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Indoor comfort evaluation of a health care facility: a case study

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Abstract

Thermal and visual comfort significantly influence the perception of an indoor environment and the subjective well-being of people. In this context, the present research focuses on the evaluation of the indoor comfort in a healthcare facility in Vienna, Austria. Short and long-term monitoring of air/globe temperatures, relative humidity, air velocity, lighting levels has been performed. Additionally, both patients and employees have been asked to assess indoor environment by means of questionnaires. Combining answerers' activity and clothing levels with measurements, Fanger's Predicted Mean Vote and Predicted Percentage of Dissatisfied have been calculated according to the European standard (ISO 7730). Furthermore, the comfort indexes have been compared with the collected votes from the survey. Both approaches for the assessment of indoor thermal comfort highlight differences between the two categories of occupants. However, for this case, Fanger's model over-predicts the percentage of dissatisfied and gives larger sensitivity to changes of the activity level because of patients' therapies. Lighting levels are found generally lower than recommended, but they have been rated acceptable by both patients and employees.

Keywords – thermal comfort; PMV; PPD; user evaluation

1. Introduction

Fanger's thermal comfort model [1, 2] is based on experiments performed with healthy adult people in a controlled environment under steady state conditions. For this reason, inaccuracies can arise if Fanger's model is applied under different hypotheses. Patients of healthcare buildings, for example, are affected by unhealthy physical conditions, undergo specific therapies and, in many cases, they are elderly. Furthermore, in healthcare facilities there are also employees - with different health status, metabolic activity levels and clothing, making the comfort analysis of all occupants more complex. As observed by Verheyen *et al.* [3], dedicated studies are necessary for these specific indoor environments since employees' and patients' comfort perceptions are different [4, 5]. Hwang *et al.* [6] studied a set of 927 data collected in a hospital in Taiwan: air temperature, humidity and velocity and global temperature were collected in different wards at patients' bed height (i.e., around 1 m height) and patients filled out questionnaires about physical strength and thermal sensations. With respect to Fanger's model, comfort neutral temperature resulted 1.4 - 2.3 °C higher in winter and 0.5 - 2 °C higher in summer. Moreover, the authors found a statistically significant correlation between patients' physical strength and thermal comfort perception. Considering the findings by Hwang *et al.* [6], Azizpour *et al.* [7] decided to focus only on staff and visitors and assessed the comfort conditions of 10 thermal zones in the University Kebangsaan Malaysia Medical Center, by collecting their votes. Van Gaever *et al.* [8] analyzed the thermal comfort of surgical staff in operating rooms of 4 hospitals in Belgium. Environmental parameters were measured, as well as clothing and activity levels of each member. The authors found that Fanger's model underestimated the Predicted Mean Votes for nurses, anesthetists and surgeons. Verheyen *et al.* [3] analysed the comfort conditions of 99 patients in 6 different wards of a hospital in Belgium. A questionnaire was developed according to ISO 10551 [9], including also questions regarding indoor air quality, acoustic, light and visual comfort, possibility to adapt the environmental conditions and a self-evaluation of the answerer's health status. Measurements of air and operative temperatures, relative humidity and air velocity were made at the height of 1.1 m within 1 m from the position of patients' beds. Thermal environment was rated as acceptable by 95 % of patients, despite of 29 % of thermal environments not complying with ASHRAE design ranges of temperature and relative humidity. However, in contrast with other researches, such as [6, 8], after some comparative statistical tests between results by Fanger's model and direct survey, the authors concluded that Predicted Mean Votes can be used for the majority of patient population, except for those of neurology ward.

In this work, we perform an analysis of the thermal comfort conditions for both patients and employees in a physiotherapy center in Vienna, Austria, with the aim of assessing if different thermal comfort perceptions are found for the two occupants' categories. Short and long-term measurements have been collected in order to assess the global comfort by means of Fanger's model and interviews have been submitted to occupants in order to check the representativeness of the model results.

