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THERMAL COMFORT ASSESSMENT FOR ADOPTING CONTROL STRATEGIES IN ATRIUM BUILDINGS

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Abstract—**The atrium was seen in origin about two hundred years ago. Glazed areas and atrium structures have been considered a symbol of advanced technology in recent years, yet they can differ in terms of arrangement and functionality. Because of the complexity of their operation and air movement, atriums are difficult to diagnose and analyze in terms of thermal comfort. The present paper has a study on the thermal environment of atrium spaces. Thermal comfort is one of the foremost important aspects of indoor environmental quality thanks to its effects on well-being, people's performance, and building energy requirements. Since our responses to our thermal environment have a considerable effect on our performance and behavior, not least in the realm of work, there has been a considerable scientific investigation of those responses and formal methods are developed for environmental evaluation and style. Thermal sensations of the occupants occupying the interior space of the building were evaluated with various approaches to understanding indoor thermal comfort. Several metrics for assessing human thermal response to interior environment conditions have been assessed describing the human thermal perception of the thermal environment to which an individual or a group of people is exposed. The article study was to gain insight into the subject's perspectives on variables of comfort levels and determine the factors responsible for the varying human thermal comfort summer. This paper is a study on the thermal environment of atrium spaces focusing on identifying the factors of thermal comfort and promoting Control measures that may be adopted in atrium buildings to reduce the energy potential.**

Keywords—**Atrium, indoor thermal Comfort, Environment Control Measures, natural ventilation, design strategy**

I. INTRODUCTION

According to the World Health Organization (WHO), Health is "a condition of complete physical, mental, and social well-being, rather than only the absence of sickness or infirmity." Because man spends the majority of his life indoors in modern industrial civilization, the indoor environment deserves special care (WHO Conference, 2002). A major segment of the population spends 23 of every 24 hours in a controlled environment, such as their homes, workplaces, hobby, recreational, and cultural centers, or while traveling by vehicle, rail, ship, or plane. As a result, there is rising awareness and purpose in investigating the impact of indoor climate on humans, allowing for the establishment of appropriate requirements that should be pursued in practice. (Ghiabaklou, 2003). Likewise, an increase in objections about unpleasant indoor climates reflects that man has become much more sensitive to the surroundings to which he is exposed. He appears to be most prone to fussing about the interior temperature of his workplace (offices, industrial premises, shops, schools, and so on), where he is forced to spend his time in conditions that he cannot control. (Fanger, 1973).

Therefore, one of the most significant industries for increasing energy efficiency is the construction industry. (Berg, Flyen, Godbolt, & Broström, 2017). Indoor thermal comfort, as a key issue in buildings for providing occupant comfort in various seasons, cannot simply depend on passive techniques of cooing. (Aram & Alibaba, 2019). Though user comfort and energy efficiency are two of the most essential factors to consider when evaluating the performance of building system controls, passive solutions such as transitional areas such as the atrium feature can be adequate. (Pitts, 2013).

II.ATRIUM DESIGN AND THERMAL PERFORMANCE

Over the last few decades, atrium features have become increasingly popular as an architectural element. The atrium creates a striking aesthetic area by exposing neighboring internal spaces to daylight, optimizing the benefits of sun rays gain, and encouraging socialization and interactions among residents. (Moosavi, Mahyuddin, Ab Ghafar, & Ismail, 2014). It also provides air circulation and communication among different stories of the building. Nowadays, these atrium features are often adopted in contemporary design, and they are frequently stated to provide some passive effects to the internal environment along with energy-saving potential, as they consist of a glassed screening on top of the building that lets plenty of light inside that building. (Yüksek & Karadayi, 2017).

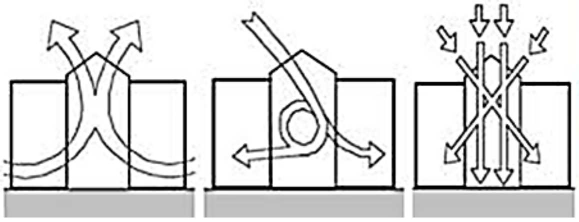

Fig. 3. Thermal performance of atrium

However, while atriums are thought to contribute to higher building market values, the predicament of indoor and outdoor, which indicates environmental factors such as solar radiation, ventilation, and increased heat energy, produces interior regions with major environmental problems. Under the influence of solar radiation, an atrium's roof skylight system is vulnerable to a variety of effects, resulting in varied environmental behavior. As a result, such behavior will either enhance or reduce the indoor load's strength. This finding necessitates determining the impact of sunlight falling on, interacting with, and emitted by a skylight system. (Al-Obaidi, Ismail, & Rahman, 2014).

