Thermal comfort in boats

K. Kritsonis
Civil Engineer, Msc in Energy Efficient Building, ECOCAT, Patras, Greece

F. Nicol
Low Energy Architecture Research Unit (LEARN), London Metropolitan, UK

ABSTRACT

The field of thermal comfort surveys has recently expanded to other areas such as vehic- les and external spaces. An area that has not been examined is boats. This research will attempt to approach thermal comfort conditions in boats and establish a background for thermal comfort surveys in boats generally. The first part took place during the summer months of the year 2003 in Greece under real conditions. Several boats took part and also people with different characteristics such as age, sex and weight answered the questionnaires. The methods from thermal comfort surveys in building have been adapted for this research and the confirmation of the Nicol graph equation has been studied. The project will repeat the summer test during the 2005.

1. INTRODUCTION

Curiosity is one of the human beings main characteristic and also one of the most powerful forces which drives them to explore, investigate and solve new problems. All scientific surveys have been based on curiosity and the need for solutions to problems through out the ages. The need for a better artificial environment where people can live comfortably and the quest to find the relationship between comfort and other factors that can effect it, have established the research projects on thermal comfort.

During the last thirty years a large number of thermal comfort surveys have taken place around the world. Those surveys had as their main target the thermal comfort in buildings such as offices, schools, houses and other commercial buildings. The results changed the way of approaching comfort and also the way of building. Now it is possible for an architect to design a building which can satisfy almost any demand for comfort from its occupants.

The present research project will attempt to approach thermal comfort conditions in boats and establish a background for thermal comfort surveys in boats generally. In this dissertation the word "boat" represents the pleasure, sailing and motor, boats with internal areas and a length from 10m to 50m. The research took place during the summer months of the year 2003 in Greece under real conditions. Several boats took part and also people with different characteristics such as age, sex and weight answered the questionnaires. The methods from thermal comfort surveys in building have been adapted for this research and the confirmation of the Nicol graph equation has been studied.

This research is a small step in a totally new area but can represent the base for further studies. Due to lack of both funds and time the project is limited but the methods that have been adapted are scientifically approved and the results are very useful. Projects on larger scales and different climates will give more easily interpreted results.

2. RESEARCH METHODOLOGY

This project will attempt to establish the state-of-art in thermal comfort surveys for boats. It will present temperature preferences of occupants and also the effect of most of the factors.

2.1. Detailed Presentation

The research will try to find what range of tem-

peratures according to personal preferences would be the ideal for the internal space of a boat during the summer months in the Mediterranean region and how this preference is affected by independent factors. Also the results will be compared with the Nicol Graph equation to confirm if it is applicable in boat design.

2.1.1 The place

The research took place in Greece. The place has been chosen because Greece and the Mediterranean Sea in general is one of the biggest markets for boat manufacturers. This makes it easier to find more people who will volunteer to take part in the survey and the results will be more interesting for the boat industry.

2.1.2 The time

The project started in May 2003 and ended in August of the same year. The temperature measurements started in June and ended on the first days of August. People answered the questionnaires during and after the measurements. The summer has been chosen as the ideal period because during that time most boat owners use their boats.

2.1.3 The people

All persons who took part in the survey were volunteers. Some of them were boat owners and others only boat users. The boat users can be separated in two categories, the first include the users which have chartered the boat and the second includes the users that they were owners guests. Most of the people were men. The age range of participants was between fifteen and sixty.

2.1.4 The boats

Motoryachts and sailing boats took part in the survey. All of them have internal spaces with saloon and cabins. The length of the boats varies from 10m up to 18m. Only one boat was made from wood, the rest were made from GRP. The age of the boats varied from thirty five (35) years (the wooden one) to ten (10) years. Any special characteristic has been recorded and checked how it effects to the results. Air conditioning systems have been found in very few boats something that makes the confirmation of the Nicol graph which has been developed in free running buildings easier.

