

LB/DCN/98/07

23

**PASSIVE TECHNIQUES TO IMPROVE
THERMAL COMFORT IN FACTORY BUILDINGS
IN SRI LANKA**

**REPORT SUBMITTED TO THE DEPARTMENT OF
MECHANICAL ENGINEERING IN FULFILMENT OF THE
REQUIREMENT FOR THE DEGREE OF
Master of Engineering**

**By
Samantha Pradeep Wijewardane**



**Professor M. T. R. Jayasinghe
(Department of Civil Engineering)**

And

**Professor R. A. Attalage
(Department of Mechanical Engineering)**

621 04
621(043)

**UNIVERSITY OF MORATUWA
SRI LANKA
November 2004**

University of Moratuwa



89424

89424

89424

DECLARATION

I, Samantha Pradeep Wijewardane, hereby declare that the content of the dissertation is the original work carried out over a period of 15 months at department of Mechanical Engineering and Civil Engineering, University of Moratuwa. Whenever others' work is included in this thesis, it is appropriately acknowledged as a reference.



ABSTRACT

Recent past the electricity prices have boosted to a certain height as to be identified by the industries, a key factor that hindered their competitiveness in international market. As a result, ways of reducing the energy consumption are called for within every segment of manufacturing. This new trend places the active techniques such as air conditioning a less feasible option for achieving thermal comfort within factories involving large workforces. Consequently, there occurs a rising preference for naturally ventilated factory buildings with passive techniques that enhanced the thermal comfort over HVAC controlled buildings as fit to the scenario.

This array of researches was a consequence of above circumstances, which aimed to find the thermal comfort preferences of factory workers and to study and develop passive techniques that reduce or totally eliminate the active means of achieving thermal comfort in factory buildings at the low altitude of the country. The thermal comfort survey formulated accordance with the "adaptive hypothesis" primarily illustrate the comparability of thermal comfort range of Sri Lankan factory workers and ambient temperature span of typical out door conditions at low altitudes. Therefore signify the possibility of adopting the methodology of creating the favorable outdoor thermal environment within the built environment thus show the opportunity to become independent from costly active means such as air conditioning. Further the results were used to compare the validity of various adaptive models and formulas published recently for tropical warm climatic conditions.

On the basis that there are abundant benefits to be gained from an improved understanding of the influence of adaptation on thermal comfort in the built environment, few novel experiments were designed and conducted to understand how workers behave and interact with different intensities of solar radiation and with different air velocities. The experiment that aimed to compare the effects of direct solar radiation on various parts of the body shows that 70% of the participants were uncomfortable when direct radiation fall on the back of their body than front of their body. Other 30% did not notice any significant difference So for existing factories, which are unable to stop the direct solar radiation inside the building, can change their

production lines if possible so that the unavoidable direct sunlight fall front side of the body rather than backside of the body.

Another experiment showed that 80% of the workers thermal comfort improves when walking, than staying in one place. It is believed that the augmentation of the relative velocity ($0.6-0.8 \text{ ms}^{-1}$) when walking makes this difference even the metabolic rate is slightly higher when having a leisurely walk. Further it was noticed that the level of thermal comfort starts to reduce when the walking speed exceeds 0.8 ms^{-1} . Moreover, the questionnaire survey shows that about 50% factory workers have the option to have a short walk around, about after 20-25 minutes time period. This may be a good technique for workers to improve the thermal comfort of themselves.

Finally A simple and basic, but pragmatic factory model is presented by integrating the results of both field surveys and questionnaire surveys. The orientations and sizes of the openings with respect to walls and the techniques that uses vegetation as a cooling potential is considered here to give practical guidelines to a factory designer. Computer simulations using programs DEROB-LTH and AIOLOS were used to compare the model that with a common type. Results show the significant improvement with respect to ACH (Air Changes per Hour) in newly designed model.

ACKNOWLEDGEMENT

The author wishes to thank the supervisors – Professor MTR Jayasinghe of Department of Civil Engineering and Professor RA Attalage of Department of Mechanical Engineering – for their guidance and support. Also, appreciate the contribution from Dr. AGT Sugathapala of Department of Mechanical Engineering towards completing the report; further appreciate the cooperation of the factory administrations and workers to conduct field surveys.

