On the Assessment of the Environmental Comfort in Operating Theatres.

Sante Mazzacane\textsuperscript{a}, Carlo Giaconia\textsuperscript{b}, Silvia Costanzo\textsuperscript{b}, Alessia Cusumano\textsuperscript{b}, G. Lupo\textsuperscript{c}

\textsuperscript{a} Department of Architecture, University of Ferrara, Italy
\textsuperscript{b} Department of Energetics and Environmental Researches (DREAM), University of Palermo, Italy
\textsuperscript{c} Department of Civil Engineering (DIC), University of Messina, Italy

Abstract

The operating theatre is a very complex environment shared, for a certain period, by a group of people having highly different needs: on one side, there is the surgical team that must carry out a demanding job that in some cases can be very stressful (e.g. orthopedics surgery or those lasting more than four hours) and on the other, there is the anesthetized patient often subject to liquid infusion.

Up to today little consideration has been given to the different needs of the surgical team whose members show different reactions according to their positions with respect to the scialytic lamp and above all to the task had within the team. Also the clothing influences the surgical team comfort degree: in fact, in some surgery (orthopedics, neurosurgery etc.) surgeons and assistants must wear non transpiring paper overalls beneath plasticized overalls besides protective masks and caps; then, if X-rays are needed during surgery, the second surgeon and the assistants must also wear lead overalls and lead thyroid collars and gloves while the anesthetists and nurses will keep on wearing non transpiring paper overalls; therefore the clothing thermal resistance of the surgical staff involved in the same surgical operation should be very different.

The purpose of the present work is to report the first data obtained during an experimental campaign carried out at the SS. Annunziata hospital in Cento (Ferrara, Italy) and presents the developed investigation methodology.

Keywords:

Operating Theatres, Hypotermia, Thermal Stress, Thermal Comfort

1. Introduction

As it is well known, the combined effect of external thermal environment and internal metabolic heat production constitutes the thermal stress on the body. The levels of activity required in
response to the thermal stress by cardiovascular, thermoregulatory, respiratory, renal and endocrine systems constitute the thermal strain. Such responses are the initial reaction to thermal stress, but the level at which they are required to operate determines whether that strain results in thermal injury. Over the years numerous methods have been employed in the attempt to quantify the effect of heat stress or to forewarn of its impending approach. Factors such as temperature, radiant heat load, air velocity, humidity, clothing, metabolic load, posture and acclimatisation should be taken into account. Environmental data are part of the necessary means of ensuring, in the majority of routine work situations, that thermal conditions are unlikely to affect negatively the worker well being. When signs of heat strain or negative concern have been observed, such data can also provide guidance as to the most appropriate controls to be introduced.

Few studies have examined so far the problem of the thermal strain of surgical patients and the medical staff in the perioperative period, and only recently have such studies been performed. Some studies have been carried out in Italy in order to define a program of prevention and reduction of the heat stress risk to health workers and patients using current thermal stress indices. However data acquired in field are scarce and they regard the study of the microbiological contamination conditions more than the thermo-hygrometrical comfort situations.

In operations involving open body cavities, there may be an even greater loss of heat. Core temperatures should therefore be measured during anaesthesia in order to detect thermal disturbances and direct thermal management.

Within the CERTECA (Air Technologies Research Centre) of the Ferrara University, with the collaboration of the Departments of Energetics and Environmental Researches (DREAM) of Palermo University and of Civil Engineering (DIC) of Messina University, a survey has begun aimed to the assessment of microclimatic and microbiological problems in operating theatres. Among the objectives of the research project, in this paper the following topics will be exposed:

- to design and validate strategies, specific for medical staff and for patients, for the assessment of the thermal conditions related to special working conditions such as those in operating theatres.
- to improve the prediction of the heat exchanges between clothed person (medical staff or patient) and the environment, taking into consideration the characteristics of normal and special clothing ensembles.
- to test the validity of current available expressions for the prediction of the mean skin temperature.

These objectives will be reached by experimental and theoretical activities. The experimental activities will be carried out in the 4 operating rooms of S.S. Annunziata Hospital (Cento, Ferrara) and in the CERTECA (Air Technology Research Centre) laboratory of University of Ferrara, where is located a full scale (1:1) operating room, equipped with every kind of device able to reproduce artificially some types of ventilation and thermo-hygrometrical conditions.