Top-lit atria are ideal for day lighting, especially on cloudy days; however, overheating during the cooling phase is an issue with this form of the atrium (Ahmad & Rasdi, 2000). While shade devices have been offered as a remedy to this problem, they significantly limit natural illumination performance in the atrium and adjacent spaces (Douvlou & Pitts, 2000). To alleviate indoor discomfort, various architectural passive design solutions have been employed. Natural ventilation with a well-designed system significantly increases interior comfort temperatures and provides a broad range of pleasant indoor temperatures (Hien, Gabriela, Tan, & Jusuf, 2017).

Indoor climatic variables, such as natural day lighting, heat gain, and energy usage, have been linked to atrium design characteristics in previous research (Galal, 2019). These characteristics are mostly determined by climate conditions, which differ from one place to the next, and the atrium design should be built accordingly. The optimal atrium design offers the best indoor conditions by using the least amount of energy (Hussain & Oosthuizen, 2012)

Several studies have found that the location of an atrium within a building has an impact on energy usage (Fini & Moosavi, 2016), but the decision is made based on design factors and the space's function. Abuseif and Gou (2018) reported that the building's thermal performance is directly affected by design options for atrium roofs and skylights, while Abdullah and Wang (2012) claimed that modifying the roof form can improve atrium performance (Wang & others, 2012).

In a study conducted in cold areas, Laouadi (2002) found that the pitched skylight optimizes solar heat gain (Laouadi, Atif, & Galasiu, 2002). According to Mirrahimi (2016), atrium opening design has a significant impact on thermal behavior and airflow pattern (Mirrahimi, et al., 2016).

III.EVALUATION OF ENVIRONMENTAL CONDITIONS IN ATRIUMS

Atrium spaces are frequently stated to provide passive environmental benefits as well as energy-saving opportunities. (Li & Pitts, 2006), but their performance in a building is mostly determined by climatic conditions; nevertheless, architectural factors like the position of an atrium within a building play a vital role in determining the potential environmental benefit of the atrium's function. Four environmental elements are known to affect occupants' thermal sensibility in a building space: air temperature, air velocity, humidity, and mean radiant temperature. (MRT) (Li & Pitts, 2006). Air temperature, air velocity, humidity, and mean radiant temperature are all environmental variables that must be quantified to achieve ideal thermal comfort (MRT).

When, in practice, it is necessary to create simulated climates that offer individuals a thermally comfortable environment. Knowing the physiological comfort circumstances is, of course, insufficient

A. Physiological Comfort Conditions

All thermal environment assessments need a calculation of the occupant’s metabolic heat generation. (Olesen, 1995).

The human thermoregulatory system's purpose is to keep a relatively constant deep body temperature, which necessitates maintaining a heat balance in which heat lost to the environment equals heat produced by the body (Kenny & Flouris, 2014).

We're well aware that a person's thermal sensation is linked to the condition of his thermoregulatory system, with the level of discomfort increasing, increasing the load on the mechanisms. In the 1920s, Yaglou (Yaglou & others, 1927) discovered a link between skin temperature and the experience of thermal comfort; later and more comprehensive research by Gagge confirmed this (Gagge, 1937). In later studies (Gagge, Herrington, Winslow, and others, 1937), DuBois, Ebaugh, and Hardy (1952) found a link between thermal sensation and skin temperature, regardless of whether the participant was nude or clothed. For a long time, it was widely assumed that the physiological prerequisites for comfort were a person's average skin temperature of 33-34°C and the absence of sweating (or shivering). This was later confirmed in experiments by Fanger (1967) but only for sedentary subjects. It's worth noting that the visceral sensations associated with dripping wet clothing, sticky skin, and skin irritation can cause non-thermal discomfort by themselves. If the sweat secretion or the clothing's vapor diffusion resistance are both high, the skin can become quite wet.

