Thermal Comfort Level of Patients and Surgical Staff in Operating Rooms at Nordic Hospital

Helena KUIVJÕGI*[1], Guangyu CAO[2]

[1] Tallinn University of Technology, Tallinn, Estonia
[2] *Norwegian University of Science and Technology*, Trondheim, Norway
* *Corresponding author: helena.kuivjogi@taltech.ee*

ABSTRACT

In healthcare facilities and hospital environment, it is essential to enable thermal comfort for occupants. Unstable thermal conditions in the operating room (OR) will influence the performance of surgical staff and the infection possibility of patients. In this study, the thermal comfort of patients and surgical staff was measured with two ventilation solutions at St. Olavs hospital ORs in Trondheim, Norway. Research methods include thermal environment measurements during mock (imitation) surgery, a survey among surgical staff, and observation during a real operation. The results show that the mean air velocity near occupants in mixing ventilation (MV) OR was low (max 0,08 m/s) and in laminar air flow (LAF) ventilation OR considerably higher, 0,36 m/s. In conclusion, there was good general thermal comfort of surgical staff in LAF OR, but the surgical staff felt mainly uncomfortable in MV OR.

INTRODUCTION

Background and motivation of the work

Thermal comfort is a condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation. "*ANSI/ASHRAE standard* 55-2017". In common HVAC systems principal purpose, thermal comfort is the first aspect to provide for human „ASHRAE Handbook - Fundamentals (2017)", but in hospital ORs, the main aim is to prevent the infection of the surgical wound by airborne infectious microorganisms. "*Mora, English and Athienitis* (2001)" As a supplement, the technical HVAC standards state that to prevent surgical site infection (SSI), thermal comfort must be achieved for the patient and all members of the surgical staff in the operating room "*Gaever et al.* (2014)". One general reason is that thermal satisfaction influences productivity and health of surgical staff. "*Sadrizadeh and Loomans* (2016)" Furthermore, the American Society of PeriAnesthesia Nursing standard recommends controlling patient thermal comfort level, because it will influence the wellbeing of the patient – hazard of hypothermia "*Hooper et al.* (2010)".

R. Van Gaever et al. brought out in their study: „it is not possible to achieve thermal comfort for each member of the surgical staff by only revising the HVAC standard." The reason is that, in OR, different people will have very extreme demands on thermal satisfaction. "*Gaever et al.* (2014)"

In spite of several studies about thermal comfort in operating rooms, there is still lack of information. Therefore, the idea of this study is to collect more information for making the better overview about thermal comfort in operating rooms.

The objective and framework of this study

The overall objective of this study is to analyze the thermal comfort of surgical staff and patients in various operating rooms with two different ventilation solutions at St. Olavs hospital. To achieve the objective and estimate the thermal comfort levels of occupants in the operating room, the following tasks were conducted:

1. field measurements of the indoor thermal environment during mock surgery,
2. the survey about surgical staff sensation, and
3. observation during real operation.

METHOD

Two operating rooms at St. Olavs hospital

The investigation puts the focus on the three following methods in two operating rooms at St. Olavs hospital (Fig. 1). There are four occupant groups under investigation: surgeons, patient, anaesthetist and assistant nurses. The ventilation system of this building is mainly controlled by the service center and can be adjusted by the surgical staff in the room via three scenarios with different condition settings (controlled by sensors in the exhaust ducts): operation is ongoing, infection risk/cleaning, operating room prepared.

Figure 1. Mixing (left) and laminar air flow (right) ventilation solution OR in X hospital

Table 1. Boundary conditions in LAF and MV OR at X hospital during field investigation in March 2019