2.1.5 The equipment

The main equipment of the survey was the dataloggers. Twenty DS 1921 iButton Temperature Dataloggers were used during the survey. They were chosen because of their size, their water resistance and their low price. These dataloggers measured the air temperature of the space where they had been installed every twenty (20') minutes in a range from 0^{o}C to 60^{o}C in 0.5 degrees increments. It was possible to measure a space for 28 days continuously. Other equipment that was used was a kata thermometer and a digital thermometer for air velocity measurements. Also an anemometer for the external air speed and a hydrometer for measuring the humidity levels. Finally a lap top (excel, word, iButton software), a camera and a printer were used for reading the measurements and analyzing the results.

2.1.6 The method

The survey is characterized as a field study method because the measurements took place in peoples natural environment. Dataloggers were installed in the internal spaces. One for the salon and the kitchen which was one space and one for each cabin. The exact place for installing the dataloggers was decided after a discussion with the users. The main idea was to put the dataloggers in a safe place were they would not interrupt any activity and also were nobody would move them. The second consideration was the effect of the air and the sun. Places near the windows were forbidden as well as the position at the top of the space where hot air concentrates. A shaded area at the mean height was deemed to be the best place. Each datalogger was accompanied by a small questionnaire asking: "how do you feel".

One datalogger was also installed in the external space. The reason for this was the need to record the external temperature in order to use it to confirm the Nicol Graph. The external datalogger was putted in a shaded area. Only in few cases were the datalogger exposed to direct solar radiation. In those cases the measurements were not used for the confirmation of the Nicol Graph because they didn't represent the air temperature but the temperature of a surface which is exposed to the direct solar radiation.

The measurements were taken during a jour-

ney. The participants asked to answer the general questionnaire (How do you feel?) while the boat was stopped. This instruction has two reasons, the first is because in the internal space there might be a strong air flow during the voyage that can totally change peoples preferences and secondly the internal spaces are not occupied while the boat is moving. Internal spaces are not occupied because of the vibrations which can make people feel dizzy, additionally in motoryachts there is a great noise coming from the engine room. So answers while the boat is moving are false and useless.

Also participants were asked to answer after they had been in the internal space of the boat for a period of time. This precondition was given because the human body needs a period of time to adjust to the environmental temperature. So if someone enters the spaces and stays only for a few seconds an unacceptable answer will be recorded.

A second questionnaire was given to the participants after the end of the measurements (the end of the journey) asking general questions about there clothes and there activities. The answers from these questionnaires gave the information for other factors that can affect peoples temperature preferences.

2.2. Questionnaire designing

This survey has some unique characteristics that makes it difficult. As it has never happened been done there is a luck of information that can help the researcher to avoid mistakes. Also the use of boats mainly for vacation is a factor that makes the would-be volunteers hesitant to participate. These reasons made the questionnaire design a very serious part of the survey.

The main idea was that the questionnaire should be as simple as possible, easy to answer without spending too much time while giving all the important information. The principal decision was to separate the questionnaire in to two. The first (general) which participants had to answer more than once had to be as simple as possible, the second (personal) that had to be filled in only once should collect all the important information about the factors that effect the results. Both of them have been translated in to the Greek language.

The general questionnaire asked "How do you feel". The possible answers were the following seven:

Comfort votes	
very cold	-3
cold	-2
comfortable cool	-1
comfortable	0
comfortable warm	1
hot	2
very hot	3

On the left there was one other column for the name of the participant and on the right there was a column for the time that the answer was given. These questionnaires were put near every datalogger that had been installed in the internal space of the boats. At the bottom of each page there was the instruction about the time that the participant should spend in the space before answering the question. The answer given should refer to a particular moment of the day and not for a period because the dataloggers were giving measurements for a specified time and not for a period of time.

