Melhado, M.D.A., Beyer, P.O., Hensen, J.L.M. & Siqueira, L.F.G. (2005).
The thermal comfort, the indoor environment control, and the energy consumption in three types of operating rooms.
Proceedings of the 9th International IBPSA Conference on Building Simulation, 15-18 August, pp. 747-754.
Montreal: International Building Performance Simulation Association.

THE THERMAL COMFORT, THE INDOOR ENVIRONMENT CONTROL, AND THE ENERGY CONSUMPTION IN THREE TYPES OF OPERATING ROOMS

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ABSTRACT

This research investigated the influence of three layouts of operating rooms on the indoor environment control, on thermal comfort and on energy consumption.
It was used the EnergyPlus software.
The parameters of the environment were described in accordance with standards.
The three layouts had controlled the temperature and relative humidity.
The patient presented extreme discomfort. The anesthesiologist presented much discomfort and in some cases discomfort. Other people remained in comfort or a little discomfort.
The layout combining two hallways and an operation room indicated the best thermal sensation for the people, and the lowest energy consumption.

INTRODUCTION

The people stay the major part of the time in the indoor environment. The indoor environment quality these environments will influence the productivity, the thermal comfort and the health of these people. This quality depends on the characteristics of the build, the type of use, the indoor air quality and other variables.
In this research were evaluated three operating rooms. These environments need a major care, mainly about the indoor air. The indoor air quality is very important factor to patients' medical requirements, and usually it is also part of the treatment.
Various papers have been published on indoor environment in hospitals. These publications reported the influence of the environment in the infection control. Siqueira (2000) verified that from 0% until 20% of the infection in hospital had the main source the environment.
The control of the indoor air in operating rooms it is made through of the controllability of the system. The temperature and the relative humidity need to attend the requirements in accordance with the type of surgery. The difference of pressure of the environments needs to ensure that the air less clean mix with the air the clean zones. It is very important an efficient politic of infection control.
Fernandes (1998) verified in a study that the day cost of the treatment of a patient with infection increase in U$ 525. The medium day this treatment was 7,4 days. However, some cases of orthopedic surgery presented a medium day of treatment of 68 days.
The subject of this research was to evaluate the behaviour of three layouts of operating rooms (OR) on the indoor environment control, on thermal comfort and on energy consumption. Considering two types of surgeries and different types of climate.
Each type of layout presents a different possibility of control through of the pressure and of the politic of access in the OR.
It is important to evaluate the predicted Mean Vote (PMV) in operating room, because each person presents different types of activities and different types of clothes. The air velocity is another important factor to consider, because this can change in accordance with the type of ventilation system used, of the position of the people in the operating room and the type of surgery.
The orthopedic and the abdominal surgeries were evaluated. These surgeries

were considered aseptic and septic, respectively. Orthopedic surgery need an indoor air requirements Class I, while the abdominal surgery need the requirements Class II, in accordance with the ASHRAE (2001) and Ministério da Saúde (2002).

It is important to evaluate different types of climate, because the air-conditioning will work with different characteristics. Therefore, the energy consumption will be not the same.

RESEARCH METHODS

The type of surgery defined the dimensions of the environment, the patient requirements, the number of people, number and type of equipments, and hours spent in the ORs. These parameters were used in the simulation.

Two types of the software were used: the Cterm version 2002 and the EnergyPlus version 1.03.

The Cterm software was developed by Prof. dr. Paulo Otto Beyer and M. José Luis Salvadoretti developed the Cterm - both of the "Federal University of the do Rio Grande do Sul" (Brazil). This software calculates the thermal comfort through of the thermal balance.

It was used the EnergyPlus, because it presented good results in some works, it was validated and also it permitted all analyses.

The results in the simulation with EnergyPlus, and in experiments, were similar in the researches of Grings and Beyer (2002), Wallauer and Beyer (2002) and Grings (2003). These results were verified in other papers too.

The Cterm was used to calculate the people level of activity of the person (LAP=metabolism x 1,8 [W/people]), thermal resistance of clothes (TRC, [clo]) and effectuated work (EW, [W/m^2]). The results of this simulation are presented in the Table 1. These values were used in the software EnergyPlus.

