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IEQ Laboratory Experiment on Thermal Perception of Air Movement

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***Abstract*—Thermal comfort, a significant ingredient in the study and implementation of indoor environmental quality in buildings, has become a major concern since the revaluation of architecture toward energy efficiency and as well the responsibility of relevant professionals to mitigate the environmental damage. Numerous researchers found that the energy consumption in buildings grew higher to maintain an artificial climate under the meretricious enclosures of human shelters all over the world. The core of the human behavior to maintain an artificial environment is the pleasure or the thermal comfort termed by the researchers in past few decades. It is consensus that the exploitation of non renewable resources can be diminished if alternative solutions are achieved to provide comfort for the occupants. However, comfort is highly difficult to define; it varies from person to person, context to context and culture to culture around the world. As a consequence of chronological investigations for achieving alternates for indoor environment, air flow has been identified as the best known energy efficient and productive solution to date. Air flow is the efficient process, especially for the warm humid climate to create a comfort situation through convective, evaporative and latent heat loss process of human biometeorological system. The process of adopting comfort with air movement is still under exploration.**

This report is based on a simple experiment performed in the IEQ lab at the University of Sydney in 2014 IEQ coursework. In light of the work by S. Tanabe and K.Kimura 1994, the experiment was performed on a number of subjects with different air speed profiles in the climate chamber. The aim of the project is to study the effect of various pattern air movements and its influence on human sensation and pleasure.

***Index Terms*— IEQ, Indoor Temperature, Built Environment, Air Flow**

I. INTRODUCTION - BACKGROUNG OF THE EXPERIMENT

In the landmark paper on acceptability and thermal comfort, Revisiting an old hypothesis of human thermal perception: alliesthesia, professor De Dear pointed a question that demonstrate a number of inequities in the classic model of thermal comfort by Levine 1970 or so many other accepted standards. Why do current comfort standards prescribe static and isothermal conditions for comfort in one building, and dynamic and spatially variable indoor climates for comfort in another? [1]

In the array of researches to investigate a standard comfort model for most of the occupants for any activity and clothing researchers found various temperatures and presented various standard for occupants under specific climatic condition. The most central contributor was P.O. Fanger (1934–2006), who created a predictive model for general, or wholebody, thermal comfort during the second half of the 1960s from laboratory and climate chamber research. In that period, environmental techniques were improving, wealth increased and workers wanted the best indoor environment, while at the same time offices were growing larger [2].With his work, Fanger wanted to present a method for use by heating and air-conditioning engineers to predict, for any type of activity and clothing, all those combinations of the thermal factors in the environment for which the largest possible percentage of a given group of people experience thermal comfort [3].

However, all these researches suggest a static artificial thermal environment for buildings and not a major shift in energy efficient design. All those models propose an isothermal condition for comfort. The major diversified outcome came from the work by S. Tanabe and K.Kimura 1994 while they introduced a dynamic indoor environment for comfort. [4] Tanabe and Kimura operates their research work on 64 college aged Japanese subjects to determine a reduced comfort temperature scale toward sustainable energy efficiency in buildings. The efficiency of air movement in the summer season under hot humid and warm humid climate was fist came into focus by this research. [4]

The experiment performed in a university environmental test chamber. In the laboratory conditioned air was supplied from the front wall and blows through the subject followed by a rear grill. Equipments were used to accelerate air movement and monitored by micro computers. The temperature and humidity were automatically monitored in a data register

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outside the chamber. Whole experiments were operated in different days in summer season in Tokyo, Japan.

The result derived by the experiment shows that thermal sensation in higher air velocities than 100fpm were much lower than the PMV model of Fanger, 1970 and also lower than other previous experiments in lower air velocity. From this research an incredible phenomenon was identified, therefore a major change has been introduced for energy efficient design of indoor environment. [5] Which arises further need to investigate whether comfort temperatures should be variable, rather than static in present model.

II. STATEMENT OF RESEARCH QUESTION

Different researchers found different comfort temperature in laboratory experiment, found lower thermal pleasure scale than the PMV under constant air flow on the subjects in low air movements and high air movements. [4]

This experiment is based on the paradigm of S.Tanabe and K.Kimura's model of low temperature for comfort and satisfiction, introducing dynamic air movement on the occupants.