Activity in operating room / Date / Variables	MIXING VENTILATED OR					LAF VENTILATED OR		
	Field experiment			Observation and survey		Field experiment		Observation and survey
	4th	8th	15th	27th	2th of April	23th	29th	21th
outdoor air temp, °C (1)	-1,8	0,6	2,7	5,3	4,7	0,6	1,6	6
outdoor air RH, % (1)	78	54	49	82	44	92	93	54
room air Temp, °C (2)	23,5	23,7	24,2	NM		23,7	22,3	NM
room air RH, % (2)	15	12,8	12,1			20,9	24,3	
Surface temp. of surroundings (average), °C (5)	20,7	20,8	22,4	22,5	22,4	21,1	21,7	NM
vapor partial pressure. kPa (3)	0,43	0,38	0,37	0,74	0,37	0,61	0,65	0,49
RH, %	15,0	12,8	12,1	26,4	13,3	20,9	24,3	17,3
pas, kPa	2,90	2,93	3,03	2,81	2,81	2,93	2,70	2,81
ta, °C	23,5	23,7	24,2	23,0	23,0	23,7	22,3	23,0
Room area, m^2	59,1					56,1		
Room volume, m^3	171					168		
Supply airflow, m^3/h	3700					12850 (ca 60% recirculated)		
Air change rate, ACH	21,7					22,5		

(1) Forecast data from YR.no; (2) Measured with Pegasor AQ Indoor device near wound area, at the center of room; (3) Calculated with (2) or (4); (4) data from service center of St.Olavs hospital for comparison; (5) Measured with Bosch PTD1 contact free device; NM – not measured

The humidity of airflow is not controlled due to the hazard of bacterial distribution. During the measurements, the scenario was operation is ongoing and the temperature was set to 23°C. The supply air temperature was about 22 °C.

One operating room was with LAF ventilation and another with mixing ventilation solution. Mixing ventilation ORs area is 59.1 m^2 and there are four wall-mounted exhaust outlets and four supply diffusers on the ceiling. LAF ventilation OR area is 56.1 m^2 and it has a 4x4m LAF zone on the ceiling (surrounded with 110 cm long walls), two wall-mounted exhaust outlets near and six exhaust outlets on the ceiling around LAF area. General boundary conditions of ORs during measurements and observations are in Table 1.

Field measurements

This study includes measurements of thermal comfort variables in real OR at St. Olavs hospital during March 2019 (Table 1).

Before the measurement, a 15 min intensive mock surgery with 5 people has been presented. Experiments in MV OR has been done during three weekdays and in LAF OR two weekdays. Surgical lamps were turned on and OR doors were closed. The height of the operating bed was 84.5 cm, the height of surgical light from the floor was in MV room 2.1 m and in LAF ventilated room 2.15 m.

The measurements have been done according to "ISO7726 (1998)". In this study, the environment is heterogeneous, due to air movement and radiation from equipment. Regarding that and the physical quantities have been measured near four subjects from the head, abdomen, and ankle level (Table 2) with TSI uni-directional instrument VelociCalc Plus. Specifically, the air temperature measurement for 2 minutes and air relative velocity for 1 minute.

Besides, the velocity measurement in MV OR has been taken as the probe tip measuring the airflow vertically from ceiling to floor, because the airflow direction is unknown. In LAF OR, the measuring description is in Table 3.

Table 2. Measuring heights from the floor for the physical quantities of an environment (ISO 7726)

Location level of the sensors	Sitting person (m)	Standing person (m)	Patient (m)
Head	1,1	1,7	0,9
Abdomen	0,6	1,1	0,9
Ankle	0,1	0,1	0,9

Table 3. Probe tip measuring direction in LAF OR

Measuring point	Probe tip measuring direction
1 –Surgeon	Under the LAF area: airflow vertically from ceiling to floor
2 – Patient	
3 – Anaesthetist	Outside of LAF area: airflow horizontal from LAF area to person
4 - Assistant nurse	

The VelociCalc Plus temperature sensor has been calibrated with the Reference Temperature Calibrator Model RTC-157 (accuracy ±0.04 °C) and the anemometer has been calibrated with TSI Flow Calibrator.

There has been measured the dimensions of room and the surface temperature of surfaces such as walls, ceiling, floor, doors, and windows. Last measurements have been done with Bosch PTD 1 contact free device and the results are used to calculate the mean radiant temperature (T_{mrt}). Regarding to the standard "ISO 7726:1998" that due to building materials high emissivity, there has been disregarded reflection to assume that all surfaces are black, so the emissivity has been taken as 0.95. Moreover, using previous data, there was calculated the operative temperature for every occupant. Finally, there have been measured overall conditions during measurements with Pegasor AQ Indoor device at the centre of the standing human (1,1 m) and it is used for the calculation of vapor partial pressure.

