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Significance of Thermal Comfort in Buildings and Its Relation to the Building Occupants

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Abstract. It should be pointed out that indoor climates in buildings is significant to the accomplishment of a building not only in making it comfortable, but also in deciding its energy consumption holistically and the thermal comfort of the occupants in the building. Thermal comfort can be defined as a psychological state of mind, often expressing a sensation of considerable heat or cold and it occurs when there is a balanced exchange of heat between a person's body and the environment, marked by the absence of regulatory sweating. Thermal comfort is imperative in both psychological and physical aspect where it could affects morale of the people. Based on their degree of thermal comfort, residents may complain, productivity may suffer and in some situations, people may refuse to work in a particular environment. This paper will discuss thoroughly the concept of thermal comfort, effects of thermal condition on occupants and some of the significant factors that influencing thermal comfort. In addition, thermal transition between the external environment and internal spaces of the buildings, human body interaction with surroundings and effective comfort range will also be presented to get a clear picture on how thermal comfort affects the building occupants comprehensively.

Keywords: thermal comfort; building occupants; human body; heat transfer; external environment.

1. Introduction

The term thermal comfort describes a psychological state of mind, often expressing a sensation of considerable heat or cold. In terms of bodily sensations, thermal comfort is the feeling of being cold, cool, slightly cooler, neutral, slightly warmer, warm, and hot. From a physiological point of view, thermal comfort occurs when there is a balanced exchange of heat between a person's body and the environment, marked by the absence of regulatory sweating.

According to Fanger (1973) there is no substantial statistical difference between women and men. It seen that the men skin temperature of thermal comfort is declining as the activity level increase as also shown by the negative correlation coefficient. Based on Fanger theory, there have 2 kinds of fluid loss by evaporation in the human body. Firstly from the latent. This is mean that the fluid loss comes from the latent respiration and vapour diffusion through the skin. The second way is active. This means that the through sweating.

Thermal comfort is important in both psychological and physical aspect. It also can affects morale of the people. Based on their degree of thermal comfort, residents may complain, productivity may suffer and in some situations, people may refuse to work in a particular environment. The factors of thermal comfort included heating, ventilation, air conditioning, and the activities of its occupants (Jones et al, 2007). Based on Nicol & Humphreys in 2002, a perfect indoor climate is important to the success of a building. It not only because makes its residents feel comfortable, but also because it affects the building's sustainability and energy consumption.

2. Effects of Thermal Condition on Occupants

According to previous studies, there are known effect of thermal condition on occupants which are decrease productivity and poor performance and health.

2.1 Decrease Productivity

Fanger (2005) reported that indoor air quality and thermal comfort have attracted growing attention as people increasingly spend more time in buildings. This is same like the hostel cafeteria. The indoor condition of hostel cafeteria can make people spent more time in the cafeteria. Based on Hao et al. (2007), displacement ventilation gives good indoor air quality although it creates a huge vertical temperature gradient that leads to thermal discomfort, which may result in decreased productivity.

A comfortable interior environment can be achieve through increase energy consumption. Rosenlund (2000) reported that productivity can be increased by 5% - 10% just by improving indoor air quality. If the productivity is decrease, the building can be categorized as the unsuccessful building. The productivity of the buildings is very important to help the buildings achieve its goal and objective. For example, if the number of students that used hostel cafeteria to having a meal, discussion or study decrease, the shops and the cafeteria lost its' function.

2.2 Poor Performance and Health

Performance is progressively reduced as more people occupy the same indoor building space with no personal means of regulating temperature. According to Heschong (2002), students with the greatest access to window areas or daylight obtain 7% to 18% higher scores than other students. This mean that the cafeteria also need open ventilation and open space so that the daylight can be move in the cafeteria. So that the students that study or having discussion at the cafeteria can have comfort situation for them. Fisk (2000) reported that indoor environments significantly influence human health in terms of allergy, asthma, respiratory illness, headaches and productivity.

Higher air temperature and humidity trigger behaviour actions such as fanning one's self, drinking cold water, wearing light-coloured clothes, increase fan speed, going out opening doors and windows and so on. Some people take this action to solve the problem of thermal comfort. Unfortunately, this action does not solve the thermal comfort problem. Instead, the solution comes from a proper understanding of how climatic factor (air temperature, relative humidity, air velocity, and globe temperature) work together.

An indoor environment can achieve satisfactory thermal comfort through natural ventilation. Based on Liping et al. (2007) reported two strategies to help the indoor environment achieve thermal comfort. Firstly is providing higher wind speed (more than 1m/s). This is to ensure the ventilation is good and suitable to people. Secondly is use of suitable designs, materials, and shading device. This is from the design stage of the building. We must make sure the designs is good, many open space and ventilation, the materials that have been chosen is good quality and not give negative effect to people and good shading devices. This technique can reduce indoor temperature by 2°C - 3°C.

A wind-catcher is an effective means of providing night cooling. Jones et al. (2007) reported that it can also function effectively as part of a natural ventilation system.

3. Factors Influencing Thermal Comfort

Properly researched internal design conditions can provide the best thermal comfort conditions for its occupants. These thermal conditions despite being subjective sensations are important elements of building design. Therefore, the aspects discussed below must be examine further to achieve optimum thermal comfort for building occupants.

3.1 Environmental Factors

For the environmental factors, there have 4 factors can affecting thermal comfort which are air velocity (V), relative humidity (RH), air temperature (Ta) and mean radiant temperature (Tr).

3.1.1 Air Velocity

Most of people are sensitive to air velocity. So the air velocity can become the important factor of thermal comfort. Still or static air in indoor environments that are artificially created may cause occupants to feel tired and uncomfortable. Air velocity can increase heat loss through convection without any change in air temperature, although when air temperature is lower than skin temperature, convective heat loss increases significantly. This can happen in warm or humid conditions. In addition with that, physical activity also can increase air movement (Liping et al., 2007).

According to Nicol (1993) the measurement of air velocity poses a number of problems due to air's erratic movement and direction. The optimum solution is to maintain a small sphere of measurement that can be kept constant in size and characteristics.

3.1.2 Relative Humidity

Relative humidity (RH) is the amount of moisture carried in the air, expressed as a percentage of the maximum amount that can be carried at that temperature (Parsons, 2003). Relative humidity also the ratio of the mole fraction of water vapour present in the air to the mole fraction of water vapour present I saturated air at the same temperature and barometric pressure. For the simple words is relative humidity s equal to the ratio of the partial pressure or density of water vapour in the air to the saturation pressure or density of water vapour at the same temperature. Prevailing humidity is a significant determinant of heat stress level, but plays only a minor role in thermal comfort.

3.1.3 Air Temperature

Air temperature (Ta) can be defined as the temperature of the air surrounding human body. Besides that, air temperature also is an essential factor in heat stress. It is representative of that part of the surrounding environment that determines heat flow between the human body and the air. According to Parsons (2003) and Randall (2005), air temperatures are uneven. Usually variations in temperature occur continuously among human bodies, and the temperature of the air cross the majority of the surface of the human body does not necessarily determine the limit of heat flow. Neither is air temperature very near a clothed body representative, because it is affected by "boundary conditions". For example, even in cold environments, a layer of warmer air encircles the body.

Air temperature is assumed to be the most significant climate factor affecting thermal comfort. However, other factor should be taken into consideration as well.

3.1.4 Mean Radiant Temperature

Radiant temperature (T_r) is heat transferred from a higher-temperature mass to a lower-temperature mass with no effect on the intervening space. According to ASHRAE Standard (55-1992), mean radiant temperature is the uniform temperature of an imaginary room or enclosure at which radiant heat transfer from the human body is balanced with the surrounding radiant heat transfer. The mean radiant temperature is defined by the ISO in relation to the human body, which is why spherical globe thermometers used to measure heat stress give a reasonable approximation of a seated person's body shape.

In an occupied space, the temperature of the floor, walls and ceiling may be very close to that of the air. Sometimes, radiant temperature is constant in all directions and essentially the same as air temperature. Similarly, in spaces with radiant floors or other forms of radiant heating, average radiant temperature exceeds air temperature during the heating season.

3.2 Individual Factors

There have 2 individual factors that can affect the thermal comfort. Clothes and activity are two individual factors that have significant correlation with thermal comfort.

3.2.1 Clothes

Human can control the exchange of heat between the body and its surroundings to a large extent though changes in clothing. Clothes can react as a barrier against heat transfer and reduce the sense of object difference in air temperature and velocity. According to the ASHRAE Standard (55-1992) on covered areas of the body, clothing acts as an insulator that slows down the heat loss from the body, enhancing endurance and comfort at lower temperatures. To know the level of thermal comfort of the place, information on the occupants' clothing must be obtained because the thermal resistance of their clothes provide heat transfer between the human body and the environment. Therefore, the "Clo" value is used as a numerical representation of clothing, and acts similarly to thermal resistance: 1 Clo = $0.155 m^2 KW^{-1}$. Evaporative resistance, meanwhile, is a measure of moisture permeability. It affects both latent heat transfer from the skin through the layer of clothing and evaporative heat loss from the skin surface. Based on Fanger (1973) , the interaction between activity and thermal aspects of clothing can be evaluated with reasonable precision by considering the usage of the room being occupied. Table 1 shows typical insulation values for clothing sets.

Table 1:

Typical insulation values for clothing

Garment description	Clo value	Garment description	Clo value
Bra	0.01	Pantyhose/stocking	0.02
Panties	0.03	Sandals/thongs	0.02
Men's brief	0.04	Shoes	0.02
T-shirt	0.08	Slippers	0.03
Sleeveless/scoops-neck blouse	0.13	Short shorts	0.06
Short-sleeve knit sport shirt	0.17	Walking shorts	0.08
Short-sleeve dress shirt	0.19	Straight trousers (thin)	0.15
Long-sleeve dress shirt	0.25	Straight trousers (thick)	0.24
Long-sleeve flannel shirt	0.34	Sweat Pants	0.28
Skirt (thin)	0.14	Sleeveless vest (thick)	0.22
Sleeveless vest (thin)	0.10	Short-sleeve short robe (thin)	0.34
Sleeveless vest (thick)	0.17	Short-sleeve pajamas (thin)	0.42
Long-sleeve Pajamas (thick)	0.57	Long-sleeve long gown (thick)	0.46
Long-sleeve Long wrap robe (thick)	0.69	Long-sleeve short wrap robe (thick)	0.48

(Source: ASHRAE standard – 55-1992)

3.2.2 Activity

The impact of metabolic rate on thermal comfort is critical. Human bodies continuously generate heat through metabolism, which is defined by the ASHRAE Standard (55-1992) as "the rate of energy production of the body" and is expressed in a standard unit called met. Physical work will produces heat, and the more heat we produce, the more we need to lose it in order to maintain a stable core temperature and avoid overheating. The average heat production by the body known as the metabolic rate. Metabolic rate is measured as 1 met = 58.2 w/m^2, and comprises all of the heat processes due to chemical reactions in the body. Table 2 shows typical metabolic rates for specific activities.

Table 2:

Typical metabolic rates for activity

Activity	**Met**	**w/m^2**
Reclining	0.8	46.6
Seated and quiet	1.0	58.2
Sedentary activity (office, dwelling, lab, school)	1.2	69.8
Standing, relaxed	1.2	69.8
Light activity, standing (shopping, lab, light industry)	1.6	93.1
Medium activity, standing (shop assistant, domestic work, machine work)	2.0	114.4
High activity (heavy machine work, garage work, if sustained)	3.0	174.6

(Source: ASHRAE standard – 55-1992)

3.3 Other Factors

In addition to human, individual and environmental factors, other factors influencing thermal comfort include acclimatization, diet, body build, and health conditions. According Fanger (1970) body build, that is, surface to volume ratio, has an effect o thermal comfort. Besides that, Koenigsberger et al. (1974) reported that age and sex influence thermal preference.

Huizenga et al. (2006) reported that aside from others factors affecting thermal comfort include acclimatization, age, sex, body form, health condition, fat stored under the skin, quality of activity an system diet. Rosenlund (2000) reported that when adapting to the climate of a specific region or to a new season in the year, changes in the metabolic system and blood circulation affect people's perception of comfort. In such times, older people adapt more slowly than the young, and metabolism rates decrease for women and increase for men (Griefahn et al. 2001).

4. Thermal Transition between the External Environment and Internal Spaces of the Buildings

Basically when solar radiation falls on the walls of a building, part of it is reflected back into the surrounding atmosphere, The other part is absorbed, increasing the surface temperature of the outer wall and merging with the indoor air of the building. In other words, heat is absorbed and transferred into the building via three process which is radiation, conduction and convection (Cowan 1980). Figure 1 shows the thermal transfer in space.

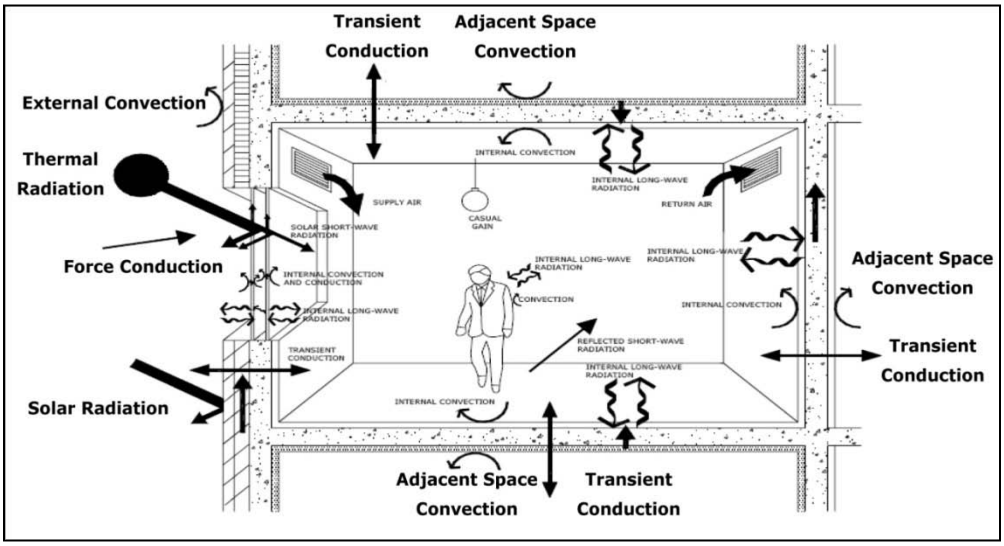

Figure 1: Thermal transfer in a space (Source: Energy Plus, 2009)

4.1 Thermal Convection

Thermal convection can be divided into two types. First, natural or free convection is the process whereby a fluid moves due to variations in its density. These variations result from temperature changes. Second, forced convection occurs when the liquid is moved by mechanical means, such as through pumps, fans, or the wind. In addition, heat can be transferred via convection from a surface to a liquid or surrounding gas, or vice versa.. If the exterior surface is at a higher temperature than the air, heat is transmitted from the surface to the neighbouring air via conduction, because of the alteration in the density of the heated air. This phenomenon cause attraction resulting from variations in the density of air currents; the impact of this trend on the movement of air temperature is much higher than if the air is completely motionless (Thomas 2006).

4.2 Thermal Conduction

The flow of heat through molecules from molecules with larger thermal energy to those with the least thermal energy is call thermal conduction. Nearly all heat exchange by conduction happens between the building frame and the ground, and this occurrence becomes most noticeable in very cold climates. According to Thomas (2006), thermal conduction is the transport of heat energy from the warmer part to the colder part of the same mass or from a wormer to a colder mass in physical contact with each other without displacement of the particles of the mass or masses.

4.3 Thermal Radiation

Thermal radiation can be both an external and internal process. Radiant heat refers to heat transfer through a vacuum of electromagnetic waves. Mossberg (2001) reported that buildings rely on the sun as their primary sources of heat gain. Actually, air temperature does not usually cause heat discomfort, but radiant energy from direct or indirect sunlight results in long infrared waves. Thus, the first function of defence against heat in building construction is to minimize surfaces affected by sunlight. The interior of the dwelling that is thusly heated tends to get very hot in the day, unless storage mass is supplied. Indirect solar radiation gain, for its part, occurs due to heat gain brought about by solar radiation absorbed by the building envelope and transmitted into the building by conduction, convection, or infrared radiation.

5. Human Body Interaction with Surroundings

Based on the Yao et al. (2007), thermal comfort is achieved when there is thermal equilibrium between the production of metabolic heat inside the body and wasted heat from the body through the mechanisms of convection, conduction, radiation and evaporation. When the person in thermal equilibrium, the person feels neither very cold nor very hot, although different people have different thresholds for warmth or cold. That why some people may feel comfortable whereas others feel uncomfortable in the same environment. Still, humans usually respond similarly to varying environmental conditions.

Heat production due to metabolism depends primarily on activity. Therefore, engaging in increased physical stress leads to increased metabolic heat production within the body. The amount of heat virtually transferred by several mechanisms of movement is affected by a number of factors, such as convection, radiation, conduction, and evaporation. Behavioural factors, such as activity level and clothing selection, also affect this process, as do environmental factors, such as air temperature, mean radiant temperature, relative humidity, and air velocity.

5.1 Internal Body Temperature

The normal body internal temperature for the human is 37 °C, with a range of 36.2 °C– 37.5 °C. Yao et al. (2007) assigned temperature between 37.5 and 38.0 °C as "the territory of fever" and temperatures greater than 38.0 °C as fever. Actually body temperatures are evaluated based on specific reference group's characteristic normal range. Figure 2 shows the heat exchange from a body to its surroundings.

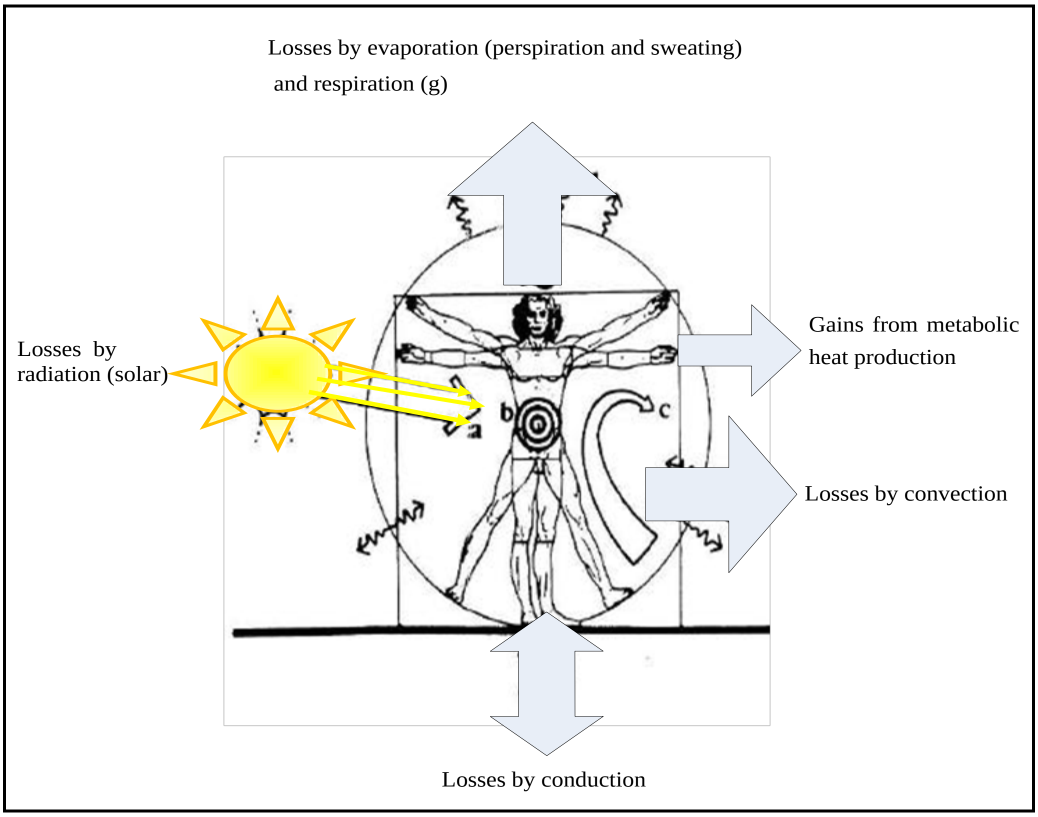

Figure 2: Heat exchange from a body to its surroundings (Yao et al., 2007)

5.2 Thermoregulation

Thermoregulation is the human ability to keep one's body temperature within assured boundaries despite the surrounding temperature. According Tanabe et al. (2002) the thermoregulation system consists of four control processes which are vasodilatation, vasoconstriction, perspiration and heat production through shivering. Thermoregulation is an important autonomic response, with fast changes in the environment leading to immediate physiological responses (Parsons, 2003). The body's thermoregulatory system emits heat through the body, which in turn warms the blood. Meanwhile, the surrounding clothing preserves a homeostatic temperature. Thus, body temperature is the sum of heat production and heat loss. The hypothalamus located in the brain is the body's thermostat; it continually adjusts the body's temperature using the nervous system's pathways to maintain the set point of approximately 37 °C.

5.3 Evaporation

Usually human sheds heat by water evaporation through the skin at low surrounding temperatures. Based on Cena and Clark (1981), evaporative heat loss depends on the body's capacity to secrete sweat, and on the physical properties of the environment.

5.4 Sweating

When body temperature rises, sweat is excreted from the skin to allow by evaporation. There are two types of sweat glands. First is vestigial apocrine glands are found in the ampits and pubic regions and are responsible for the characteristic smell of these areas. Second is the eccrine glands are distributed all over the body. (Parson, 2003)

6. The Effective Comfort Range

Nicol and Humphreys (2002) reported that acclimatization to thermal comfort can potentially narrow the actual temperature required to achieve comfort to $\pm$ 2 °C. In cases where these acclimatization opportunities are obtainable and suitable, the comfort zone may be much wider.

6.1 Heat Balance

Heat transmittance among people in an enclosed environment can be formulated to establish the activity level. Heat that produced by human either raises body temperature or is transferred to the surroundings directly through the skin or through perspiration. According to Parsons (2003), there have three conditions are necessary for a person to enjoy whole-body thermal comfort which are body heat balance, sweating rate within comfortable limits and mean skin temperature.

6.2 Thermal Comfort Requirement

Each building must meet thermal comfort requirements for human occupancy. According to Muncey (1979), to evaluate human comfort, the temperature of the air and surfaces within the building should assessed and relative humidity must be kept between 30 % and 70 %. These measures reduce the risk of distastefully wet or dry skin, eye discomfort, stable heat, microbial growth, and respiratory sickness. If the environmental conditions are within the bounds of comfort, more than 80 % of the residents will find the thermal conditions acceptable. According to Olesen and Brager (2004), there are two methods of estimating comfort requirements: one involves a resident survey, and the other involves environmental variables that delimitate comfort conditions.

6.3 Comfort Zones

Comfort zones means it can provide an acceptable thermal environment for occupants wearing typical indoor clothing and performing near-sedentary activities. Usually a thermal environment is considered acceptable for occupancy when at least 80% of the occupancy find the area thermally acceptable. Humans regulate their body temperature through circulation of blood, excretion of sweat (perspiration), shivering, and other physical manifestations. The idea temperature for internal tissues is 37.2 °C (Aouf Abed Rahim Said, 2000). However, although thermal equilibrium is essential to human life, it is insufficient for thermal comfort.

Establishing a clear and specific definition for the concept of thermal comfort is difficult. Relating ultimately to a sense of personal well-being, thermal comfort refers to the acclimatization of a person to his or her surroundings, and the maintenance of thermal balance between the body and the environment while considering other factors, such as sex and age. There is no similar method for regulating an occupant's clothing or metabolism, which explain why two people sitting next to one another may perceive significant difference in temperature. Nevertheless, most people do not feel thermally comfortable within a narrow temperature range between 18 °C – 26 °C and with relative humidity between 30% – 60%. The range of thermal comfort is a combination of various factors. This including air temperature, radiation temperature, relative humidity and air speed at which the majority of the people feel a sense of total comfort and satisfaction. If a person is unable to determine the climatic to be either cool or warm it called the sense of thermal comfort. This range, known as neutral thermal to a certain group of people, depends on the following : acclimatization, quality of clothing, and activity. Furthermore, the thermal comfort zone is contained within the thermal equilibrium in the narrow limits of the components' interaction, which in turn, consists of climatic elements affecting the thermal exchange between the climate and humans.

7. Conclusion

Thermal comfort describes a person's psychological state of mind and is usually referred to in terms of whether someone is feeling too hot or too cold. Thermal comfort is very difficult to define because you need to take into account a range of environmental and personal factors when deciding what will make people feel comfortable. These factors make up what is known as the 'human thermal environment'. People working in uncomfortably hot and cold environments are more likely to behave unsafely because their ability to make decisions and/or perform manual tasks deteriorates. Thermal comfort is related to the daily lives of humans; it is a condition that results from the complex interactions of the human body with the surrounding air. Thus, reaching a balance in temperature is important in maintaining an optimum level of comfort.

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Значение температурного комфорта в зданиях и его влияние на жителей

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Аннотация. Нужно отметить, что внутренний климат в зданиях важен для здания не только с точки зрения комфорта, но и для энергопотребления в целом и для температурного комфорта жителей. Температурный комфорт можно охарактеризовать как психологическое душевное состояние, часто определяющееся ощущением жары или холода. Оно наступает, когда существует сбалансированный обмен теплом между организмом человеком и окружающей средой, характеризующееся отсутствием регулятивного потоотделения. Температурный комфорт обязателен как в психологическом, так и в физическом понимании, когда он может влиять на моральное состояние человека. В зависимости от уровня температурного комфорта, жители могут жаловаться, может страдать их продуктивность, а в некоторых ситуациях, они могут отказываться работать в определенном климате. В данной статье тщательно исследуется понятие температурного комфорта, влияние температурных условий на жителей и некоторые важные факторы, которые влияют на температурный комфорт. Кроме того, тепловой обмен между внешней средой и внутренним помещением зданий, взаимодействие человеческого организма с окружающей средой и эффективный диапазон комфорта также представлен в работе, с целью получения ясной картины влияния температурного комфорта на жителей.

Ключевые слова: температурный комфорт; жители дома; организм человека; транспортировка тепла; внешняя среда.