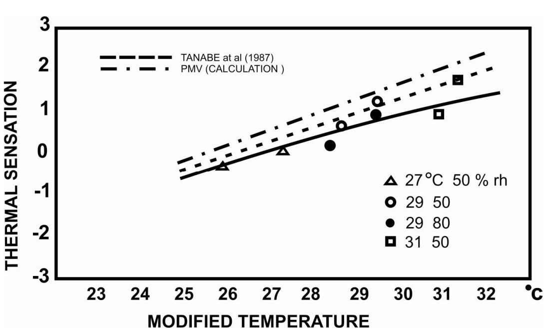

Fig 01 . Thermal sensation vs Modified temperature below air velocity of 100 fpm. The broken curve represents the Japanese college aged subjects under low air movement. The dotted curve calculated by PMV. (FIG 01 Tanabe et el 1987)

In the experiment of Tanabe, he found two different results for two different type of air speeds applied on the subjects. In this experiment fluctuating air speed of four patterns were applied on the subjects to determine thermal sensations and pleasure in the warm climatic environment created in the chamber.

The major research for this experiment is to determine if different air speed patterns elicit different subjective thermal experiences.

Test whether fluctuating air speed is more effective than constant, steady air motion in generating pleasant cooling sensations in warm environments.

III. LITERATURE REVIEW- SHIFT IN CLASSIC MODEL

As the enquiry of this project is to investigate the standards on thermal comfort and low-energy cooling and its application, especially the application in dynamic thermal environment under various air flow pattern. Thus the existing thermal comfort standards has to be related to new research results. In this project, thermal comfort in transient environments is a major topic since low-energy cooling concepts are under exploration, hence, from the earlier researches it is evident that a certain room temperature thermal comfort condition cannot be guaranteed. Previous standards, PMV model of Fanger, had a large variation within different experiments in various contexts.

Many laboratory researches have been conducted on the thermal comfort in warm-humid climatic context. For example [5]; [6];[1]. However, some researchers pointed that there are significant variation in laboratory and field studies. The core of all previous researches were to propose a standard temperature scale for comfort and apparently to reduce the HVAC consumption rate. Some of the experiments were based on the static indoor climate. Soon it has become unreliable since other researches found enormous variation under different circumstances.

The most imperative results come from P.O. Fanger [7], who shaped a predictive model for whole body, thermal comfort during the second half of the 1960s from laboratory and climate chamber research. In that time, environmental techniques were improving, wealth increased and workers wanted the best indoor environment, while at the same time offices were growing larger[8]. In his work, Fanger wanted to present a technique for use by heating and air-conditioning engineers to predict, for any type of activity and clothing, all those combinations of the thermal factors in the environment for which the largest possible percentage of a given group of people experience thermal comfort [3].

Fanger_s PMV model is adopted by many international standards and guidelines, for instance, ISO 7730, ASHRAE Standard 55 [9], and CEN CR 1752, for providing an index of thermal comfort, and, even after the latest rounds of thermal comfort standard revisions, is still the official tool to evaluate thermal comfort, although a new adaptive model developed in the 1990s by Brager and De Dear was incorporated alongside the PMV model as an optional method (Indoor Air 2008; 18: 182–201).

Fanger derived his comfort equation [8] based on college-age students exposed to steady-state conditions in a climate chamber for a 3 hour period in winter at sea level (1,013 hPa)

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while wearing standardized clothing and performing standardized activities, for use within temperate climate zones. Although the comfort equation may probably be applied in the tropics as well, Fanger [10] stated this needed further research. According to PMV, human body produces heat, exchanges heat with the environment, and loses heat by diffusion and evaporation of body liquids. During normal activities these processes result in an average core body temperature of approximately 37 C (Prek, 2005). The body's temperature control system tries to maintain these temperatures even when thermal disturbances occur.

Since the introduction of the PMV model, numerous studies on thermal comfort in both real-life situations and in climate chambers have been conducted. The model's validity and application range were subject to study. Many studies have given support to the PMV model while others showed discrepancies [11]. Criticism involves various aspects, for instance, the model as a whole, its geographic application range, application in various types of buildings, and the model's input parameters.