Observations

There have been used several observation methods described in Table 4, but in this paper, only these results are considered, what are directly related to PMV-PPD calculation.

The tabulated values for observations taken from "ISO 8996:2004" are generalized and concern an „average" individual: A man 30 years old, weighing 70kg and 1.75 m tall (body surface area 1,8 m^2); A woman 30 years old weighing 60 kg and 1.70 m tall (body surface area 1.6 m^2).

Survey

The survey among surgical staff in both above mentioned OR was conducted to get knowledge about occupants´ real sensation in ORs thermal climate. The questions in the survey, corresponding to "ISO 28802:2012" and "ISO 10551:2019", are asked to answer as based on the last operation the occupants had. Occupants have been answered to seven subjective questions about thermal sensation, comfort, and acceptance. In addition, they have been asked to evaluate their work level (according to "ISO 8996:2004" Table A.2) and clothing.

The final mean thermal sensation level has been correlated with Fanger scale and the standard deviation (SD) has been calculated by IBM SPSS software. The survey has been conducted in two parts, one during the observation days in MV OR (at 27 of March and 2 of April) and in LAF OR (at 21 of March). The second part occurred in between 29.04-5.05.

There were 30 participants in MV OR and 13 in LAF ventilated OR survey (also a clean zone nurse is included to extend the investigation). Altogether, 44 filled questionnaires.

Table 4. The methodology of observation in the operating room

Task	Object	OR	Source/tool	Method/input
Activity level	Surgical staff	MV	recorded video according to ISO 8996:2004 [8]	Duration aprox. 2h; after every movement end, the body segment work together with mean value of metabolic rate and time has been stated.
		LAF		
	Patient	MV, LAF	Malcolm A. Holliday et al. Study	averaged person, who have weight of 65 kg and body surface area 1,7 m2, due to this, the metabolic rate is 2400 kcal/day, what is 68,4 W/m2.
Thermal comfort of real patient	Real patient	MV	Body temperature: hospital surgery team	Measured as bladder temperature. Three surgeries. First measuring point: after the patient enters the room. The measuring period: after every 0.5 hour. Duration: 1.5-4.5h.
			Air temperature and RH: TinyTag near surgical area	Logged after every 5 minutes near surgical area.
Clothing	Surgical staff and patient	MV, LAF	Material info from hospital and manufacturer	Surgical staff: surgical underwear, cap, hat, mask, socks, shoes and gloves (in MV OR lead apron for x-ray). For surgeons also sterilized surgical gown. Patient: naked; covered with warm blanket, surgical drape and polyethylene film (in MV OR-s forced-air warming blanket system).
			From literature	Thermal resistance of clothing is taken from the study of Anna Bogdan et al. (20)[1] Brought out in Table VIII.
Surface temperature	surgeon forehead	MV, LAF	infrared thermograph camera FLIR E60[2]	Duration: the first 40 minutes of real surgery. The skin temperature of surgeon forehead has been marked down after every 1 minute.
	surgical lights			Analysis of the thermal camera picture of surgical lights

[1] clothing also manufactured by barrier according to the requirements of EN ISO 9001 and EN 13795
[2] The emissivity to walls, human skin and equipment has been taken 0,95.