In this paper the first results obtained during an experimental campaign carried out in May 2005 at the SS. Annunziata hospital in Cento (Ferrara, Italy) are presented and the developed investigation methodology is summarized. The experimental data highlight the different thermal stress conditions affecting the surgical staff. They may be useful in developing a methodological base apt to correlate local and global comfort situations to measurable physiological parameters such as body superficial temperature $T_{\text{skin}}$ (Jansky et al., 2003).
2. Investigation Methodology

Starting from May 2005, at the orthopedics operating theatre of S.S. Annunziata Hospital in Cento (Italy) a monitoring campaign was carried out on the surgical staff members who actively collaborated with the research group for setting up by the investigation protocols. The surgical staff included two surgeons, two assistants and three nurses. The research ran on two contemporaneous investigation lines: an objective and a subjective one.

The objective investigation pointed at measuring several physiological parameters (Huang et al., 2001; Huizenga et al., 2004) such as:

- Superficial temperature $T_{\text{skin}}$ for each member
- Relative humidity between skin and overalls in order to define the condition of sweating for each member

The subjective investigation pointed at determining the comfort or discomfort sensations felt by the staff members on duty in the operating theatre. For this purpose each staff member was given a questionnaire to be daily filled at the end of each operation.

3. Objective Investigation: Physiological Parameter Measurements

The recording of the physiological parameters, relevant for the present survey (Perl et al., 2004), had to have – in agreement with the operating room staff - a measurement protocol which included methodologies and behaviors that each of them had to follow during the experimental survey campaign.

At the same time the research group set up such a data acquisition system as not to hinder the normal progress of the operating room activities.

It is obvious that traditional systems with connecting wires between sensors and acquisition units would hamper the surgeon’s movements when operating.

Then, not needing to immediately know the values of the parameters, it was decided to use two kinds of i-Button sensor/recorders produced by Dallas Semiconductors (Fig. 1) for temperature and relative humidity.

The common characteristics of the two elements are the compactness (diameter 17 mm and thickness 6 mm), the possibility to get up to 4096 records at set time intervals ranging from 1 second to 273 hours starting from an initial instant defined by the user or tied to an alarm condition, enough memory space for individual calibration data, the possibility of password protection, a specific identifier for each unity and a communication interface that only uses one active wire to communicate with a computer through the OneWire protocol.

The model DS1921H is particularly suited to monitor body temperature thanks to its high resolution (1/8 degree) in the range $+15/+-64$ °C, while the model DS1923, besides measuring temperature values in the same range and with the same resolution, is also provided with a capacitive polymeric sensor able to measure relative humidity with a 0,04% resolution.

The recorders were applied on the workers through a special transpiring adhesive tape.
According to the measurement protocol, the workers had to wear the i-Buttons before entering in the operating block and could take them off at the end of their working day. The authors took in consideration some formulas to calculate $T_{\text{skin}}$ (Choi et al., 1997; Sramek et al., 2000) available in the literature to determine the smallest number of i-Button to be used and the best position on the volunteers’ bodies. An in-depth experimental study was able to establish that the most reliable formulas were these of Hardy and Dubois (1) with seven measurement points (Hardy et al., 1938), the Houdas’ one (2) with five measurement points (Houdas et al., 1982) and Olesen’s (3) with three measurement points (Olesen, 1982):

\begin{align*}
T_{\text{skin}} &= 0.07 A + 0.35 D + 0.14 L + 0.05 M + 0.019 N + 0.13 R + 0.07 T \quad (1) \\
T_{\text{skin}} &= 0.07B + 0.17 E + 0.17 H + 0.19 J + 0.39 Q \quad (2) \\
T_{\text{skin}} &= 0.5 D + 0.14 I + 0.36 S \quad (3)
\end{align*}

where:

- **A** Forehead
- **B** Cheek
- **D** Chest
- **E** Abdomen
- **H** Lumbar
- **I** Posterior Upper Arm
- **J** Antero-lower Upper Arm
- **L** Posterior Forearm
- **M** Hand
- **N** Anterior Thigh
- **Q** Postero-Lower Thigh
- **R** Anterior Calf
- **S** Posterior Calf
- **T** Foot

Considering that (1) and (2) are not acceptable since they use measurement points (forehead and cheek) that could hinder the surgeons’ work and since the calculated $T_{\text{skin}}$ values among the three different formulas do not vary in a meaningful way, it was decided to exploit Olesen’s formula that contemplates superficial temperature measurements on the chest, forearm and on the back of the calf (Fig. 2).
Along to the DS1921H i-Buttons used for $T_{\text{skin}}$ calculation another DS1923 (Hygrochron) i-Button sensor was placed on the workers’ abdomen; it gives temperature values and relative humidity in the space between the workers’ skin and the overall, useful to quantify the evapo-transpiration phenomena.