The personal questionnaire contained five blank spaces and nine questions. In the blank spaces the person put his/her age, weight, height, nationality and sex. The questions were about clothing, discomfort areas in the boat, activities, use of the air conditioning system, sunbathing and skin colour. Some of the questions were multiple choice, others were filing blank spaces. At the beginning of each questionnaire there was an instruction informing the participants that the answers should be given according to the conditions of the trip that was being measured, not in general. The reason for this was that it was possible during the journey to come across with extreme conditions so the answers would not be the same as for a normal trip. This questionnaire was given after the end of the journey so the participants had to remember everything they had done during it.

Both the questionnaires were tested before their use in the survey on volunteers that have previous experience on boats.

3. DATA ANALYSIS

3.1 General opinion

The answers on the general questionnaire were in total two hundred and ninety four (294). One hundred and seventy six (176) of those answers

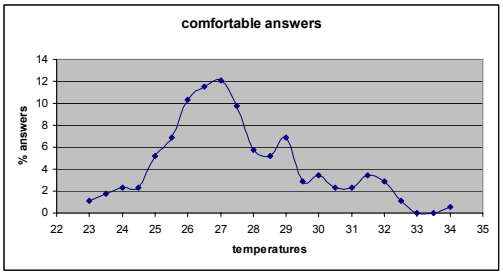

Figure1: Comfortable answers percentage.

were in the comfortable area (comfortable warm – comfortable – comfortable cool). More comfortable answers (21) corresponded to twenty seven degrees Celsius (27°C). Temperatures between twenty five and twenty nine degrees Celsius (25-29°C) included more comfortable answers (117) than any other area. The comfortable answers, from the area between twenty five and twenty nine degrees, represents seventy three point five percent (73.5%) of the whole answers (Fig. 1).

3.2 Comfort vote

According to peoples’ answers and the method of the comfort votes the following graph has been produced. The point where the trend line cut the x – axis represents the comfortable temperature (Fig. 2).

The equation that gives the above trend line is:

$$y = 0.2874x - 7.3271 \quad (1)$$

For:

y = 0 than x = comfortable temperature,
x = 25.49 (Griffiths method Tc=25.96°C).

3.3 Preference during the day

After the observation of the answers a different temperature preference was found according to the time of the day. The day has been divided into three periods according to people activities and external temperatures. Those periods are:

1) 5:00 – 10:00 waking up, breakfast etc
2) 10:00 – 22:00 swimming, fishing, eating
3) 22:00 – 5:00 eating, relaxing, sleeping

The comfortable temperatures for the above periods are:

1st period (Fig. 3):

$$y = 0.3106x - 7.904 \Rightarrow (y=0)\ x = 25.45^{o}C = Tc\ (25.47) \quad (2)$$

2nd period (Fig. 4):

The Tc for the second period has been calculated according to Griffith method because most

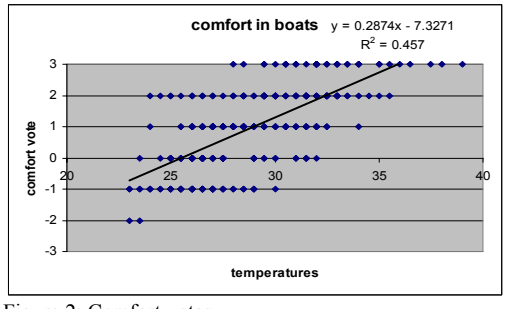

Figure 2: Comfort votes.

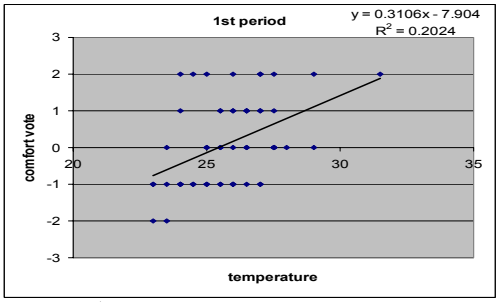

Figure 3: 1st period.