2. Case study and measurements

This study regards a private physiotherapy center called "Physikalisches Institut Leopoldau", located in the East side of the ground floor of a 20-year old building in Vienna, Austria, with 3 floors. The centre occupies an area of 504.75 m^2 which can be divided into two main zones:

1. the first zone is composed by a reception, a waiting room, a doctor's and director's offices, three bathrooms, a laundry, a private area for employees and a storage with technical rooms;
2. the second one, i.e., the "therapy zone", includes a main hall, several small therapy rooms, larger rooms for specific treatments (e.g., hydrotherapy, lympho-drainage, etc.), two bathrooms, three gym rooms and a veranda.

Two kinds of measurements have been collected: detailed short-term measurements and long-term measurements. Short-term measurements have regarded air temperature, relative humidity, mean radiant temperature, air speed and illuminance. An Ahlborn ALMEMO 2590 system with 5 different probes has been used. The monitored quantities have been recorded with accuracies of 0.1 °C for air and mean radiant temperatures, 2 % for relative humidity, 0.01 m s^{-1} for air velocity and 1 lx for illuminance. Short-term measurements have been repeated 3 times in all rooms of the therapy zone: on 12/03/2015 from 3 till 7 pm, on 25/03/2015 from 2 till 8 pm and on 21/04/2015 from 11 am till 4 pm. Time interval has been set at 200 s for the first two measurement campaigns while 60 s has been used for the last one. The collected data have been exploited in order to assess the errors of long-term measurements and to derive correlations for the estimation of mean radiant temperature.

Long-term measurements of temperature and relative humidity have been collected by means of 22 HOBO U12 data loggers and probes. 12 of them acquire both air temperature and relative humidity and the remaining 10 only the air temperature. These probes have nominal accuracies of ±0.35 °C for temperature and ±2.5 % for relative humidity. The two main zones of the building have been subdivided into 9 smaller zones, according to boundary conditions and type of treatment and the probes installed in each one of them:

1. East side therapy rooms with a window (light blue areas in Figure 1);
2. West side therapy rooms with a window (dark blue areas in Figure 1);
3. Central therapy rooms (red areas in Figure 1);
4. Lympho-drainage rooms (a veranda and some rooms – green areas in Figure 1);

5. Gym rooms (yellow areas in Figure 1);
6. Hydrotherapy rooms (purple area in Figure 1);
7. Doctor's office (rose area in Figure 1);
8. Waiting room (grey area in Figure 1);
9. Dressing rooms (brown areas in Figure 1).

The installation of the HOBO sensors has been made at a height of 1 m, considering the positions more representative of air temperature and relative humidity of each environment compatible with the rooms activities. The chosen timestep has been 10 minutes, which have been adopted in order to record at least two measurements during each treatment. The measurement campaign started on 08/03/2015 and ended on 21/04/2015.

Figure 1 - Physiotherapy Center layout and locations of air temperature and relative humidity probes for long-term measurements.

3. Questionnaires

In order to evaluate employees' and patients' opinions about comfort conditions, questionnaires have been prepared according to ASHRAE 7-points thermal sensation scale [1] and developed according to [1-4, 6-8]. Date, time and room where therapy has been performed have been asked, in order to match the answers with the measurements in data analysis. Answerers have been identified by means of their name initials (in case of employees) or code (in case of patients), in order to allow studies of questionnaire repetitions. Pieces of information about gender, age, weight, height and dressed clothes have been collected as well. Furthermore, patients have performed also a self–valuation on their own health status, choosing among "healthy", "slightly weak" and "weak status".

The questionnaires have been divided into three sections, one to be filled by the employee (section A) and two by the patient, before (B) and after the therapy (C). All sections have included questions about:

- Opinion on temperature when completing the survey ("too cold", "cold", "slightly cold", "neutral", "slightly warm", "warm", "too warm");
- Opinion on illuminance level when completing the survey ("too dark", "dark", "slightly dark", "neutral", "slightly bright", "bright", "too bright");
- Opinion on air humidity when completing the survey ("too dry", "neutral", "too humid").

Sections B and C have proposed also questions about:

- Opinion on presence of draughts ("yes" or "no");
- Opinion on air quality when completing the survey ("very bad", "bad", "neutral", "good", "very good").