A color was associated to each body part to ease up the surgical staff in positioning sensors; this way each sensor is identified by a relative code to a volunteer and by a relative color to the placement position.

Table 1 reports an example of code-sensor, code-volunteer and code-position associations.

<table>
<thead>
<tr>
<th>Sensor Code</th>
<th>Personal Identification Code</th>
<th>Colour</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>A34F2000007C9D21</td>
<td>1</td>
<td>€</td>
<td>Chest</td>
</tr>
<tr>
<td>7A4F200000709621</td>
<td>1</td>
<td>€</td>
<td>Posterior Upper Arm</td>
</tr>
<tr>
<td>AD4F200000770721</td>
<td>1</td>
<td>€</td>
<td>Posterior Calf</td>
</tr>
</tbody>
</table>

Table 1: Example of Code association

This method facilitated the management of the measurements, making the medical staff autonomous.

The sensors were worn by the surgical staff, on average made up by eight people, for about six hours a day, from the moment the subjects entered inside the operation block to the conclusion of the operations. Each sensor acquisition rate was set at six minutes, so each sensor could record up to a month worth of data.
3.1 Result Analysis

The analysis of the acquired data show that the workers subject to a greater stress condition are the two surgeons and the two assistants.

In fact, figures 3 and 4 show higher $T_{\text{skin}}$ values for the surgeons and assistants since they are more committed even if for a smaller time, while the $T_{\text{skin}}$ values for the nurses that suffer less stress for the entire operation time stay around 31 °C.

It must be noted how the same subject, with the same type of clothing, reveals rather high $T_{\text{skin}}$ gradients in accordance with the type and complexity of the undertaken surgery. For example, in figure 3 the surgeon’s $T_{\text{skin}}$ passes from 22°C (practically room temperature) for a simple operation such as the removal of a cyst in the hand to 34°C for a more complex operation such as a knee prosthesis. The greater stress experience endured by the surgeons and assistants may be actually due to the above mentioned temperature levels.

The different thermal condition experienced by the surgeons and assistants with respect to the nursing staff may also be attributed to the position each staff member occupies within the surgical area. In fact besides the performed task also the closeness to the scialytic lamp for a period longer than an hour has an noticeable effect.

Figure 3: May 9th 2005, $T_{\text{skin}}$ courses for the entire surgical staff in relation to the performed task
The type of clothing worn by the staff members is another variable that must be taken in consideration in this study; in fact, while nurses generally use disposable or cotton jackets and trousers, surgeons and assistants, besides these garments, also wear plastic overalls, gloves, visors and in some cases, when the operation requires X-ray equipment, they also wear lead overalls, gloves and thyroid collars.

As it can be noted in the example in figure 5 the second surgeon’s $T_{\text{skin}}$ goes from 32°C – measured when he wore a cotton overall with a non transpiring overall to 34 °C – when he wore a paper transpiring overall, lead long overall, gloves and protective cap.

In this case the highlighted stress condition is localized in the worker’s trunk as shown by the superficial temperature recorded with the blue i-Button applied on the subject chest.
Fig. 5: 2nd surgeon’s $T_{\text{skin}}$ course as a function of clothing

The analysis of the data related to the two assistants that also wore the sensors for the relative humidity better highlighted the thermal stress condition that takes place in a controlled environment such as the operating theatre.

In fact, figures 6 and 7 show that when $T_{\text{skin}}$ reaches values of about 35 °C, the relative humidity reaches several times the 100% limit in the air inter-space between the body surface and the overall, implying sweating and subsequent discomfort.