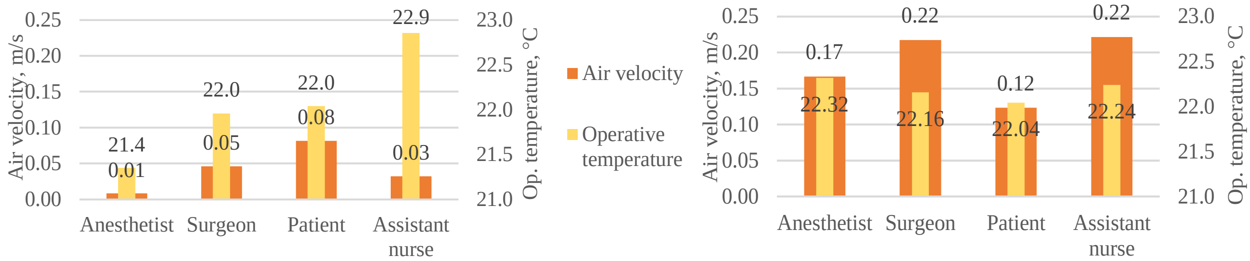

Figure 2. Average operative temperature and air velocity near occupants in MV (left) and LAF (right) OR

DATA PRESENTATION

The boundary conditions during the experiments have been brought out in Table 1 and during survey in Table 5.

Table 5. ORs conditions during the survey logged with TiniTag Plus 2 at St. Olavs hospital

		ta, °C	RH%
Mixing ventilated OR	Measure point near anesthetist		
	MAX	24,12	39,24
	MIN	22,80	13,93
	Measure point near surgeon		
	MAX	24,91	38,88
	MIN	23,13	14,34
Laminar air flow OR	Measure point near assistant nurse		
	MAX	22,68	44,65
	MIN	20,72	17,05
	Measure point near surgeon		
	MAX	24,11	44,22
	MIN	20,97	17,06
Outdoor	MAX	12,8	53
	MIN	1,2	81

Field measurements in ORs

Let's take the operative temperature (Top) as the indicative value.

In MV solution OR, during the experiments, the average room air temperature was around 23.6 °C.

However, the thermal comfort conditions of occupants will vary in a wide range. For patients, the T_{op} was 22.0° C (Figure 2), and the air velocity at the range 0.06-0.11 m/s (respectively, head level and ankle level). For surgeons, the T_{op} was slightly below 22.0 °C, and the air velocity was 0.0-0.09 m/s (last to head level). For the anaesthetist, T_{op} was 21.4 ° C (Figure 2), and the air velocity is nearly zero.

For the assistant nurse, the experiment was for one additional day, where the average room air temperature was around 24.2 °C (air temperature in the vicinity of assistant nurse is lower – 23.4°C). Operative temperature is higher (22.9°C) and not comparable with other occupant conditions, because also the mean radiant temperature was higher at this day. The air velocity is in the range of 0.0-0.07 m/s (last in abdomen level).

In LAF solution OR during the two main experiment, the room air temperature was 22.3°C and 23.7°C. Results in Figure 2 shows that the thermal comfort conditions will not vary that much as in MV OR. For patient the T_{op} was 22.04° C, and the air velocity at the range 0.03-0.3m/s (respectively, abdomen and head level). For surgeon, the T_{op} was 22.16 °C, and the air velocity was 0.0 m/s in ankle level and about 0.30 m/s in the abdomen and head level. For the anaesthetist, the T_{op} was 22.3 ° C, and the air velocity was 0.10 m/s and 0.23 m/s, respectively in head and abdomen level. For the assistant nurse, the T_{op} was 22.2°C, and the air velocity about 0.07, 0.23 and 0.36 m/s, respectively in head, ankle and abdomen level.

Observation in operating rooms

In this paper, we will focus on the main results from observations. The principal was the estimation of activity level and clothing insulation of surgical staff and patients. The results for 101 and 135 minutes (respectively, in MV and LAF OR) lasting surgery and estimated clothing insulation are in Table 6. The highest activity level and clothing insulation is for surgeons and the lowest is for patients. Therefore, they are two extremes and the thermal comfort will be discordant.

Results from survey

The following result present the answers received from surgical staff in mixing and LAF ventilation solution OR. In mixing ventilation OR, only 17% of repliers says that the environment is comfortable, the other 83% says that it is slightly uncomfortable (53%), uncomfortable (20%), and very uncomfortable (10%). The thermal sensation, SD of answers and dissatisfaction in MV OR has been brought in Table 7 and comparison with PMV is in Figure 3.