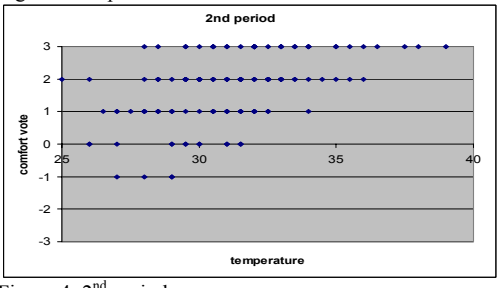

Figure 4: 2nd period.

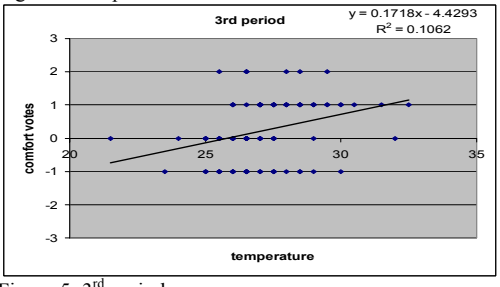

Figure 5: 3rd period.

of the answers were corresponded to part of the scale (+1,+2,+3) and not to a uniform distribution.

$Tc = Tm - 3Cm \Rightarrow Tc = 31.083 - 3*1.764 \Rightarrow Tc = 25.79^{o}C$ (3)

(Tm average temperature, Cm average comfort vote)

3rd period (Fig. 5):

$y = 0.1718x - 4.4293 \Rightarrow (y=0)\ x = 25.78^{o}C = Tc\ (26.46)$ (4)

3.4 Confirmation of Nicol Graph (equation)

The equation of the Nicol Graph is:

$Tc = 13.5 + 0.54\ To$ (5)

Tc: comfortable temperatures
To: external temperatures

The dataloggers that had been installed in the external area of the boats recorded the To (Fig. 6). From the participants' answers and the recordings that were taken from the internal dataloggers the Tc was found. If those two numbers can confirm the above equation then it is possible that this equation can be used in boat designing.

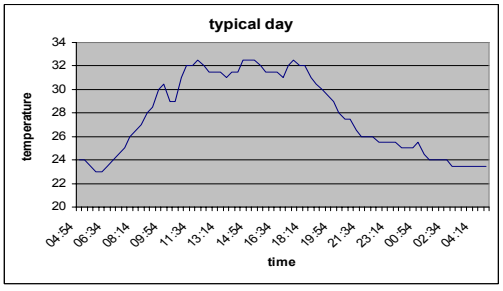

Figure 6: Typical day.

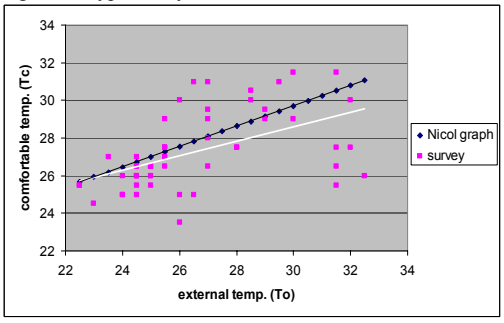

Figure 7: Nicol graph.

The following graph shows the line that comes from the equation and the points from the answers of the participants.

The linear rendering of the equation between the average comfortable temperatures proportionally with the external temperature according to participants' answers is given with the white line. The equation that represents this line is:

$Tc = 17.12 + 0.3826To$

The only number that satisfies both equations is $To = 23^{o}C$. It is obvious that the difference between the two lines is not big (Fig. 7). More research will show which of the above equation is closer to reality and satisfies more people.

4. SUMMARY OF FINDINGS

The factors that affect the thermal comfort of a person have been checked through the survey on all measurements. These are the results:

Temperature: It is a common knowledge that temperature affects peoples' thermal comfort. This acknowledgement has been confirmed during this survey. People felt hotter while the temperature was rising and cooler while the temperature was dropping. Some answers showed that participants felt comfortable in higher temperature and uncomfortably hot in lower temperatures. That happened only when other factors were involved.