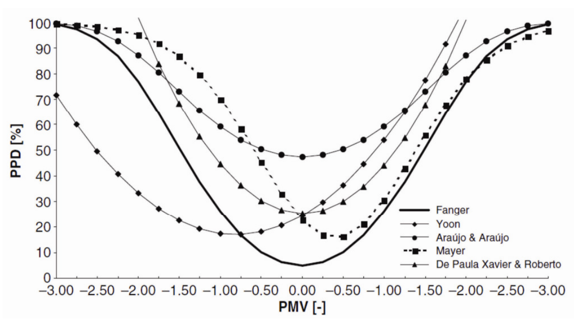

Fig 02 Wide variation in the work of a number of researches were depicted by Hoof, 2007, Indoor Air 185. Figure shows PMV vs PPD within different research projects. Fig: Hoof, Indoor Air , 185.

Criticizing Fangars work, Clark and Edhom 1985 suggested that the influence of exercise, body size, body composition, sex, age and effect of adaption or acclimatization to particular conditions have little or no effect on thermal comfort. [12]

Another realm of enquiry was proposed by Tanabe and Kimura 1994, after the experiment on 64 college aged subjects in Japan. Effect of air movement to achieve thermal comfort was investigated by this research. Since under hot humid weather air movement in a ventilated space would help to achieve thermal comfort for occupants in a lower temperature that considered as standard earlier.

Based on Gagges Scale, namely, "comfortable", "Slightly comfortable", "Uncomfortable" and "Very Comfortable", [13] Tanabe represents his experiments both in static thermal condition and under two different constant air flow. The comfort temperature in his experiment was lower than the previous paradigm set by other researchers. [14] This is indeed an area that needs further research and can have a high impact on using less energy to run our buildings.

IV. RESEARCH METHODOLOGY

The students from the course Indoor Environmental Quality were attained the experiment as the subjects. The participants were placed in a thermal chamber to experience a single warm exposure and four air movement patterns, constant, sinusoidal, pulsed, and saw tooth. Participants have spent 30 minutes seated in the warm conditions (27.5°C) before undergoing each air movement profile for 5 minutes in a randomized sequence, giving a total experiment duration of 50 minutes. The results were collected by instruments and from the vote of subject's pleasure experience.

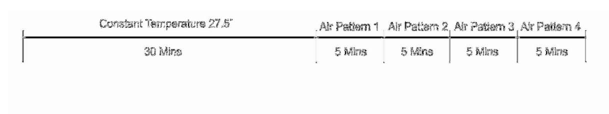

Fig 03: Time span and activity

Fig 05: Different Laboratory instruments and subject position in laboratory experiment.

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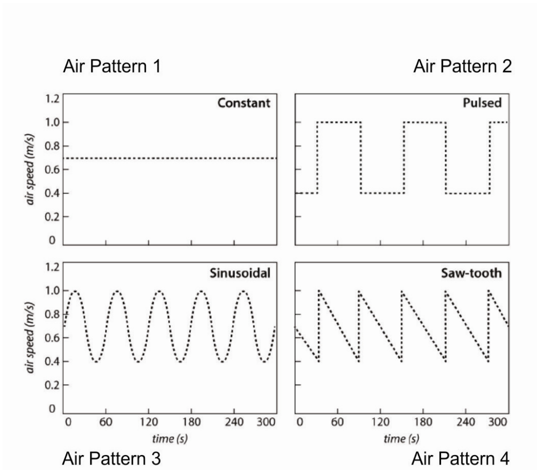


Fig 04: Different Air Profiles. Air pattern 1 represents an air flow steady type. Air Pattern 2 is applied as two different air speeds with gradually altered during experiment. Air Pattern 3 is a Type of Air flow which increased gradually and decreased gradually like the curve shown. Air Pattern 4 also a gradual fluctuation of sir flow, but with sharp acceleration of air speed.

V. Result and Discussion

For the analysis of results four male's and four female's data were taken randomly from the result sheet of 38 subjects. The subjects have different clo values , different weight , age and gender to ensure variation in physical properties.