The data solicited for Cterm were: the temperature (19°C), the relative humidity (45%), the wind speed (0,25 m/s for patient and for the surgeon and the auxiliary nurse. For the anesthesiologist and other nurse[4,5] it was 0,28 m/s for the abdomen surgery and 0,39 m/s for the orthopedic surgery).

Another data solicited for Cterm is about the person occupying the environment and him clothes. It was stipulated a typical person of weight 70 kg and height 1,70 m. The clothes were described in accordance with the function of this person during the surgery. The value for the Emissivity and Permeability of the clothes were described like 0,9 and 0,4, respectively.

Table 1
Results of Cterm

People	LAP	TRC	EW
Patient	72	0,65	0
Surgeon	230,50	0,90	11
Anesthesiologist	108	0,70	3,50
Nurse [4]	216	0,90	10
Nurse [5]	180	0,70	10
Nurse [6]	180	0,70	7,50
"Cleaning view washing"	284,50	0,70	15,50

Three types of layouts of operating rooms were evaluated - Case 1, Case 2 and Case 3. The layout Case 1 presents a hallway and a surgery room. The Case 2 combine a clean hallway (Class I), the operating room and other hallway (Cass II). The Case 3 combine a hallway, an anteroom and an operating room. These layouts can be observed in the Figure 1.

The dimensions of the environments were established by Ministério da Saúde (2002) regulations.

The North of the building is defined conform presented in the Figure 1. All walls of the north and east divided the indoor environment of the outside. Other

4 - Auxiliary nurse

5 - Nurse work into surgery room and in the hallway

6 - Nurse that prepare the room and patient

walls divided the indoor of the operating room with other environment.

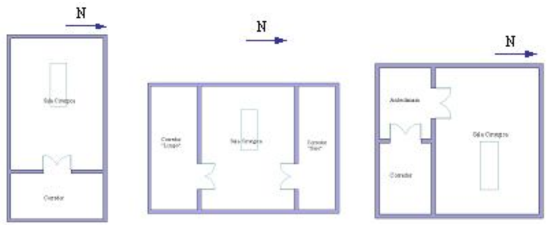

Figure 1 Layouts evaluated – Case 1, Case 2 and Case 3, respectively

The walls north and east, and the wall of surgery room had a width of 0,27 m. However, the other walls had a width of 0,22 m.

The walls were "built" in brick (0,15 m and 0,20 m – type "six hole"), mortar (0,025 m), plaster (0,01 m) and paint. These walls were described in layers, where the order was: plaster, mortar, brick, mortar and plaster again. The paint was not considered, because its thickness is insignificant. However, it was stipulated the absortivity of the paint on the place of the absortivity of the plaster (last layer).

The floors were described in layers: ceiling of gypsum (0,03 m), air layer (1 m), flagstone (0,12), mortar (0,02 m) and gait (0,05 m, this is made of "plastic").

The ceiling was also described in layers: flagstone (0,12 m), air layer (1 m) and ceiling of gypsum (0,03 m).

Any window was used in the three layouts. Therefore, any window was described in the software.

The doors were described by two pieces of steel and air (total thickness was 0,15 m).

In the orthopedic surgery, all surfaces of the operating room (walls, ceiling, floor and door) were described with an additional layer of lead (Pb).

The characteristics of the materials were described in accordance with the specifications of Lamberts, R., Ghisi, E. and Papst, A.L (2000), and Incropera, F.P. and Witt, D.P. (1992).

The heating sources influenced in the thermal environment and in the energy consumption. The heating sources considered in the operating room were: the medical equipment, the lights and the people. These variables were described in accordance with the use of the environment. The time schedule and the power profile will be presented below.

Four types of lights were used: the incandescent light (240 W), the operating light (630 W), the fluorescent light (480 W) and the auxiliary operating light (150 W).

The incandescent light, the operating light and auxiliary operating light were used in the period from 07:00 hrs until 09:00 hrs, from 10:00 hrs until 13:00 hrs, from 14:00 hrs until 16:00 hrs, from 18:00 hrs until 20:00 hrs. The fluorescent lights in the operating room and anteroom were switch on at 06:00 hrs until 22:00 hrs. However, when there was not surgery (from 22:00 hrs until 06:00), 50% of the fluorescent lights were switch on in the hallway. These details were described in accordance with Santana (1996).