4. Analysis of collected measurements and answers

Air temperature has resulted always between 23 °C and 25 °C and relative humidity between 25 % and 55 % during the occupancy time, except for veranda and gym rooms, which are slightly colder, and for hydrotherapy room, which presents peaks of temperature and relative humidity when therapies occur. Analysis of short-term measurements confirmed that temperature and relative humidity are very stable and within the ranges of 24 - 26 °C, with the exception of gym rooms, and 20 - 50 %, respectively. Air speed is very slow and well under the 0.2 m s^{-1}. As regards the illuminance level, according to the technical standard EN 12464-1:2011 [10] 200 lx should be ensured for waiting rooms, 300 lx for massage rooms and 500 lx for offices and examination rooms. However, values around 100 lx have been

measured in most of rooms, suggesting that the lighting system is largely undersized with respect to technical standard prescriptions.
137 filled questionnaires have been collected and only 13 have been rejected because of missing data necessary to the analysis. The largest numbers of questionnaires have been collected in therapy and lympho-drainage rooms. On the contrary, for hydrotherapy rooms and doctor's office, the number of answers have been not enough to build an adequate dataset. Many questionnaires have been repeated by the 33 interviewed employees, with an average repetition rate of approximately 4 and a total of 129 useful questionnaires. 75 % of all answers are given by female employees; for 35 % of cases people age is between 45 and 55 and for 32 % of cases it is between 35 and 45; employees' weight is in the range 50-60 kg for 44 % of women's answers and 70-80 kg for men's answers. Most of patients have filled out the questionnaire only once. Also for patients, 70 % of questionnaires have come from women's answers; 3/4 of answers have been provided by people born between 1940 and 1970, almost equally subdivided into the 3 decades; patients' weight is larger than employees' one and the highest frequencies are between 60-70 kg for women's answers and in the range 70-100 kg for men's answers. About 60 % of patients' answers indicate a "slightly weak" status. From answers about dressed clothes, clothing levels have been determined. Half of employees' answers are in the range of 0.25-0.5 clo while the remaining half is between 0.5 and 0.75 clo. These two ranges are the most common also for patients' answers, even if some cases clothing levels lower than 0.25 clo or larger than 0.75 clo are found.
As regard sections B and C of questionnaires, minor differences have been found among patients' answers before and after the therapy. As it can be seen in Figure 2, employees feel the environment warmer than patients.

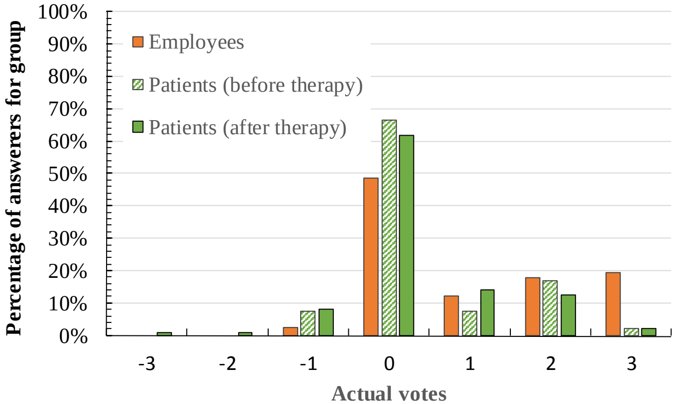

Figure 2 - Comparison between thermal comfort rates of employees (blue), patients before therapy (green) and after therapy (orange).

While patients consider appropriate the value of relative humidity, according to 42 % of employees' answers air is too dry. The patients' perception of air quality is neutral for half sample and does not vary during the therapy; draught problems are negligible. As concerns visual comfort, both employees (63 % of employees' answers) and patients (almost 80 % of patients' answers) are satisfied by the current conditions, even if the measured illuminance level is much lower than technical standard recommendations. No particular trends are found grouping the results by category of occupants with the exception of employees' gender: thus, women employees tend to feel the indoor environment warmer and drier with respect to men employees. Considering the different zones, occupants feel warmer conditions in therapy rooms, especially east and central ones (Figure 3).