Gagge (1937), the founder of theskin wetness idea, recommended that it be kept below 25%. (Gagge, Stolwijk, and Nishi, 1969a. The relationship between a person's thermal experience and his physiological reactions to fast environmental changes is undoubtedly complex, and further research is required before quantified physiological comfort criteria for thermal temperature variations can be established.

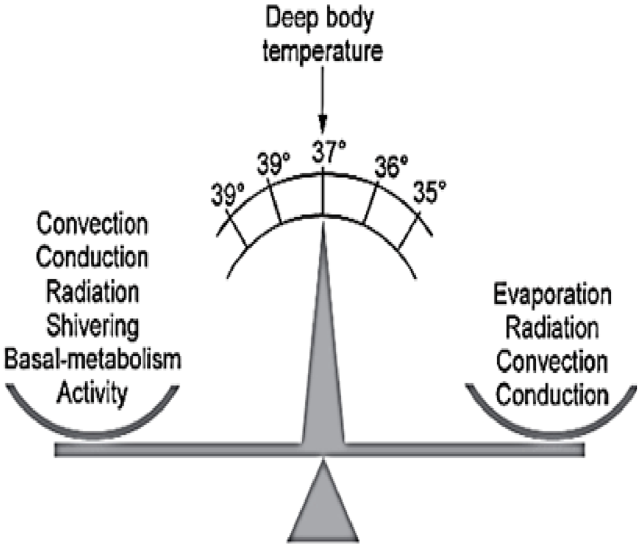

Fig. 2.Human Thermal comfort Source: Steve Szokolay

1. Physiological Genesis

The human body generates heat constantly. This metabolic heat generation can be of two types: basal metabolism, which occurs as a result of non-conscious biological systems, and muscular metabolism, which occurs when performing work and is consciously regulated (except in shivering) (Auliciems, Szokolay, & others, 1997).

Table 1 shows some typical metabolic rates, which can be expressed as power density, per unit body surface area (W/m²), as the power itself for an average person (W), or in a unit devised for thermal comfort studies, called the met. 1 met = 58.2 W/m²

The heat produced must be dissipated to the environment, or a change in blood heat will occur. The deep blood heat is about 37°C, whilst the skin temperature can vary between 31°C and 34°C under comfort conditions. Variations occur in time, but also between parts of the body, depending on clothing cover and blood circulation (Stephen, Mercy, Shanthi, & Joe, 2013). There is a continuous transport of heat from deep tissues to the skin surface, from where it is dissipated by radiation, convection, or (possibly) conduction and evaporation (Böer, 2012).

Table -1 Metabolic Rates at Different Activities (Auliciems, Szokolay, & others, 1997)

Activity	met
sleeping	**0.7**
reclining, lying in bed	**0.8**
seated, at rest	**1.0**
standing, sedentary work	**1.2**
very light work (shopping, cooking, light industry)	**1.6**
medium light work (house~, machine tool ~)	**2.0**
steady medium work (jackhammer, social	**3.0**
heavy work (sawing, planning by hand, tennis)	**up to 6.0**
very heavy work (squash, furnace work)	**up to 7.0**

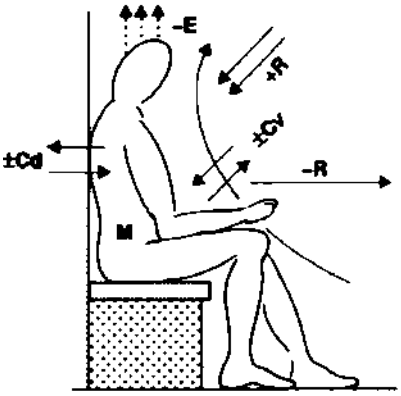

Fig. 3. Heat Exchanges of the human body (Auliciems, Szokolay, & others, 1997)

B. Environmental Comfort conditions in Atrium

The atrium is an open interior space that is theoretically connected to the outdoor environment, and it can have a favorable impact on the inhabitants' indoor environmental perceptions in addition to its impact on energy optimization (Nasrollahi, Abdollahzadeh, & Litkohi, 2018). Therefore, in practice, artificial climates are to be created which can provide thermal comfort for man. Detailed quantitative knowledge is required with combinations of the environmental variable which will result in optimal thermal comfort (Parson, 2014).

1. Human Thermal Comfort

According to Health and Safety Executive (HSE) (HSE 2016), the term 'thermal comfort' describes a person's state of mind in terms of whether he/she feels too hot or too cold. Environmental factors, such as humidity and sources of heat, wind, etc., combine with personal factors, such as clothing and work-related factors to influence the thermal comfort of feeling Health and Safety Executive (HSE 2016). The interaction of those factors makes the term thermal comfort difficult to define.

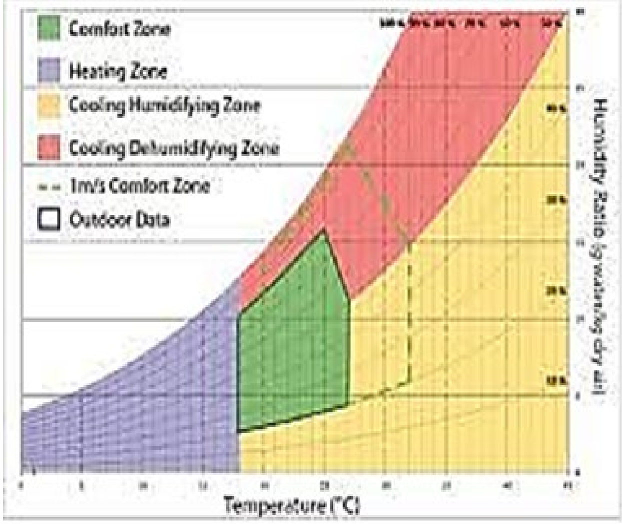

Fig. 4. Thermal Comfort Chart

Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation (De Dear & Brager, 2002) This indicates that the person is unable to decide whether he prefers a warmer or cooler atmosphere. It is also observed that the person's heat loss is not uniform. One of the key tasks of Design Engineers is to maintain this degree of thermal comfort for inhabitants of buildings or other enclosures. Thermally and in other ways, people are not the same, due to biological diversity, it will not be able to satisfy everyone at the same time if a group of people is subjected to the same room temperature (Taleghani, Tenpierik, Kurvers, & Van Den Dobbelsteen, 2013). As a result, the goal should be to provide the group with optimal thermal comfort, i.e., a comfortable atmosphere in which the majority of the group is thermally comfortable.

2. Comfort parameters for Indoor Environment

The thermal sensation experienced by occupants in a building space is known to be affected by four environmental factors - air temperature, air velocity, humidity, and mean radiant temperature (MRT).Sharmin in his study considered the variables that affect heat dissipation from the body (thus also thermal comfort) can be grouped into three sets (Sharmin & Steemers, 2020):

a) environmental: air temperature, air movement, humidity, radiation
b) personal: metabolic rate (activity), clothing

c) Contributing factors: food and drink, acclimatization, body shape, subcutaneous fat age, and gender state of health.

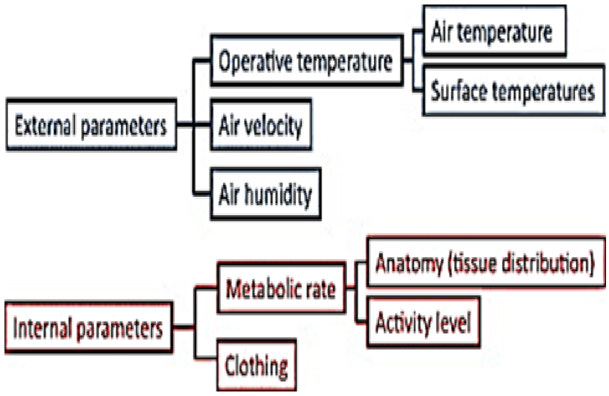

Fig. 5. Comfort parameters affecting the indoor environment

It is mandatory to work on comfortable physical parameters which are controllable and which constitute the thermal environment. Besides these environmental factors, man's comfort also depends on two more factors- activity level (internal heat production in the body) and thermal resistance of clothing. As suggested by Gagge, Burton, and Bazett (Gagge, Burton, & Bazett, A practical system of units for the description of the heat exchange of man with his environment, 1941) (Gagge, A new physiological variable associated with sensible and insensible perspiration, 1937) (1941), activity is often expressed in met-units (1 met = 58 W/m2 (50 kcal/m2h) and the thermal resistance of the clothing is expressed in clo-units (1 clo = 0 155 m2 °C/W (018 m2h °C/kcal)).

C. Psychological Parameters

The human thermoregulatory system's purpose is to keep a comfortable deep body temperature. The objective is to improve a thermal balance in which the amount of heat lost to the environment is equal to the amount of heat produced by the body. The most effective physiological mechanism for maintaining a thermal balance is found in humans. (Parson, 2014). Shivering or muscle tension increases internal heat production, whereas a change in the affected blood flow and thus the skin temperature changes sensible heat loss. Sweat secretion increases latent heat loss and shivering or muscle stress increases internal heat production. These systems are extremely efficient, and the heat balance is almost always maintained within the parameters of the environment. (Arens & Zhang, 2006). As a result, psychological factors such as a person's perspective have an impact on thermal comfort. (Auliciems, Szokolay, & others, 1997). Expectations concerning thermal comfort can be also achieved by asking the people in the place if they are pleased with the thermal environment or not and this can be done by using a thermal comfort checklist as suggested by Health and Safety Executive (HSE 2016), such as:

Does the air feel warm or hot?

Does the temperature in the place oscillate during a normal day?

Does the temperature in the place change a lot during hot or cold seasonal variations? etc.

This checklist makes it easier to determine whether there is a possibility of thermal discomfort posing a threat to the persons in the area. Standards can be used for extra measurement. If this checklist identifies an issue, it can be rectified by increasing a location's thermal comfort, hence thermal comfort is also examined as part of the risk assessment. (Burton, 2010).

D. Assessment of Indicators for Thermal Comfort level

Air temperature is the most often used indication of thermal comfort, according to the Health and Safety Executive (HSE 2016). It is simple to use and most people can relate to it. Air temperature, on the other hand, is not a reliable or accurate predictor of thermal comfort or stress. It should be weighed against other environmental and personal considerations at all times.

Fig. 6. Indicators of Thermal Comfort

The best one can aim for in terms of thermal comfort is a thermal environment that satisfiesthe majority of individuals sharing it, which isn't assessed by room temperature, but by the number of people complaining of thermal discomfort (Faria Neto, Bianchi, Wurtz, & Delinchant, 2016).Air temperature is the most common factor used by the Health and Safety Executive to assess risk; however, air temperature is not a reliable or perfect predictor of thermal comfort or thermal stress. It should be evaluated in the context of other environmental and human factors. As a result, both environmental and personal factors influence thermal comfort (temperature, Air, Humidity, Insulation, Metabolic). They may be independent of one another but jointly contribute to occupant thermal comfort.

E. Control Factors of Thermal Comfort

Health and Safety Executive (HSE 2016) has mentioned several controlling factors of thermal comfort by applying main control which can help create thermal comfort in the space such as;

1. Controlling of Environment (Separating source of heat or cold from the space)
2. Monitoring
3. Seasonal Design Strategy
4. Control by Management Systems

1. Controlling of Environment

The environment could be managed by exchanging hot air with cold air, or cold air with hot air, as the case will be. Humidity can also be controlled by humidifying or dehumidifying the air while enhancing the airflow by evaporative cooling or air conditioning. The Health and Safety Executive (HSE 2016) recommends separating heat-generating equipment by creating barriers that screen or insulate the atrium area and, if possible, redesigning the space to remove the emission source.

To regulate radiant temperature, a high-performance thermal envelope is provided (hot or cold surfaces). Even in very cold areas, an effective curtain wall or another wall system can eliminate the requirement for perimeter heating in big structures. The necessity for delivering heating and cooling to the exterior walls can be eliminated with well-insulated walls and windows (De Dear R. J., 2006).

Providing occupants with some influence over their local surroundings

When users have control over their environment, whether it's the option to open a window, adjust a temperature, or vary the airflow from a diffuser, they're more willing to put up with less-than-ideal conditions. This occupant flexibility can translate to reduced energy spent maintaining a fixed temperature set-point, as well as fewer mechanical systems in some circumstances (Karjalainen & others, 2008).

2. Administrative control by monitoring

Any viable solution for controlling thermal comfort is likely to be a combination of multiple alternatives developed in collaboration with users and their representatives.

The suggestion given by Health and Safety Executive (HSE 2016) should be incorporated by providing regular supervision for checking the factors at the scheduled time with the expert committee.

Planning and rescheduling work times and practices, as well as relaxation schedules, are examples of administrative controls. For example, scheduling 'hot' work for cooler periods of the day or allowing staff to work flexible hours can assist avoid the worst impacts of working in high temperatures.

3.Designing a control strategy

To lessen or eliminate the hazard, these should be the initial options. Even if the initial cost of engineering controls appears to be considerable, it has been discovered that the execution cost is generally offset by the production benefits that result.

Engineering controls could be implemented if the climatic conditions of the buildings were known. If correctly incorporated into building design, two sets of design strategies could give a solution for controlling indoor thermal comfort.

Seasonal Design Strategy

This technique entails designing seasonally based on exterior climatic conditions, which essentially regulates the opening percentage dependent on outdoor temps. When the outside temperature is cold in the winter, opening the windows will not increase the internal temperature; consequently, the building windows could be opened for a brief period.

In the summer, opening the windows improves air circulation in the building. The airflow inside the building will be determined by the placement of these openings. For weekdays and weekends, the building should always be open a few hours during working hours.

Ventilation Design Strategy

Previous research has shown that night ventilation has a significant impact on indoor temperatures. In the case of building fenestration, increasing the ratio between inlets and outlets increases interior thermal comfort, which is caused by high-pressure differences; thus, in naturally ventilated structures, the passive cooling strategy chosen with the applied methodology shall be for thermal comfort.

5. Comfort management systems

Human well-being cannot be attributed solely to the thermal environment, without regard for the other factors that influence indoor air quality. As a result, health, behavior, and productivity must be linked to the overall work environment: comfort requirements must go beyond mere thermal considerations (Auliciems, Szokolay, & others, 1997). All who achieve an appropriate balance between attaining maximum adaptation and habitually dwelling in comfortable environments of their choosing are likely to be physiologically and psychologically well-adapted (Hanna & Tait, 2015). Appropriate designs are those that provide amenities and settings that encourage physical activity while delivering enough thermal stimulus but are otherwise free of thermal stress during daily work and rest hours (Muhammad, 2014).

Adaptability-focused techniques, such as acclimatization, higher dependence on clothing variety, and reduced emphasis on active energy use, would foster a more harmonious synchronization between people's psycho-physiological functioning and the natural environment (Nrgaard, 1997). Variable indoor comfort ideas allow for more natural garment changes and minimize the average temperature differential between indoors and outdoors by about a third of a degree for every degree of the gradient. Such a decrease would suggest a 30 % drop in the demand for active energy usage for room heating and cooling, without sacrificing comfort, and with likely significant improvements in ambient air quality and human health (Mangum & Hill, 1977).

IV. DISCUSSION

This section demonstrates a method for determining thermal comfort. Natural forces are exploited to achieve environmental and economic benefits concerning the outer climatic conditions in a well-designed atrium; one or more passive design techniques can be used for this goal. Several efforts have been made as research on Man's Comfort conditions for Atrium, which has been confirmed. However, the understanding should be quantified so that the result may be used in practice.

When there is fluctuation, such as during temperature variations, it is a major issue to consider (including temperature and humidity fluctuations and sudden changes, for instance, when a person moves from outdoors to indoors).In this link, it is also essential to have an elucidation of the relationship between man's thermal sensation and the function of his thermoregulatory system, as well as more information about the fundamental studies that are required to have a clear study on age group and the need to confirm whether comfort conditions are applied equally to all age groups. Another research question is the potential impact of non-thermal environmental elements on man's thermal sensation. The effect of generating sound in an interior environment on a person's thermal feeling, as well as the psychological impact of the human mind, can be investigated further. Furthermore, research into the comfort circumstances of a person’s performance in various tasks is required.

V. CONCLUSIONS

Implementing building construction procedures that promote a healthy thermal environment would be a step forward in the construction industry's economic development. It would also be good to limit construction's negative environmental consequences and achieve thermal comfort indoors using three principles: energy efficiency, cost efficiency, and human adaption design strategy. They provide a framework for incorporating thermal comfort principles into building projects from the beginning. The framework has a lot of potential for accelerating thermal comfort design in the building industry.

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