The equipment medical presented a total power of 2245 W to orthopedic surgery and 1815 W on the abdominal surgery.

The operating room was occupied for patient and for surgical team. These hours were: from 07:00 hrs until 09:00 hrs, from 10:00 until 13:00 hrs, from 14:00 hrs until 16:00 hrs and 18:00 hrs until 20 hrs.

The operating room was disinfected from 09:00 hrs until 10:00 hrs, from 13:00 hrs until 14:00 h, and from 20:00 hrs until 22:00 hrs. In this time schedule, two people were considered.

About the air-conditioning, the system work during 24 hours, with the same characteristics.

The environment requirements were pre-established by patterns and type of surgery studied – aseptic (AS) and septic (SS). The dry bulb temperature, relative humidity, air velocity, pressure and other variables were used in accordance with the standards ABNT (1982) and the Ministério da Saúde (2002). These requirements are presented in the Table 2.

The temperatures simulated in the operating room were: 19 °C (from 07:00 hrs until 19:00 hrs) and 24 °C (from 20:00 hrs until 06:00). On winter day, it was simulated a temperature of 24 °C in all day.
The relative humidity was not informed for the software. It was described the Wet-Bulb Temperature.

Table 2
Environment requirements for the operation rooms

Requirements	**AS**	**SS**
Air change rates	25	15
Filter	G2/F2/A3	G2/F2
Pressure	+	0
Temperature	19 - 24	19 - 24
Relative Humidity	45 - 60	45 - 60

The temperature of the neighbour environments at operating room was described in accordance with ABNT (1982).
In the operating room was used the Laminar Air Flow system, together with the Linear system. In the other environments were used the Conventional systems.
Five Brazilian cities were evaluated: Belem, Brasilia (DF), Porto Alegre (POA), São Paulo (SP) and Recife. These cities were chosen, because they present different types of climate and represent different regions in the Brazil.
The characteristics of the climate were based on the ASHRAE (2001). However, the humid bulb temperature was based on the values of Gourlart, Lamberts and Firmino (1997).
The city of Porto Alegre was only simulated for a summer day and a winter day. The other cities were simulated for one year, a summer day and a winter day.
The days simulated were 21 January (summer day) and 21 July (winter day).
The PMV, the temperature and the relative humidity were simulated for a summer day and a winter day. While the energy consumption was simulated for a year.
The "Sky Clearness" was stipulated clean.
The case simulated were: **C1AS** [**C**ase **1** and **A**septic **S**urgery], **C1SS** [**C**ase **2** and **S**eptic **S**urgery], **C2AS** [**C**ase **2** and **A**septic **S**urgery], **C2SS** [**C**ase **2** and **S**eptic **S**urgery], **C3AS** [**C**ase **3** and **A**septic **S**urgery] and **C3SS** [**C**ase **3** and **S**eptic **S**urgery].

RESULTS AND DISCUSSION

The dry bulb temperature remained within in the required range and it was conform expectation, in all the cases and cities.
The medium air temperature and medium radiant temperature modified in accordance with the use of the environment.
Of sixty cases simulated, 88% presented a relative humidity above of the limit accepted. In some cases the relative humidity was 60% in the OR and in the hallway (Class II). Therefore, it was needed to use a dehumidifier in the cases with high humidity. The dehumidifier influenced in the energy consumption.
The thermal comfort was simulated and evaluated in accordance with the ISO (1993).
In all cases the patient was in extreme discomfort, with alterations in the PMV from -4 until -6. The patient presented this thermal sensation, because it was only using a clothe of hospital and a sheet, the effectuated work was zero, and because of the variables air velocity and temperature.
The anesthesiologist presented values between discomfort and much discomfort. The main factor that influenced the thermal sensation of the anesthesiologist was the air velocity, the effectuated work (3,5) and the clothes – it was used fewer clothes than the surgeon and auxiliary nurse.
The anesthesiologist indicated thermal discomfort for the cities of Brasilia and São Paulo, in the winter day, and only in the Case 2. It presented this behaviour,