Air velocity: Due to the lack of suitable equipment the air-velocity didn't recorded during the survey. All internal areas were measured with anemometers and kata- thermometers. These measurements showed which areas are more affected by the external wind speed. In those areas it was found that the comfortable temperatures were higher. That means that air flow affected peoples preference and make them feel comfortable at higher temperatures

Humidity: The recordings for the humidity levels were very few and too general so they couldn't give any useful result about the effect of humidity on the participants preference.

Clothes: Most people answered that during the survey were wearing swimming costumes or short trousers and t shirts. This means that a variety of clothing preference to show a difference in temperature preference wasn't recorded. Finally due to lack of equipment it was unknown when people removed or added clothes to see

how they deal with the temperatures.

Body characteristics: The results showed a small difference between lighter and heavier participants. In general heavier participants felt comfortable in cooler temperatures. The number of the participants that were compared were very few that's why more research is necessary. Also a comparison would be correct only if the persons were on the same boat under the same conditions. Persons on different boats at different periods of time cannot be compared because it is possible for other factors to involve and change the results.

Age/Sex: Very few young people or women participated so it would not be correct to comment on this.

Health problems: no health problem were recorded.

5. CONCLUSION

The project was based on the strategies of the thermal comfort surveys in buildings. Similar questionnaires have been used and the comfort vote model with Humpreys and Griffiths techniques has been adopted for the analysis of the results. The thermal comfort in boats it is not such an easy area as buildings. The main reasons are the numbers of the boats as well as the use of the boats. There are not as many boats as buildings so it is more difficult to find participants and boats that will be available. Also boats are not used on a daily basis such as buildings so the available days are reduced and boats are mainly used for vacation a fact that makes it more difficult for the person to participate.

The area between twenty five and twenty nine degrees Celsius included the most comfortable answers (25-29). The results of the answers according to comfort vote method showed a temperature preference of twenty five and a half degrees Celsius (25.5^{o}C). Due to project limits it was impossible for all the factors to be checked, so more research is necessary for more accurate results. An interesting finding was the psychological effect on peoples' preference. The comparison of the answers that have been given during a journey and the answers that have been given while the boat was moored in its home town marina showed a small difference in temperature preference. People preferred higher temperature during a journey. The fact that people answered under different conditions and the difference is small makes the results not totally reliable and more research is necessary as well.

Finally the first step in the area of the thermal comfort in boats has been carried out.

The interest that has been shown by manufacturers and boat owners makes the further research in this field necessary. The best thing would be the application of the results on boat construction under an energy efficient approach. Human comfort and environmental protection are two targets, which can be reached in parallel.

BIBLIOGRAPHY

Athienitis, Santamouris and Berger, 1995. Thermal analysis for summer comfort in buildings, Athens, pp 137-146.

Checcacci, L., 1984. Medicina Preventina e Igiene, 5a edizione, chapter 6 pp 421-423, chapter 8 pp 482.

Debroof, L.J., 1995. Text Book of Endocrinology, 3rd Edition, Volume 1, pp 687, 798.

Fanger, P.O., 1972. Thermal Comfort Analysis and applications in environmental engineering, pp 13-18.

Guyton, A.N.D., 1990. Φυσιολογία του ανθρώπου (Humans Physiology), chapter 47, pp 635.

Harrison, 1986. Εσωτερική Παθολογία (Internal Pathology), 10th Edition, volume A, chapter 8, pp 79.

Koutras, Adamopoulos, Raptis and Souvatzoglou, 1994. Βασική ενδοκρινολογία (Basic endocrinology), Athens, pp 217-256.

Roaf, S., 2003. Ecohouse 2 A design guide, pp 285 – 289.

Ugo, T., 1981. Trattato di Patologia Medica, Universo Roma, volume 1, chapter 9, pp 659-676.

www.unl.ac.uk/LEARN (find all pages attached).