The above mentioned graphs point out that the higher stress conditions depend in a meaningful way from the type of worn clothing and on its thermal resistance, in fact the most intense sweating conditions correspond to the periods when the subjects wore lead overalls.
Fig. 6: May 10th 2005, Skin-overall $T_{skin}$ and relative humidity courses for a surgical assistant
Fig. 7: May 11\textsuperscript{th} 2005, Skin-overall $T_{\text{skin}}$ and relative humidity courses for a surgical assistant.
The data up to now gathered and elaborated have allowed to single out the types of surgery where the worst conditions are reached. Figures 6 and 7 point out that surgeries with prostheses – such as femur fracture and reconstruction - are the ones where the whole staff is subject to serious thermal stress. These are the longest operations with the greatest number of recorded infections.

4. Subjective Survey: Questionnaire

Along with the objective survey, a subjective survey was also carried out to determine the wellbeing or discomfort sensations the operating staff felt. In order to gather information tied to personal evaluations, each surgical staff member was given a questionnaire made of three parts: the first concerned the subjects’ physical characteristics (age, sex, weight etc…), the second concerned the subjects’ job and the clothing they wore, and, the third – to be filled during or after working in the operating theatre - concerned the subject’s judgment on the thermal environment, the overall comfort sensations and requests of eventual changes of the microclimatic characteristics of the operating theatre. Figure 8 reports the score percentage referred to the environment thermal evaluation. From the gathered responses it can be deduced that the first surgeon was very hot 25% of the times and hot the remaining 75%; the second surgeon was hot 50%, slightly hot 33% of the times and had a neutral sensation the remaining 17%. The surgical assistants were hot 67%, slightly hot 23% and neutral the remaining 10% of the times. Finally the nurses felt good 75% of the times while the remaining 20% were cold.

![SS. Annunziata Hospital (May 2005) Thermal Environment Evaluation](image)

Fig. 8: Judgment given on the operating theatre thermal environment
Figure 9 shows the evaluation expressed by the subjects on the overall sensation (comfort, slight discomfort, discomfort, severe discomfort). The data confirm the evaluation expressed on the thermal environment: in fact the nurses claim to be comfortable 75% of the times and only to feel slight discomfort 25% of the times; the assistants feel slight discomfort 90% and comfort only 10% of the times, while the first surgeon feels discomfort 25% and slight discomfort 75% of the times; more articulated is the second surgeon’s situation who, passing from a type of task to another, has less possibilities to adapt and therefore reports a discomfort sensation 33% of the times, slight discomfort 50% of the times and comfort only 17% of the times.

![Bar chart showing overall sensation on orthopedics operating theatre thermal environment](image)

**SS. Annunziata Hospital**
**(May 2005)**

**Global Environment Evaluation**

Finally figure 10 shows the requests of the operating staff members concerning changes in the operating theatre temperature. In particular surgeons and assistants for a percentage between 70% and 100% would like it to be colder while nurses do not ask for any microclimatic environmental changes in about 70% of the requests, they even ask for heating in the surgical theatre in 23% their requests.
In conclusion the gathered data show that the first and second surgeon experience discomfort tied to a sensation of too much heat and would like an environment with a lower temperature. To a lesser extent, the same thing happens to the assistants, while the nursing staff claims to be in a state of wellbeing and is satisfied with the environmental conditions in which it works. As seen, the objective sweating and $T_{\text{skin}}$ measurements confirm the subjective claims of the different staff members.

5. Conclusions

The survey methodology described above and the experimental data gained during the measurement campaign – begun in January 2005 and still ongoing at SS. Annunziata Hospital in Cento (Fe) and Sant’Anna Hospital in Ferrara - highlighted the correlation between the comfort/discomfort sensation manifested by the different surgical staff members, the specific tasks and the clothing worn by each one of them.

Specific operating theatre provisions, still to be defined, should take in consideration the aforementioned differences. In fact, as far as the Italian provisions are concerned, the ISPESL guidelines (ISPESL, 1999) regarding hospital microclimatic conditions, generically suggest that the microclimatic conditions in an operating theatre should be such as to ensure, through an adequate amount of wellbeing, the worker’s good “performance”. The above report shows how difficult is to realize such conditions since the different metabolic needs and the different conditions of the surgeons, anesthetists, nurses and in particular of the patient undergoing surgery must be respected at the same time.
Acknowledgments

The authors heartily thanks the orthopedics operating theatre staff directed by Dr. Specchia and the medical director Dr. Cavicchioli from S.S. Annunziata Hospital in Cento.

References