In LAF ventilation OR, about 46% of repliers says that the environment is comfortable, the other 54% says that it is slightly uncomfortable (38%), uncomfortable (7%) and 7% did not give the answer. The thermal sensation, SD of answers and dissatisfaction in LAF OR has been brought in Table 8, and the comparison with PMV is in Figure 4.

From the questionnaire came out that in MV OR, two anaesthetists felt a draught or breeze near the chest or head, and 5 occupants from staff gently breeze near the chest or head. However, the thermal sensation was slightly warm. In LAF OR, one assistant nurse and one anaesthetist often felt slightly draught near the chest or head from ventilation.

Table 6. The clothing and activity level of occupants in OR

Occupant group	Clothing insulation, m²K/W (clo)		Activity level, W/m² (met)	
	LAF solution OR	MV solution OR	LAF solution OR	MV solution OR
Surgeon	0.202 (1.3)	0.234 (1.5)	138.3 (2.38)	103.0 (1.78)
Assistant nurse	0.154 (0.99)	0.193 (1.25)	74.8 (1.29)	92.2 (1.59)
Patient	0.165 (1.06)	0.165 (1.06)	68.4 (1.18)	68.4 (1.18)
Anesthetist	0.154 (0.99)	0.193 (1.25)	90.1 (1.55)	85.0 (1.47)

Table 7. Occupants general thermal sensation during operation in MV OR (Survey)

Occupant	Thermal sensation (Fanger scale)	SD	Dissatisfied, %
Anesthetist	neutral or slightly warm (0.14)	1.07	0
Assistant nurse	slightly warm or warm (1.6)	0.55	60
Surgeon	slightly warm or warm (1.7)	0.68	10

Table 8. Occupants general thermal sensation during operation in LAF OR (Survey

Occupant	Thermal sensation (Fanger scale)	SD	Dissatisfied, %
Anesthetist	neutral (0.0)	-	0
Assistant nurse	slightly cool to slightly warm (0.0)	1.16	0
Surgeon	slightly warm (1.0)	0.0	0

The estimation of PMV level of occupants in ORs

The PMV level for the estimation of thermal comfort has been calculated by using the well-known Fanger equation from [8]. There have been considered the measurement results from experiments, T_{mrt}, clothing and activity level. The calculation has been done first for local body parts and then the final mean PMV level has been correlated and the SD has been calculated by IBM SPSS.

The results of MV OR have been brought out in Figure 3 (*occupant*_PMV) and the data is in Table 9 and the results of LAF OR have been brought out in Figure 4 and the data is in Table 10. There should be careful with the conclusion of patient comfort, because the PMV level varies in a big interval among local body parts due to difference in air velocity.

Table 9. PMV level of every occupant in MV OR (experiment)

Occupant	PMV	SD
Anesthetist	0.25	0.27
Assistant nurse	0.69	0.04
Patient	-0.14	0.13
Surgeon	0.91	0.03

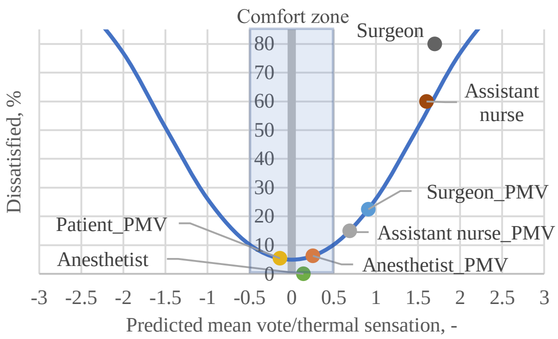

Figure 3. The comparison between predicted and real thermal comfort in MV OR

DISCUSSION

The objective of this study was to clarify the thermal comfort of four occupant groups in two different ventilation solution operating rooms at St. Olavs hospital. There has been concentrated on the predicted and real thermal comfort of surgical staff and patients using three main methods: field experiment, observation, and survey.

