has been applied for three staff members. In this model the individual aspects of a person are used to determine the ambient temperature at which the heat production/loss of the body is neutral. The small amount of results show that this model can give correct prediction of the temperatures, but in order to determine if this is a useful model more research needs to be done. Due to the individual characteristics of a person that will be taken into account in this model, this model can be used best in single-patient rooms in which the ambient temperatures can be changed.
From this research it can be concluded that the PMV and ATC model do not always give a correct prediction of the perception of the users. The PMV model might be possible to use in hospitals if the right minimum/maximum clothing level and activity levels are determined and the model is used in a part of the hospital (a room) in which during a certain time the situation is steady state (equal activity levels for all users).

The ATC has not been tested completely on the applicability for staff members and patients with a higher activity level, because the inside temperatures were above the comfort class boundaries in which it predicts the amount of dissatisfied people. Because this research is done with a small group of participants (±20 staff members and ±9 patients for each of the seven measurements) more research is needed with a larger group of participants to determine if the results represent an entire group of users.

Recommendations

Measurement locations
The location of the measurement equipment in a room can influence the measured values, positive or negative. Research needs to be done to determine the optimum location of the measurement equipment, provided that the location doesn’t create an obstacle for the hospital users. It is also important to consider a short term measurement, for example half an hour, in case of a stable indoor environment. The advantage of the short term measurement is that the equipment can be temporarily placed in any part of the room.

PMV Model
From the research it can be found that the PMV model can be applied in steady state situation as patient rooms. In order to use the PMV model also in the other rooms, the local situation needs to be steady-state, this means with an activity level that is stable for all of the staff members at a certain time. Additional research on the activity levels and corresponding locations is needed, in this research the activities and locations of the staff members need to be divided into groups which can be considered as steady-state.

ATC model
Within the ATC model the prediction boundaries can be corrected to match the activity level of the staff. In order to determine if the ATC model can be used as a tool to predict the preferred indoor temperatures of hospital users with a higher activity level a separate research needs to be done. In this new research the indoor temperatures need to be varied within the comfort class boundaries, in which a maximum of 25% should be uncomfortable, these new results need to be compared to the opinion of the staff members at the adjusted temperatures.

Biophysical model
The results of the biophysical model are similar to the results of the questionnaires. The amount of results on the application in this research is very small due to the restrictions of the model. It is recommended that research will be done to the application of this model on single-patient rooms in which the user can adjust the temperatures. This is because the model predicts the optimum ambient temperature for each individual based on their characteristics and is developed for low and stable activity levels.
**Different types of heating systems and patients**
In this research the different heating systems and different types of patients can also influence the perception of thermal comfort. But because the adaptability options are different in all of the investigated wards more research is needed. In order to determine whether the heating systems or patients types influence the perception of thermal comfort, a comparison needs to be made while the climate conditions and the adaptability possibilities are equal.

**Questionnaires**
During this research several improvement points towards the questionnaires have been found:

- Incorporate the clothing level and the location (chair or bed) in the patient questionnaires, this way a more exact clothing insulation value can be determined.

- Ask the staff member for their function or daily activities in order to determine which activity levels are best suited for that staff member. This needs to be incorporated because there are also staff members who are partly nursing staff and partly administration staff.

- Within the questionnaires people have been asked how they experienced the environment and how they perceived it. According to the subjects these questionnaires are equal because in their opinion if the temperature is uncomfortable it is automatically bad, this was also found in the results of the questions. In order to decrease the work load of the questionnaire for the participants it should be sufficient to only ask how they experience the environment.

- Add the option “not applicable” to the questionnaires. For example, during the night there is no daylight but because there is no other option some people will fill in the question based on early experience.

- When the questionnaires are not anonymous the number of participants can be determined, this can be used to predict which percentage of users participated in the research. On the other hand, if not anonymous the response may be lower in number.
References