5. PMV and PPD calculation and comparison

Occupants' answers have been compared with comfort indexes calculated from the measurements collected at the same time. Air temperature and relative humidity have been taken from long-term measurements. Mean radiant temperature, instead, has been available only from short-term monitoring. In order to perform an estimation, linear regressions have been developed with respect to air temperature for each zone. Only those regressions with index of determination R^2 larger than 0.7 have been used to calculate mean radiant temperature from long-term values of air temperature. In the other cases, i.e., central therapy and hydrotherapy rooms, mean radiant temperature has been assumed equal to air temperature. Air speed average conditions have been calculated from short-term measurements. According to [1, 2], a metabolic rate of 2 met has been assigned to employees while different metabolic rates have been imposed to patients depending on the specific activity performed in each location: 1 met has been assumed for each room except gym rooms, where 3 met have been considered. The clothing level values have been determined from the answers to questionnaires according to ASHRAE Standard 55 [1]. Together with activity and clothing levels, air and mean radiant temperatures, relative humidity and air speed have been used to calculate Predicted Mean Votes and Predicted Percentage of Dissatisfied [1, 2, 9]. Clothing surface temperature has been estimated by iterative process, assigning an initial value equal to air temperature and a tolerance of 0.3 °C.
A comparison between PMVs and answerers' votes has been made. Since votes are discrete numbers, to make the comparison easier, PMVs have been approximated to the closest integer value. Some discrepancies have been found between PMVs and votes. In particular, patients' PMVs calculated after the therapy suggest many people feeling warm but this trend is not observed in patients' answers.

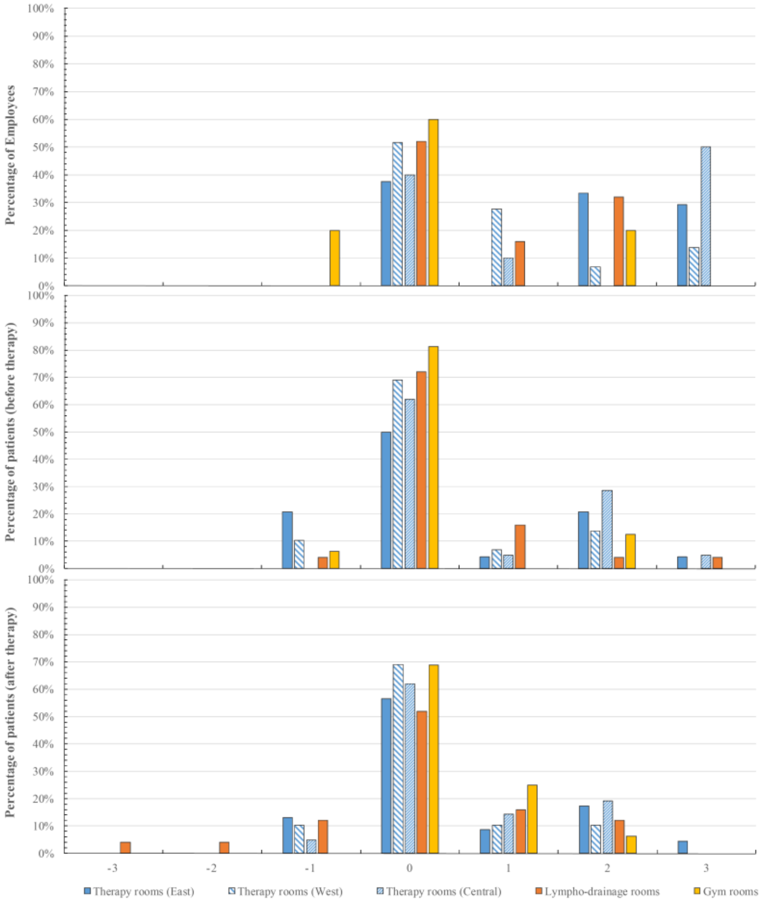

Figure 3 - Thermal comfort rates of employees (on the top), patients before therapy (in the middle) and patients after therapy (on the bottom) in the different zones.