Wyon et al. investigated that 20.5°C is the comfortable operative temperature for an average staff member in the OR. "*Wyon, Lidwell ja Williams* (1968)" However, Mora et al. found from the surveys, that the air temperature 19°C is good for the surgeon thermal comfort. "*Mora, English and Athienitis* (2001)"

Generally, all surgical staff in MV OR at this hospital will experience about 1.5-degree higher operative temperature than suggested and low air velocity did not balance the temperature. The anaesthetist and patient will experience local thermal comfort as well as general, as can see from PMV calculation and answers from survey. However, for surgeon and assistant nurse, there will be too warm. In LAF OR, the operative temperature is at least 1.6-degree higher than suggested, and the PMV calculation shows also that the surgeon will have a little warmer feeling, but unlike MV OR, in LAF OR the air velocity will balance the temperatures.

The rest of all in surgical staff will feel comfortable. Furthermore, the answers from the survey will confirm it.

Table 10. PMV level of every occupant in LAF OR (experiment)

Occupant	PMV	SD
Anesthetist	0.39	0.19
Assistant nurse	0.07	0.31
Patient	-0.49	0.51
Surgeon	1.29	0.17

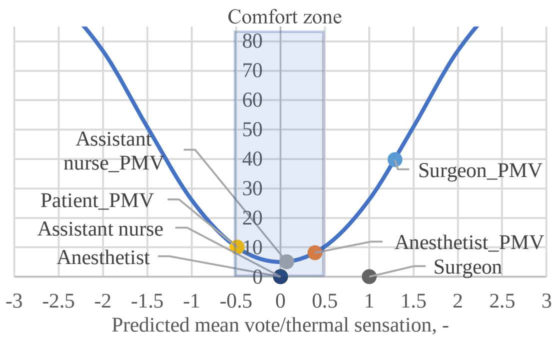

Figure 4. The comparison of predicted and real thermal comfort in LAF OR

On the basis of this study, it can be suggested that one option to improve the thermal comfort level in OR at St. Olavs hospital, is to reduce the mean radiant temperature. Mixing ventilation OR will have many equipment, mostly surgical lights, what will influence occupants by radiant heating. There have been investigated also in thermal camera observation results, that the light surface temperature is around 32.7-34°C in MV OR and around 31-32.9°C in LAF OR. This is very high, if to compare with other surfaces around, and even due to that, they are closer to the surgeon, the radiant heat to surgeon will be very high.

Another possibility is to investigate how much it is possible to raise the air change rate in the mixing ventilated OR (as suggested by "*ANSI/ASHRAE/ASHE Standard* 170-2017") to take out the heat gain produced by equipment) to be in the comfort zone and without enlarging the SSI.

Anaesthetists, who has a low activity level and at the same time, feel slightly draught from the ventilation, should wear warmer clothing. The problem is mainly in LAF OR, because the air velocity is larger.

As can see from Figure 3 and Figure 4, that even if the PMV calculation could be similar to the real sensation, then the percentage of dissatisfaction is totally different, perhaps due to local discomfort. Therefore, there is not the right to do fundamental conclusions and further investigations should be on local thermal comfort, instead of calculating the PMV level. About survey, the best is to investigate the environment, conducting the field survey with asking questions about thermal comfort at the precise moment and on a particular body part.

CONCLUSION

The challenging around thermal comfort in the operating room is in its beginning, but to reach somewhere, there is a need to collect the information constantly. This study has been focusing on the thermal comfort of the surgical staff and patients in OR. The two research questions were what is predicted and what will be the real thermal sensation in OR. However, the investigation is conducted in real OR environment and there has been used three methods: experimental measurements to measure the variables influencing the thermal comfort; observation to estimate the metabolic rate and clothing thermal resistance; and the real sensation of surgical staff has been discovered through the survey in two ORs. The study will be therefore a good overview of the actual conditions in OR.

The conclusion over calculations and survey shows that in OR conditions, the PMV is similar to real sensation, but the percentage of dissatisfaction is totally different, perhaps due to local discomfort. Also, thermal comfort conditions in OR will vary in a wide range:

1. In mixing ventilation OR, the surgeon and assistant nurse will experience the environment as slightly warm or warm, the anaesthetist as neutral. From survey came out that the assistant nurses and surgeons will have substantial dissatisfaction about the thermal environment in MV OR. The conditions for the patient seem to be comfortable, but need more investigation, because of the patient actual wellbeing – we do not know about actual local comfort.

