Journal of Building Engineering 3 (2015) 104–113

Contents lists available at ScienceDirect

Journal of Building Engineering

journal homepage: www.elsevier.com/locate/jobe

Role of building material in thermal comfort in tropical climates – A review

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ARTICLE INFO

Article history:
Received 28 March 2015
Received in revised form
27 June 2015
Accepted 28 June 2015
Available online 4 July 2015

Keywords:
Thermal comfort
Building material
Energy conservation
Health risks
Productivity
Climate change

ABSTRACT

Changing climatic scenario and raising temperature is likely to subject nearly 60% of the working populations in India to thermal discomfort in their workplaces. Half of the total energy produced in the developed world is used to heat, cool, ventilate and control humidity in buildings, to meet the increasing thermal comfort demands of the occupants. Indoor workplaces many times cannot offer thermal comfort to workers attributable to the location, processes involved and resource constraints that may pose a negative effect on worker's health, their ability to function effectively and also on their work productivity. In most situations, mechanical cooling devices offer solutions that are neither environment friendly nor energy sustainable. These mechanical devices are non-functional and cannot offer thermal comfort without energy input. Hence utilization of advanced building materials and passive technologies in buildings may offer the solution for thermal comfort demands, substantially reduce the energy demand, impact on the environment and carbon footprint of building stock worldwide. This also could offer a sustainable solution in the context of predicted raising temperatures and constraints in energy availability especially in the developing world. The review particularly identified certain materials such as VIPs, PCMs, ACC, polymer skin, with good thermal properties with a potential to be incorporated in different parts of the building envelope to enhance thermal comfort. Light colored external surfaces, reflective paints, window treatments and roof gardens are also discussed as preferred options to help reduce the heat load of the building.

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1. Introduction

Buildings are large consumers of energy in all countries, especially in regions with extreme climatic conditions and a substantial share of the energy goes towards heat and cool buildings. Though there are multiple ways of reducing the heat and air-conditioning load in the buildings, notable among them are proper design and selection of building envelope and its components. The increase of the thermal loads in the building is primarily due to the arrival of office computers and lighting requirements that has made the installation of air conditioning systems necessary to neutralize these loads and to create a comfortable indoor thermal environment. The new European energy regulation now considers a high standard of thermal

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http://dx.doi.org/10.1016/j.jobe.2015.06.003
2352-7102/

protection in buildings with reasonable energy consumption, satisfactory thermal comfort conditions and low operational costs [1]. American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 55 defines thermal comfort as "that state of mind which expresses satisfaction with the thermal environment." It involves the well-being of the occupants in a particular environment for a particular climate about their capacity to adapt to thermal equilibrium, physiological, psychological and behavioral changes [2]. Thermal comfort is dependent and influenced by a range of environmental factors viz. air temperature, radiant temperature, humidity, air movement, metabolic rate or human activity, clothing [3,4] and other personal factors such as; metabolic heat, state of health, acclimatization, expectations, and even access to food and drink [5].

Hot indoor thermal environment at workplaces may lead to a range of to heat related symptoms or illnesses like heavy sweating, weakness, dehydration through sweating, low blood pressure, salt imbalance leading to sharp muscle pain or cramps, fainting or reduced mental ability and even death [3] and could be aggravated/influenced by high metabolic work load, radiant and air temperatures or relatively impermeable protective clothing [6–9].

Numerous studies across the world have shown the impacts of hot working environments on the working population [10–15]. In the context of climate change, and in the view of predictions made by Intergovernmental Panel on Climate Change (IPCC) [16–19], the rise in temperatures across the globe is further expected to adversely affect the thermal comfort in the work places, health of the workers, consequent productivity losses and other related issues. Planning ahead of time to protect the workers from the future risks of Climate Change and implementing protective measures is one of the adaption strategies that is needed at this juncture.