because in the winter day the thermostat was fixed in 24 °C.
The surgeon, the auxiliary nurse and cleaning view washing, presented one slightly discomfort, with thermal sensation of slightly hot. The nurses[5,6] presented the slightly comfort, with thermal sensation of slightly cold. As well as the anesthesiologist, these people presented a small change in the parameter of thermal comfort for the cities of Sao Paulo and Brasilia. However, the thermal sensation did not changed.
Below, they will be presented the results of the PMV for the cities of São Paulo and Porto Alegre, for the Cases 2.
The best situation of thermal comfort was observed for city of Sao Paulo, in the Case 2 and in the winter day. The thermal sensation improved for the patient and for the anesthesiologist. In the case C2AS the patient presented -4 and the anesthesiologist the value between -1 and -2. However, in the same case the slightly discomfort of the surgeon and auxiliary nurse increased a little – but it does not reached -1 on the scale of PMV.
The thermal sensation for the city of São Paulo was similar to the summer day and to the winter day, on majority of the cases. It changed only for the anesthesiologist in the Case 2.
The Case 2 was also the best to the PMV for the city of Porto Alegre. The thermal comfort presented a little alteration in some cases, because of the climate and simulation day. However, the thermal sensation does not changed for any people.
In the total energy consumption were included the consumption with light, equipment and air-conditioning. It is important to remainder that only four cities were simulated in this part – Brasilia, São Paulo, Recife and Belem.
In the Table 3 will be commented only the cases simulated to orthopedic surgery, because these presented the highest energy consumption.
The orthopedic surgery presented the highest energy consumption, because the heating source was higher, the patients' requirements are different than the abdominal surgery. The orthopedic surgery need a more air change rate, the OR need to have a pressure positive in reference with other environments.
The abdominal surgery did not presented difference in the pressure in the environment. All these parameters were described in accordance with ABNT (1982) and the Ministério da Saúde (2002).
The Table 3 present the results of annual energy consumption in orthopedic surgery, for the cities of Belem, Brasilia, São Paulo e Recife.

Table 3
Annual Thermal Consumption

CASES	EC [kWh]	EC [kWh/ m²]
C1AS - Belem	25715,00	530,20
C1AS - DF	25492,90	525,60
C1AS - SP	25520,60	526,20
C1AS - Recife	25659,50	529,00
C2AS - Belem	28880,80	421,60
C2AS - DF	28880,80	421,60
C2AS - SP	28880,80	421,60
C2AS - Recife	29158,50	425,70
C3AS - Belem	28880,80	362,15
C3AS - DF	28603,00	358,70
C3AS - SP	28603,00	358,70
C3AS - Recife	29436,20	369,00

The highest energy consumption occurred on case C1SA to the city of Belem, while in the case C2SA and C3SA were verified to the city of Recife. These cities presented these results, because both have the winter day with characteristics of a summer day. The Case 2 and Case 3 presented highest annual energy consumption and the different verified was of 278,70 kWh.
It was verified a difference on energy consumption of 277,80 kWh for the cities of São Paulo and Brasilia, in the Case 2 and 3.

The Case 1 presented lowest energy consumption. However, the Case 2 presented the lowest energy consumption, when it was evaluated only the energy consumption in the operating room.
The medium day/cost of the energy consumption was U$ 9,15. This cost was calculated in the Brazil in 2003, but it was converted for the value of the Dollar today (U$ 2,35).

CONCLUSION

It was verified that the layout of the operating room had a little influence in the thermal comfort.
The thermal comfort in the operating room was influenced for type of surgery and also for climate of the city. The type of surgery influenced, because the requirements and the heating sources were different for the orthopedic and abdominal.
About the indoor environment control, for all cases the temperature and relative humidity remained within in the required range. Therefore, there were not favorable conditions for growth of microorganisms.
The Case 2 presents the advantage in the control of the environment, because it permitted to use different pressures in each zone. Other advantage of this case, it is that in the layout there is a major control on access of people in the operating room. Therefore, it was possible to difference the access in accordance with the type of surgery.
The layouts influenced also on energy consumption, like it could to verify in the results. However, the difference between each case it was not significant.
Other analyse important is to evaluate the cost-benefit of each layout. Of the cost to build the three layouts, the Case 2 is the more expensive. It must to be also evaluated, before to opt for a layout or other, what case it the more efficient on infection control, and to compare the cost of the treatment/day of one patient with infection and also the energy consumption cost.
In this research it was made these analyses. It was verified various advantages in the Case 2, mainly because this ensure a more control of the environment.

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