PMVs and votes have been averaged and the corresponding PPD values calculated. As seen in Figure 4, Fanger's model and collected votes are in agreement as regards the prediction of employees' comfort conditions, even if the percentage of dissatisfied is overestimated by the comfort model. A general satisfaction of comfort conditions is found only for patients' after therapy: moreover, in this case there is a very good agreement between the results of Fanger's model and collected votes. If the conditions of patients before the therapy is considered, large discrepancies are registered and the average PMV is far lower than the mean vote, suggesting a general cold sensation while the votes express a general comfort condition.

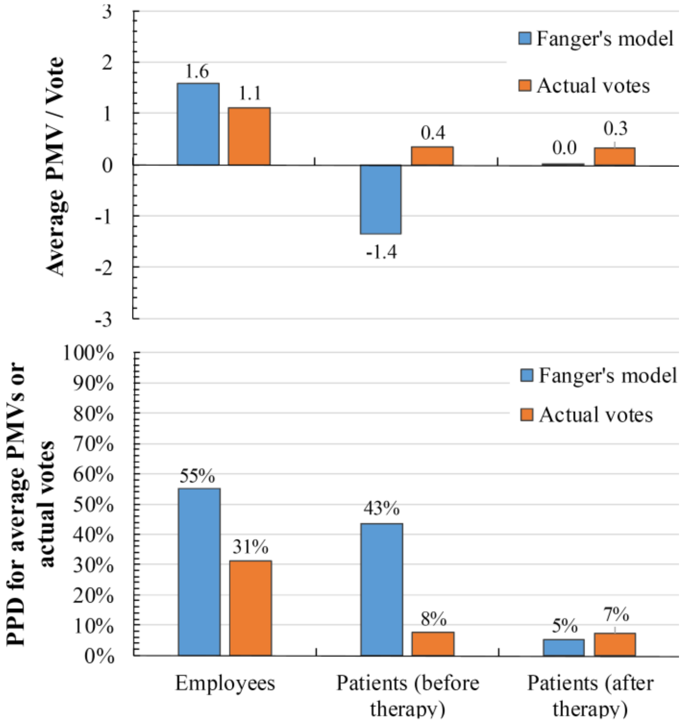

Figure 4 - Average PMV and PPD for employees and patients according to Fanger's model and direct survey.

7. Conclusions

In this work, we assessed the thermal comfort perceptions of occupants of the physiotherapy center “Leopoldau” in Vienna, Austria. Attention has been paid to the two categories of people in the building, i.e., employees and patients, and to the effect of therapy on patients well-being sensation. Measurements of air and mean radiant temperatures, relative humidity and air speed have been collected during 6 weeks in March and April in the different rooms of the center. In parallel, questionnaires have been provided to employees and patients in order to characterize the properties of the sample of answerers, their clothing and activity levels and to record their votes about indoor temperature and humidity. Opinions about visual comfort have been collected as well and, only for patients, also about draughts and air quality. Measurements and occupants’ activity level and clothing have been used to calculate PMV and PPD according to Fanger’s comfort model. The elaborated comfort indexes have been compared with answerers’ votes.

Also answers about visual comfort have been compared to the illuminance levels measured in the different rooms of the physiotherapy center.
Similarly to what observed in the literature for hospitals and clinics, we found that employees and patients can have significantly different perceptions of thermal comfort, also when patients are not subjected to bed rest. In this specific case-study, indoor conditions seem designed to optimize only patients' comfort and employees are more dissatisfied of indoor ambient conditions and consider the environment warmer. Discrepancies have been found between Fanger's model predictions and actual answerers' votes, with the model generally overestimating the percentage of dissatisfied. Moreover, the impact of metabolic activity on answerers' vote has been assessed and it has been found that Fanger's model overestimates the effect of the metabolic rate associated to patients' therapy, which seems negligible according to patients' votes.
As regards visual comfort, the occupants expressed satisfaction of current conditions, even with illuminance values much lower than EN 12464-1 prescriptions for healthcare facilities.

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