The Health and Safety Executive (HSE) previously defined thermal comfort in the workplace, as "roughly between 286.1 K and 303.2 K (13 °C and 30 °C), with acceptable temperatures for more strenuous work activities concentrated towards the bottom end of the range, and more sedentary activities towards the higher end". The thermal comfort of occupants in workplaces is their well-being in a particular environment for a particular climate with their ability to adapt to the thermal equilibrium, physiological, psychological and behavioral changes [20]. Environmental thermal stress imposes health and productivity consequences in the occupants' especially working individuals [21,22]. According to the study conducted by Nag et al., in 2011, 80% of the occupational groups in India exposed to higher indoor temperatures reported excessive sweat, thirst, tachycardia and dryness of mouth, 70% reported feeling of elevated body temperatures and 33% reported reduced urination and itchy skin. Thermal discomfort shall also impair a person's ability to do physical and mental work [23] with consequent reduction in worker productivity. In the United States, from 2008 through 2010, 99 deaths related to environmental heat stress were recorded by the US Bureau of Labor Statistics (BLS) Census of Fatal Occupational Injuries (CFOI). Thermal discomfort includes thirst, fatigue, and decrements in vigilance, visual tracking, response time, short-term memory, and auditory discrimination [24–26]. The results of a series of studies (1919–1927) by Vernon's [27] in hot manufacturing industries like glass, steel, tinplate and munitions as well as coal mining clearly indicated a decline in work rate/output and increased accident rates with increasing temperatures that is substantiated by observations made by Weston (1922) [28] in the linen weaving industry [3]. In tropical settings and hot regions, the issue of heat stress is a much bigger problem in terms of thermal comfort and heat related deaths and illnesses [29,30], that especially affects working population who have physical exertion [17,22,23,31].

The HSE, 2005 has stated that "engineering controls should be the first choice to reduce or eliminate such hazards" [32]. Although the initial cost of engineering controls maybe high, it has been found that the implementation cost is often offset by the resulting improvements including better working environment, workers' health, reduced productivity losses and sustainable economic growth. To offset the hot working environment and provide thermal comfort to the workers, many workplaces have installed mechanical devices including air conditioners, fans and various kinds of ventilation devices that are energy intensive, costly to maintain and are operational with only electricity. Earth Tube Heat Exchanger System Coupled to a Space Model has been used to Achieve Thermal Comfort in Rural Areas [33] which could make a sustainable and energy efficient solution, but it applicability in large work spaces is yet to be tested.

Buildings by itself can contribute to thermal discomfort and if this is not addressed while choosing materials for its construction and applying them appropriately in the design stage (apart from the location and orientation of the building), the issue of thermal comfort could be costly to handle at a later stage. A sustainable option is still debated and have not be widely used is a passive method to achieve energy efficiency and thermal comfort, that could be in the materials that are used to build the buildings itself. Use of eco-friendly and low thermally conductive building materials for living spaces/work places while at design and construction stage shall offer a sustainable solution to address the problem of heat stress due to Climate Change depending on the choice of materials and the intended use of the building space.

In recent years, the concept of green buildings has emerged that primarily aims to use eco-friendly materials and reduce the resource usage including energy demand that is gaining focus in the western world. In developing country setting and tropical regions, traditional knowledge in use of eco-friendly and thermal resistant building materials has been passed on through generations which are being practiced in rural areas. But many workplaces have not been able to adopt the practices as a solution to address the issue of thermal comfort for various reasons. Eco-friendly materials used for construction such as bamboo, straw, timber, grass, linoleum, sheep wool, panels made from paper flakes, compressed earth block, baked earth, rammed earth, clay, vermiculite, flax linen, sisal, sea grass, cork, expanded clay grains, coconut, wood fiber plates etc. are both natural materials and also reduce the energy usage within buildings [34–36]. To benefit from the use of these materials in building, however, one needs to check their material properties like specific heat, thermal conductivity, transmissivity and heat transfer coefficients (for convective and irradiative surfaces) to ensure their fair thermal performance and load bearing properties in the building envelope. The present review focuses on materials used in green buildings and other materials, compounds or molecules that have the properties to respond to heat and may be incorporated into the workplace built environments itself to provide thermal comfort to its occupants that will have positive health and productivity consequences.

2. Factors influencing thermal comfort of building

The thermal comfort of a building in addition to energy saving is influenced by various factors, including the thermo physical properties of the building materials, building orientation, ventilation, building space usage and integration of modern and passive energy saving technologies. The envelope of a building is not only a separator from the external environment but also a protection from climatic elements affecting the building directly [37]. The internal thermal comfort is dependent on the properties of the building materials used and that are affected by the external temperature and humidity [38]. Heat and cold can enter the building through transparent and translucent materials, windows