Subject ID	Gender (M,F)	Age (y)	Weight (kg)	Height (cm)	Clothing (clo)	Preference	Median Pre_TPLES	Pre_TSENS	Ambient Temp (degC)	Rel. Humidity (%)
1I	M	28	70	178	0.48	NONE	0.00	0.00	27.8	49
1J	M	39	93	192	0.51	COOL	0.00	1.66	27.8	49
1K	M	29	68	173	0.49	COOL	-0.67	1.33	27.8	49
1L	M	37	80	178	0.57	WARM	-1.67	0.66	27.8	49
2A	F	28	62	162	0.77	COOL	-1.00	1.00	27.4	51
2B	F	25	58	161	0.44	WARM	0.00	0.00	27.4	51
1D	F	26	65	160	0.64	WARM	-0.34	2.00	27.8	49
1F	F	29	50	154	0.63	WARM	-1.00	0.33	27.8	49

Table 01: Experiment results of 8 subjects taken randomly.

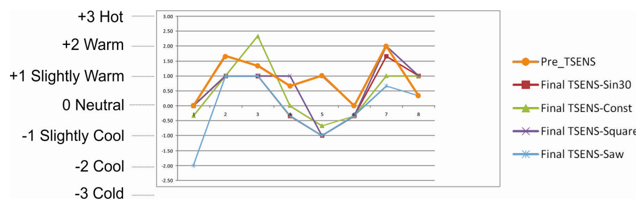
Subject ID	Pre_TSENS	Final TSENS-Sin30	Final TSENS-Const	Final TSENS-Square	Final TSENS-Saw
1I	0.00	0	-0.34	0.00	-2.00
1J	1.66	1	1.00	1.00	1.00
1K	1.33	1	2.33	1.00	1.00
1L	0.66	-0.34	0.00	1.00	-0.34
2A	1.00	-1	-0.67	-1.00	-1.00
2B	0.00	-0.34	-0.34	-0.34	-0.34
1D	2.00	1.66	1.00	2.00	0.66
1F	0.33	1	1.00	1.00	0.33

Table 02: Experiment results of 8 subjects taken randomly.

Pre-TSENS: Thermal sensation vote without air movement prior to the initiation of fans (t25-t30)

Final TSENS: Thermal sensation vote at the end of that air movement pattern.

Thermal Sensation Scale: -3 cold, -2 cool, -1 slightly cool, 0 neutral, +1 slightly warm, +2 warm, +3 hot



Graph 01: represents thermal sensation votes (Final TSENS) from 08 subjects under 04 different air speed patterns and (Pre-TSENS) Thermal sensation vote without air movement prior to the initiation of fans (t25-t30)

From Graph 01 it is seen that the Pre TSENS (Color Code Orange) remains higher than the Final TSENS for all subjects under four different air speed patterns. Between 8 subjects only Two vote exceeds the Pre TSENS value in the graph, 6 votes remain same and all other thermal sensation votes (26 votes) are lower than Pre TSENS. It can be defined that the thermal sensation without air movement is higher than the thermal sensation under different air speed patterns.

From the line graphs under different air speed patterns it is seen that the thermal experience differs in a wide range for each type of flow.

Type of air flow pattern has significant impact on the subject's thermal sensations. Among four different flows, "Saw" creates the most cool sensations in all subjects and the constant flow has the warmest experience, depicted from the line graph. All sensation votes from fluctuating flows are cooler than the constant flow. It can be demonstrated that fluctuating air speed is more effective than steady air motion in generating pleasant cooling sensations in this experiment. Apparently, as through the experiment chamber's humidity and temperature this finding should be applicable for warm climate.

Pre_TSENS	Final TSENS-Sin30	Final TSENS-Const	Final TSENS-Square	Final TSENS-Saw
2.00	1	1.33	1.00	1.33
0.66	0.66	0.66	0.66	-0.34
1.00	1	1.00	1.00	-1.00
1.00	1.66	0.33	0.33	0.00
0.66	-0.67	-0.67	0.33	-1.00
1.00	-1.67	-1.00	1.00	-2.00
1.00	-0.67	-1.00	0.66	-1.34
0.00	-1	-1.00	1.00	-1.00

Table 03: Experiment results of 8 subjects other than the Table 1, Table 2.

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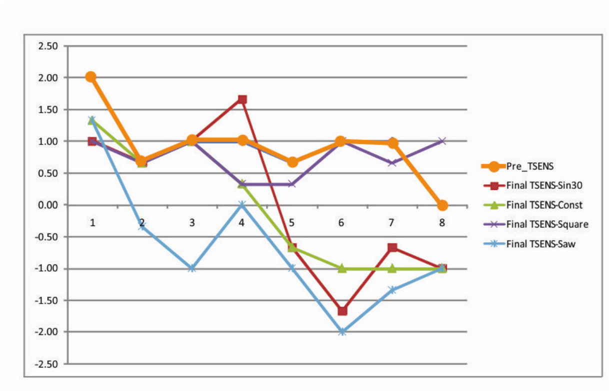
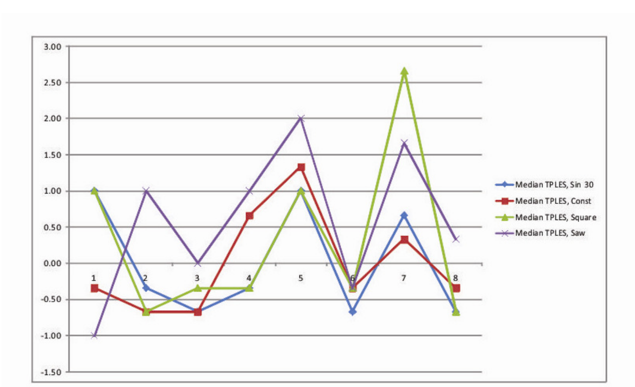


Graph 02: (Final TSENS) and (Pre-TSENS) for 8 subjects other than graph 01

To verify previous outcomes, same parameters from 8 other subjects represented in the graph 02. The fluctuating values are different from the previous sensation votes, however, the represent similar result among other 08 subjects taken randomly in this stage. Therefore, the decision came from the previous step is similar to the second stage. The aforementioned results are verified and can be considered as an authentic statement, fluctuating air speed is more effective than steady air motion in generating pleasant cooling sensations.

Subject ID	Median TPLES	Median TPLES	Median TPLES	Median TPLES
1I	1.00	-0.34	1.00	-1.00
1J	-0.34	-0.67	-0.67	1.00
1K	-0.67	-0.67	-0.34	0.00
1L	-0.34	0.66	-0.34	1.00
2A	1.00	1.33	1.00	2.00
2B	-0.67	-0.34	-0.34	-0.34
1D	0.66	0.33	2.66	1.66
1F	-0.67	-0.34	-0.67	0.33

Table 04: Experiment results of 8 subjects, Median TPLES



Graph 03: Thermal Pleasure votes, Final Tens from 8 subjects under 4 different air speed patterns.

Median Tples: Median of the three trermal pleasure votes during the air movement pattern

Median Pre_TPLES: Median of the three thermal pleasure votes without air movement prior to the initiation of the fans (t25-t30)

Thermal Pleasure scale: -3 very unpleasant, -2 unpleasant, -1 slightly unpleasant,

0 indifferent, + 1 slightly pleasant, +2 pleasant, +3 very pleasant

From graph 3 it is seen that the ling graphs are fluctuating in a wide range for all pleasure votes from the subjects. Therefore it can be determined that different air speed patterns elicit different subjective thermal experiences.

VI. CONCLUSION

The experiment has derived some significant outcomes and is an useful addition to the study of thermal comfort. Impact of air speed was previously studied, however, fluctuating air flow is the newest dimension in the sequence of the study. As it is found that the human thermal sensation and pleasure can be achieved through fluctuating air speed, so that the range of temperature would be higher than the previous standard. As a consequence it keeps the artificial cooling load lower in the buildings in the warm climate.

Further research can be conducted under different indoor temperature and humidity to find whether the comfort temperature is more variable for different regions. Thus, the current study provides most required experiment data for the research and study of various air flow patterns to achieve higher comfort temperature for indoor environment and thereby serves as a methodology and database to support future studies, reporting on sustainable building environment and helps the relevant professionals to appraise the indoor environmental quality.

VII. ACKNOWLEDGEMENT

A research requires detailed reading and I gratefully acknowledge my debt to the persons who helped me with advice. Professor Richard de Dear is the course coordinator and a prominent researcher in the field, has guided me intensively to plan the research technique, methods and enquiries.

The experiment was operated in the IEQ lab at the Faculty of Architecture, design and Planning at The University of Sydney. It was not possible to conduct such an experiment

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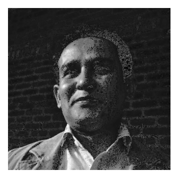

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