2. In LAF OR, the operative temperature is similar to all occupants, and the air velocity has a bigger impact as it is higher and will achieve cooling effect or may cause slight draught. For the anaesthetist and assistant nurses, the environment is comfortable, for the surgeons, it is slightly warm. The patient will experience slightly cool climate in LAF OR.

The gap of thermal sensation is significantly caused by different clothing and activity levels of occupants. Surgeon, who is wearing several layers of clothing (1.3/1.5 clo), is doing hard and active movements (ca 2 met) during surgery. At the same, time the anaesthetist, who is wearing just one layer of clothing (0.99/1.25 clo), is mainly sitting/standing (ca 1.5 met). The patient has a little higher clothing level, but smaller activity, so one could be the most critical case. In this study has been investigated the thermal comfort of the patient through observation of body and air temperature, but this is not enough to investigate patient total thermal comfort in OR.

To investigate the thermal comfort aspect as the mean radiant temperature, it will be interesting to examine the equipment effect in OR. As found out, the surgical light will affect surgeons' thermal comfort, but there is also many other equipment that will produce heat.

Overall, this is challenging to adjust the temperature in the operating room, but it is not impossible. For future work, the authors suggest investigating how low the air temperature could be and how it can improve the clothing thermal insulation of the patient and anaesthetist, that they still meet thermal comfort and will be in the normothermia condition.

ACKNOWLEDGEMENT

This present study is written during the exchange studies in Norwegian University of Science and Technology at Department of Energy and Process Engineering. My thanks to Erasmus+ and NTNU; Liv-Inger Stenstad, Gabriel Kiss, Jan Gunnar Skogås and staff from St. Olavs hospital for providing OR facilities, supporting experimental measurement, assisting survey and field observation; my supervisors Guangyu Cao, Martin Thalfeldt, Anna Bogdan; Jarek Kurnitski and not least, to our research team: Christoffer Pedersen, Minchao Fan, Yixian Zhang, Jakub Wladyslaw Dziedzicand and Masab Khalid Annaqeeb.

REFERENCES

ANSI/ASHRAE standard 55-2017: Thermal envisonmental conditions for human occupancy. 2017.

ANSI/ASHRAE/ASHE Standard 170-2017 - Ventilation of Health Care Facilities. 2017.

ASHRAE Handbook - Fundamentals. 2017.

Bogdan, A., Sudoł-Szopińska, I., Szopiński, T. (2011). " Assessment of textiles for use in operating theatres with respect to the thermal comfort of surgeons." Fibres & Textiles in Eastern Europe 19 (2): 65-9.

Gaever, R. Van., Jacobs, V., Diltoer, M., Peeters, L., and Vanlanduit, S. (2014). “Thermal comfort of the surgical staff in the operating room.” Building and Environment 81: 37-41.

Hooper et al. (2010). “ASPAN’s Evidence-Based Clinical Practice Guideline for the.” Journal of PeriAnesthesia Nursing 24: 346-365.

ISO 10551:2019. Ergonomics of the physical environment — Subjective judgement scales for assessing physical environments.

ISO 28802:2012. Ergonomics of the physical environment — Assessment of environments by means of an environmental survey involving physical measurements of the environment and subjective responses of people.

ISO 8996:2004. Ergonomics of the thermal environment — Determination of metabolic rate.

ISO7726:1998. Ergonomics of the thermal environment - Instrument for measuring physical quantities.

Mora, R., English, M. J., and Athienitis, A. K. (2001). “Assessment of Thermal Comfort During Surgical Operations.” ASHRAE Transactions pg. 52.

Sadrizadeh, S., and Loomans, M.G. (2016). “Thermal comfort in Hospital and Healthcare Facilities - a Literature Review.” IAQVEC, (Korea).

Wyon, D. P. ,Lidwell, O. M., and Williams, R. E., Jun (1968). “Thermal comfort during Surgical Operations.” The Journal of Hygiene 66 (2): 229-248.