Samantha P Wijewardane

November 2004

CONTENTS

	Page no
1. INTRODUCTION	12
1.1 Thermal comfort and factory designing	12
1.2 Thermal comfort and Sri Lanka climatic conditions	13
1.3 Development of thermal comfort standards	14
1.4 Modern trends of the standards	14
1.5 The factory environment and the workers	17
1.6 Objective	18
1.7 Basic Approach	18
2. NATURAL VENTILATION	20
2.1 Introduction	20
2.1.1 The Causes of Natural Ventilation.	20
2.2. Building Design for Natural Ventilation	21
2.2.1 Responsibilities of Planners and Designers	21
2.3. Natural ventilation and thermal comfort	22
2.4. Cooling Potential of Natural Ventilation	23
2.5. Wind Characteristics	24
2.6. Site design	27
2.7. Building characteristic and natural ventilation	41
2.8 Improving Cross Ventilation.	47
2.9 Air Quality	49
2.10 Methods for the estimation of the air velocity	51
3. ADAPTIVE MODEL	52
3.1 Adapting to Climate Extremes	52
3.2 Launching towards adaptive model	54
3.3 The “adaptive” hypothesis	57
3.4. Evidence for adaptation	67

3.5 The semantics of thermal comfort	80
3.6 Variable temperature standards	81
3.6.1. Conditions for an acceptable thermal environment	82
3.6.2 Analytic PMV Method	82
3.6.3 Adaptive PMV method	83
3.6.4 Prescriptive method	84
4 METHODOLOGY	86
4.1 Field Surveys	91
4.2 Extended Field Surveys	92
4.3 Questionnaire survey	95
4.4 Basic Model	95
4.4.1 A Description of Two Software	97
5. RESULTS AND DISCUSSION	98
5.1 Analyses of the results	99
5.2 A comparison with comfort models	100
5.3 Results and analyses of the extended field surveys	102
5.4 results of the questionnaire survey	104
5.5 Analyses of the basic factory model	104
5.6 Further development of the basic factory model	106
5.7 Advantages of the configuration	108
6 CONCLUDING REMARKS AND FUTURE WORK	109
References	111
Appendix A	117
Appendix B	120
Appendix C	122

List of figures

- Figure2.1** Typical record of the wind velocity near the ground
- Figure2.2** The best location for a building on a hill site
- Figure2.3** The best location for a building on a site near a shore
- Figure2.4** Example of good and bad locations of a building on an urban site, with respect to wind
- Figure2.5** Critical positions for pedestrian discomfort due to wind on an urban site
- Figure2.6** Airflow patterns through (a) a normal, (b) a scattered and (c) a Diagonal layout of buildings
- Figure 2.7** Effect of wind incidence angle and length and shape of the Obstruction
- Figure 2.8** Building wakes and inter-building spacing
- Figure2.9** Airflow pattern through a building in relation to their distance from the windward opening
- Figure 2.10** acceleration of wind under trees
- Figure 2.11** acceleration of wind under trees
- Figure2.12** Funneling of air to direct air (a) towards (b) or away from a building
- Figure2.13** Narrowing of spacing between windbreaks and a building to accelerate the airflow
- Figure2.14** Position of an opening; or (a) optimum body cooling and (6) Structural cooling
- Figure 2.15** Night flushing of exposed surfaces of thermal mass
- Figure 2.16** Air Flow Pattern through single banked rooms for various window types
- Figure2. 17** Air Flow Pattern and pressure Zones
- Figure2. 18** Possible combination of wall systems
- Figure 2.19** Effect of wing-walls
- Figure 2.20** Air circulations due to stack effect

- Figure 2.21** Effects of wind incidence angle on interior airflow
- Figure 2.22** The impact of the exterior characteristics of the building:
- Figure 3.1** The three components of adaptation to indoor climate
- Figure 3.2** The "adaptive model" of thermal perception (after Auliciems, 1981)
- Figure 3.3** behavioral feedback loops
- Figure 3.4** Physiological feedback loop
- Figure 3.5** Psychological feedback loop
- Figure 3.6** The statistical dependence of indoor thermal neutralities on climate
- Figure 3.7** Thermal comfort experiments in the field: Observed and predicted neutralities in relation to outdoor climate
- Figure 3.8** Relationship between the number of workers sharing an office and perceived level of control over room heating and ventilation systems.
- Figure 3.9** The adaptive PMV comfort zone's optimum and limits for an 80% acceptability level in HVAC premises.
- Figure 3.10** The adaptive PMV comfort zone's optimum and limits for an 90% acceptability level in HVAC premises.
- Figure 3.11** Psychometric charts showing summer and winter comfort zone
- Figure 3.12** The adaptive comfort zone's optimum and limits for an 80% acceptability level in naturally ventilated
- Figure 3.13** The adaptive comfort zone's optimum and limits for a 90% acceptability level in naturally ventilated premises.
- Fig 4.1** The approximate orientation of factories and the areas used for the Surveys
- Fig. 4.2** Base case
- Fig. 4.3** Basic model
- Fig 5.1** Free nerve endings that respond to mechanical, thermal or noxious stimulation
- Fig 5.2** Distribution of the thermal receptors



List of tables

Table 4.1 Details of the Factory buildings

Table 5.1 Combined results of factories A & B

Table 5.2 Results of Factory C

Table 5.3 Responses to High Temperatures with Relatively High Velocities

Table 5.4 Resulted upper limits [(+1) Slightly Warm condition]

List of Graphs

Graph 5.1 Temperature Comparisons

Graph 5.2 ACH Comparisons



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk