IDENTIFYING THE ADAPTIVE OPPORTUNITIES IN FACTORY ENVIRONMENTS FOR A BETTER THERMAL COMFORT - PRELIMINARY STUDIES

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Abstract: Achieving thermal comfort by active means has become one of the largest energy intensive activities in factory environments, which directly influence the manufacturing cost. As a result searching for new methodologies that could improve the thermal comfort with minimum usage of energy has become vital. In the scope of adaptive thermal comfort model, improving the adaptive opportunities is a potential passive technique that can be used to minimize the energy requirement. However not many researches were conducted especially in tropical climates to investigate the ways of expanding adaptive opportunities. The research presented was conducted to understand the existing adaptive opportunities and to explore and identify new methods that could improve thermal comfort in factory environments.

Key words: *Thermal comfort, adaptive model, Adaptive opportunity*

1. Introduction

The rising energy costs and also associated reduction in energy supplies has created many opportunities for optimization of energy usage. One of the possibilities that offer energy saving options in factory buildings is the optimum use of climatic acclimatization and adaptive opportunities to ensure thermal comfort with minimum use of active means. For this, countries close to the equator with tropical climatic conditions could become a good candidate. On one hand, there is a significant manufacturing base located within factory buildings. Also the optimization of energy needed for thermal comfort could make a reasonable impact on the manufacturing costs. The factory workers are generally inhabitants of tropical climates. Hence, they may be tolerant to the climate conditions. This can be attributed to climatic acclimatization and the clothing worn. Hence, it offers good thermal comfort exploitations even with simple means such as enhanced air movements when the surrounding temperatures rise to higher levels during the day times.

Therefore with the perception that there could be many adaptive opportunities in which when implemented could save much energy, a preliminary investigation was done by questionnaire surveys and field surveys in selected factories in low altitudes of Sri Lanka. These surveys were designed and implemented to understand the existing adaptive opportunities in naturally ventilated factory buildings mainly with respect to behavioral adjustments. Further, this preliminary research can be considered as an attempt to explore and identify the components of “behavioral adjustments”, which have higher energy saving potential, for further detailed studies.

2. The Background

Sri Lanka, located close to the equator with *5*° to 9° latitude, is a good example for warm humid tropical climatic conditions where many light-work manufacturing factories are located. Because of the warm humid condition, achieving thermal comfort without active means is a challenging problem in most of the factories operated in low altitudes. As there are many evidences supporting the fact that thermal comfort influences the productivity of workers [1-5], operating a fine line between reductions of energy for thermal comfort and obtaining the maximum productivity is a challenging problem. Therefore, the ability to maintain a good harmony between optimizing energy needed for thermal comfort and productivity has become a key factor that influences the competitiveness between different manufacturing environments. As a result, searching for new methodologies that could improve thermal comfort with minimum usage of energy has become a crucial task.

"Adaptive opportunity" is one of the main *concepts* in adaptive hypothesis. It is defined as the varying degree of opportunity or scope that building provides their occupants to adjust the internal environment (and themselves) to achieve thermal comfort [6]. Enhancing the adaptive opportunities in built environments allow adapting to the situation without searching for alternative active means. Sealed, centrally air conditioned buildings provide minimal adaptive opportunity, while naturally ventilated buildings with operable windows and ceiling fans typically afford high degrees of adaptive opportunity [7]. There are many benefits to be gained from an improved understanding of the influence of adaptation on thermal comfort in the built environment [8]. In the scope of adaptive model, improving the adaptive opportunities is a potential passive technique that can be used to minimize the energy requirement for thermal comfort.

There are three modes of adaptation [6] (1) Behavioral adjustment (Personal, environmental, technological or cultural), (2) Physiological (genetic adaptation or acclimatization) and (3) psychological (habituation or expectation). Behavioral adjustment includes all modifications a person might consciously, or unconsciously make, which in turn modify heat and mass fluxes governing the body's thermal balance. The behavioral adjustment was defined in terms of three subcategories [8]: (I) Personal adjustment: adjusting to the surroundings by changing personal variables such as adjusting clothing, activity, posture, eating/drinking hot/cold food or beverages, or moving to a different location; (2) Technological or environmental adjustment: modifying the surroundings themselves, when control is available, such as opening/ closing windows or shades, turning on fans or heating, blocking air diffusers or operating other HVAC controls, etc.; and (3) Cultural adjustments, including scheduling activities, siestas, adapting dress codes, etc.

3. The Worker and Factory Environment

Factory worker is Classified here as an employee who is directly involved in the production related activities of the factory establishment excluding any working supervisory personal and administrative personal. Majority of the factory staff consisted of factory workers that have comparatively least authority to adjust the thermal environment [9].
The pattern of occupancy in factories is different from other buildings. In factories, there is a specified time to arrive and leave and very few enter the environment in between, contrast to office buildings where people visit in different times. Because of the uncertainty of number of people in and out from office buildings$_1$ the thermal load of office buildings vary compared to factory buildings. Thus, factors can encourage thermal adaptation easily than office buildings. Often factory workers have a certain dress code that used by all, thus simplified the clothing effect on individual thermal comfort. Further it stimulates the adaption because of using the same form of dress over a long period. The rules and regulations practiced within factory premises are also different from other building types. In addition factory workers could be identified as different respect to the non thermal issues that affect the thermal preferences [10]. These factors, which illustrate the uniqueness of factory environment and workers, encourage the research on adaptive opportunities within factory buildings.

4. The Methodology

In a factory environment, the need for quality assurance of manufacturing activities will create many specific constraints to adaptive opportunities available for workers. Therefore, adequate information has to be collected from the management on the existing scenarios and preferences. It was also necessary to check the actual possibilities prior to formulating the experiments. They were obtained with observation made with factory visits and also conducting questionnaire surveys among the workers.

4.1 Questionnaire Survey for Factory authorities and workers

A questionnaire survey was carried out to find with factory authorities to obtain the following information.

(a) The preference ideas and basic knowledge of factory authorities regarding adaptive opportunities and related issues,
(b) Existing "adaptive opportunities" within the factory environments and to explore and identify the potential "adaptive opportunities" that can be implemented within the working environments.

A survey form was created as shown in appendix A, in Microsoft word format and distributed among factory authorities mainly by e-mails. They have the convenience of filling the survey form and return back via c-mails. About 10 factories that engage in light to medium work were also visited to acquire knowledge on thermal comfort issues and to investigate the rules and regulations practiced within the factories that influence the adaptive opportunity thus thermal comfort. A similar questionnaire survey was carried out with a sample of worker as well. Few preliminary field surveys were designed and carried out in a steel fabrication factory and in a plywood factory located low altitudes of Sri Lanka. The main purposes were to find the effectiveness of some behavioral adjustments on thermal comfort in warm humid conditions and to perceive the potential of some methodologies that arise as a result of questionnaire survey to use as "adaptive opportunities" in warm humid conditions.

5. Results and Discussion

5.1 Identification of Adaptive Opportunities

A good understanding of available behavioral adjustments (behavioral opportunities) and the behavioral opportunities that can be implemented for better thermal comfort within the factories were gained from the questionnaire survey. Further, the activities that would enhance the adaptive opportunities if implemented at right time were identified.

From the field surveys and questionnaire surveys it is found out that for a better adaptation not only workers but also supervisors and factory planners or designers have a role to play. Potential activities that affect the behavioral adaptation can be classified regarding different parties involved as follows:

1. Worker's control: Adjusting clothing, posture, eating/drinking hot/cold food or beverages, or moving to a different location if permissible; Technological adjustments such as opening/ closing windows or shades, turning on fans or heating when control is available.

2.Supervisory restrains: Selecting time and time interval for lunch breaks, tea intervals, water breaks, etc. selecting the operating time and intensity of electrical appliances such as fans, control over changing places of workers, etc.

3. Planners and designers tasks: Determining the sizes and orientation of openings in the building envelope, selecting the positioning of fans and blowers, designing of production lines taking the thermal issue as a constraint, initiating thermally favorable dress code for workers, etc.

5.2 Possible Adaptive Measures.

There are many adaptive measures that can be used within factory buildings. They are the following.

Moving*:* - The adaptive opportunity "moving" is mainly considered as the spatial shift seeking for a better comfort. Examples include moving away from a sun-patch or moving into an air-stream where thermal comfort is better than the initial position. But the fixed workplace layouts and set team structures designed for a particular process flow, which are a common observe in the bulk of factories provide little room to employ this option for thermal comfort. The economic pressure combined with

relative low attention on thermal comfort would make it unfeasible to consider the spatial adaptation even in future factory designs. But it was noticed that the workers were allowed to walk away and comeback for personal requirements from their working positions time-to-time depending on the activities they are involved. Observed time gaps that workers have a chance to initiate a short walk were ranged from 10 minutes to an hour. This opportunity for a short walk could be used effectively to improve the thermal comfort.

Altering the clothes: - The clothing effect on thermal comfort was studied extensively in laboratories [15] and in office environments [16]. But not much information is available in tropical climates and in places like factories where clothing is prescribed. Most of the factory workers have an imposed dress code depending on the factory they are working. Usually a long sleeve shirt was used for upper body and only alternations allowed were scrolling up the sleeve and unbutton more often the top button of the shirt. In hot climates where upper temperature limit is more significant the clothing effect gets more complicated due to two effects called "pumping" effect and "wick" effect [17]. The pumping effect is due to the air-movement between clothing and skin and wick effect is due to the evaporative cooling enhanced by certain types of clothing fibers. It is showed that clothing insulation values could even become negative due to these effects, thus highlighted the significance of clothing effect on adaptation.

Changing posture and activity: - By changing the posture the effective surface area of the body can be increased facilitating the heat loss by evaporation. The effective surface area can be increased by about 20% just by holding the arms further away and sitting with legs further apart than normal [17]. Not only the posture but also the postural changes affect the body temperature and heat balance and therefore the thermal comfort [18]. But in the factory work the posture is associated with a particular endeavor, which a worker is performing, and a good body weight balance determined by the posture is important to carry out the task effectively. Even though there might be few opportunities for changing the posture in favor of thermal comfort it's consequences on the body such as additional muscle strain and on the working efficiency is questionable and complicated therefore need well-directed extensive research to understand the problem, which is beyond the scope of this research. .

The "activity" is directly related to the thermal comfort as the metabolic rate, which influences the heat balance of the body, depends on the nature of the activity. The metabolic rates given in the literature [20] are average values and in reality these rates differ from a person to a person [18]. Also an individual can carry out the same activity for a range of metabolic rates by changing the rate or rapidness of the work. In this scenario the metabolic rate can be considered as an adaptive opportunity. A worker has the option to self-pace the rate of work depending on the environment and the perceived heat strain. But in factories in which the workers are paid for "piece-rate" this option hardly exists due to the monetary pressure. Workers tend to keep the same working tempo even in harsh warm instances to complete more work within the time available. The gross mechanical efficiency of human work, i.e. useful work out per metabolic energy production varies with type of work but for many activities it is order of 20% for an average person [19]. The other 80% dissipate as heat through the body to the environment. But for a well-adapted skillful worker this efficiency can be quite high causing less body heat production and he could dissipate this less amount of heat much more easily to the surrounding. Therefore he could feel a better comfort than an average worker doing the same work.

Eating/drinking hot/cold food or beverages: A study done on a group of Australian Shearers [21] revealed how adequate meals; tea and water breaks prevent them from dehydration and maintain the same productivity level even in harsh hot conditions. Although Eating/drinking were not allowed at the working premises in bulk of the factories due to quality controlling regulations workers can be encouraged to drink more water regularly by facilitating easy access. Also lunch, tea and water breaks can be scheduled properly such that workers get more breaks when temperature is high and a fewer number of breaks at moderate comfort temperatures.

Apart from the personal adjustments that described so far, controlling the ventilation and solar glare are two popular technical adjustments that could be done to adapt to the thermal environment. The

significance of the effect of ventilation and solar radiation respect to warm and humid climates was highlighted in many publications [22].

Most of the naturally ventilated factories use electrical fans especially ceiling fans to provide the adequate airflow. Many field surveys [23] have showed that people prefer variable fluctuating air-movements rather than uniform and monotonous airflows. Also the higher fluctuations of natural wind have close relationship with people's pleasure [24]. The fluctuation of electrical fan airflow is different from the fluctuation characteristics of natural wind. Therefore for a better thermal comfort and thermal adaptation it is required to increase the variability of air-movements as much as close to the variability of natural airflow. This scenario motivated to compare two basic types of fans i.e. ceiling and pedestal fans on the basis of the variability of airflow.

6. Conclusion

Useful information about the adaptive opportunities the potential to implement adaptive opportunities and also the difficulties arising when implementing the adaptive concepts were gathered. Also it is required to implement some experiments to understand especially regarding the effects of posture and activities to thermal comfort and productivity.

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Appendix A

Questionnaire Survey

1. Please comment on the following
    - Freedom of the worker’s to control electrical appliances and windows, shadings, etc
    - About the uniform of the workers
    - The frequency of having a short break

2. Describe the satisfactory/unsatisfactory of
    - Positioning of the windows, shades, fans, blowers, etc
    - The orientation of the production line(s) relative to the building envelope

3. Comment on your overall satisfaction about the thermal comfort of the factory

4. Your ideas of improving the thermal comfort of the factory