

STUDY FOR DEVELOPMENT OF PASSIVE EVAPORATIVE METHOD AS AN AFFORDABLE COOLING MEASURE IN HOT CLIMATE

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Name

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AS AN AFFORDABLE COOLING MEASURE IN HOT CLIMATE

(暑熱気候における affordable な冷却手法としてのパッシブ蒸発手法の開発に関する研究)

Title

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Category

論 文 内 容 の 要 旨

Thesis Summary

In the 21st century, rapid urbanization and rising technological advancement have led to a huge increase in energy consumption. Rapidly growing energy demand worldwide has increased concern over depletion of conventional energy sources, increase of energy cost as well as associated adverse social and environmental impact such as global warming, climate change, ozone depletion, etc. According to the Intergovernmental Panel on Climate Change (IPCC), the building sector is the second largest energy-consuming sector after industries. A large part of energy in buildings is consumed for space cooling. Conventional heating, ventilation, and air conditioning (HVAC) systems used for space cooling consume a huge amount of electrical energy and also responsible for harmful greenhouse gas (GHG) emissions. Therefore, to mitigate this rising energy consumption and corresponding environmental hazards, researchers and building energy engineers are aiming towards passive techniques for space cooling. Passive evaporative cooling is one of the most effective and ancient passive techniques to cool a building by spraying water over the roof or walls. Its simplicity and low cost make it suitable for economically lower class people who can't accommodate expensive passive techniques. Besides, in several developing countries such as India, many people still belong to an economically lower class who can't afford to buy an air conditioner during harsh summer conditions. The low-cost buildings of these people also lack proper architectural standards such as insulation, shading, glazing, etc to be protected from direct heat gain. An inexpensive technique like passive evaporative cooling can be the best alternative for space cooling in such types of buildings. Therefore, keeping in mind both the energy crisis and low-cost alternative of space cooling this thesis aims to develop an efficient passive evaporative cooling technology that can be used to improve the thermal comfort condition of low-cost houses of India.

In the first chapter background study about passive cooling and its need in India is carried out. The objectives of the thesis are outlined.

The second chapter provides a summary of various passive cooling techniques employed to mitigate the thermal load and increase the thermal comfort of the buildings. The past and recent research on passive evaporative cooling are reviewed thoroughly. The advantages and challenges of passive evaporative cooling are studied through case studies. It is concluded that the main problem associated with passive evaporative cooling is the heavy water consumption, which causes concern for its use in arid or semi-arid regions. Secondly, there are no proper guidelines in terms of water requirement or spray rate to implement the roof spray cooling technique in different climatic zones. Also, there is a lack

of proper simulation tool to evaluate the performance of passive evaporative cooling before recommending it to any type of building or any type of climatic region.

At the beginning of the third chapter, the thermal modeling techniques of passive evaporative cooling are reviewed. It is observed that the existing methods of modeling heat and mass transfer from the wet roof are of two types. In one approach simultaneous heat and mass transfer are considered through the whole roof slab, which makes this method very complex and computationally expensive. Another method models the evaporative heat transfer from the wet roof surface in a similar way like heat transfer from the water surface by assuming the roof to be always completely wet, which is rather unrealistic. Therefore in this study, a simple numerical model is developed based on the field measurement done previously by Koji Tsukimatsu (2001), in which the transient evaporation from the wet roof just after the water spray is expressed as a function of dynamic variation of moisture content of the roof surface layer. This model is validated against the results of the previous experimental data. Numerical simulation is then carried out using this new model to investigate the effect of roof spray evaporative cooling. It is concluded that a low spray rate as 0.125kg/min.m^2 is enough to cool a building with concrete or asphalt sheet roofing, as the excess amount of water beyond the water holding capacity of roof material will be just wasted.

The fourth chapter is devoted to the development of a new simulation tool based on the numerical model developed in chapter 3 to analyze passive evaporative cooling. At first, it addresses the limitations of the existing building energy simulation tools such as TRNSYS to model passive evaporative cooling. Then a new simulation tool has been developed combining MATLAB and TRNSYS utilizing the concept of 'wrapper' or 'adaptor'. The performance of this new simulation tool is then tested by comparing it with the original TRNSYS model for a dry roof condition. Finally, the application of this new simulation tool has been explained with a case study of New Delhi, India.

Chapter 5 carries out the Sensitivity analysis of the developed intermittent roof spray cooling technique in low-cost houses of India through numerical experiments. First, eight major metropolitan cities of India are selected for the case study based on the population and the number of low-cost houses. Next, the annual thermal load of a simple low-cost building located in the climatic condition of these cities is estimated using the new simulation tool. Then the effectiveness of the roof spray cooling technique in all the cities has been analyzed in terms of reduction in discomfort degree hours. The regression equations have been then developed to estimate the daily water consumption from the data of daily average ambient temperature depending upon the climatic condition. The results of this chapter serve as a guideline in terms of water requirements and the number of water sprays needed per day to implement the roof spray cooling for the climatic condition of any Indian city.

In chapter six, the field experiment is carried out to validate the low flow rate established in the third chapter, and the results predicted by simulation in the fourth chapter. A water supply system with an ordinary low-cost irrigation pipe to provide a stable flow of water at a low flow rate is installed. The minimum flow rate possible by the pipe is measured manually to be 0.18kg/min . The evaporative cooling effect of this low flow rate on a calcium silicate board which is widely used as a building material is investigated experimentally. The whole surface temperature before, during, and after the water, the spray is measured using an infrared camera at regular intervals. It is concluded that this low flow rate is sufficient to cool the surface effectively and uniformly. Therefore, roof spray evaporative cooling can be effectively implemented in arid or semi-arid climates, where water supply is limited. In the seventh chapter results of each chapter are summarized and future recommendations are outlined.