Applied Thermal Engineering 60 (2013) 218–224

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

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

# Analytical model for double skin roofs

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ARTICLE INFO

Article history:
Received 18 January 2013
Accepted 28 June 2013
Available online 8 July 2013

Keywords:
Passive ventilation system
Heat discharge system
Analytical model
Double roof

ABSTRACT

In the current study, an analytical model is proposed that describes the thermal behavior of a heat discharge system in roofs. To validate it, an experimental prototype is used which has been tested by exposure to the sun and the measured results compared with the predicted values from the analytical model proposed by the authors. The results show that the thermal performance of the system can be appropriately determined and described by the analytical model, within a small margin of error. The proposed analytic model can calculate the behavior of a heat discharge system in roofs by defining the system dimensions for the environmental conditions of the location where it is to be used.



## 1. Heat discharge systems

Among the passive systems that are available at present, we have heat discharge systems (HDS), which are systems that allow absorbing the heat flow surrounding a building, which could cause an increase in the temperature of the interior air, and unloading it into the environment and in this way obtaining close to thermal comfort conditions inside a building. The HDS can be classified according to its placement in the building and can be a wall HDS or a roof HDS. The HDS in roofs can be applied in different climatic conditions; what is important, is to consider the interaction of these systems and the environment with the building to control climate which is why it is very important to consider their design. The HDS is formed by two parallel plates; one of them is glass which protects the other plate (for example aluminum) that is mounted on a wall or roof, forming a channel where air circulates. In the day, the sun's rays impact the aluminum plate (aluminum plate mounted on a roof) which, due to its absorption characteristics, thermal conductivity and thermal storage modifies its temperature and because of its thermal capacity, becomes an accumulator of heat. This stored heat is transmitted to the air that is introduced into the system by the channel causing natural convection. This air can be introduced into the interior of the construction to heat it or can be expelled to the exterior providing ventilation inside the construction, propitiating an ambient temperature near to the area of comfort. Nowadays, these systems are designed based on the availability of the area that has the space where it is going to be used and occasionally it does not supply the enough airflow to remove the thermal load from the space to protect. If HDS is designed based on the volume of room air, it is capable of doing enough natural ventilation [1]. In the night and depending on the atmospheric transparency, the aluminum board can present radiative cooling that is given in absence of the solar radiation in form of a radiant flow (infrared). If during the night it is necessary to diminish the temperature of the interior of the room, it can take advantage the cold generated in the aluminum plate to cool air that is introduced to the interior of the room to acclimatize. Depending on the materials with which it is made, the HDS in roofs can be classified in two ways: those that make use of opaque surfaces and those with one clear and one opaque surface.

## 2. Antecedent

There is an ample literature on the topic. Studies have been carried out to learn the behavior when varying the type, thickness, spacing and the number of materials that conform the HDS in roofs, as is the case in Sodha et al. [2] presented a theoretical study of the effect of a metal sheet in the middle of the hole formed in a lightweight concrete slab, one side of the slab is exposed to solar radiation and ambient air another is in contact with the room air at a constant temperature. Optimum distribution concrete thickness on the inside and outside to a leveling maximum thermal load is obtained, it is seen that this is achieved when the thickness of the outer surface of the concrete is as small as possible. These results

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http://dx.doi.org/10.1016/j.applthermaleng.2013.06.057

were also compared to the corresponding results in hollow concrete slabs single and double hollow.

Jiang He et al. [3] have a house that was designed based on the local climate, building materials using own the place. Design includes double and triple wall ceiling in order to reduce heat gain in the interior. The results for a year to monitor the behavior of the housing are presented.

A. Dimoudi et al. [4], compared to the two roofs summer weather, of which one of them had a ventilation space that could be changed between 6 and 8 cm. Obtained a more suitable temperature and the inside of the housing using the air space.

Risto Kosonen [5] observed as natural ventilation flow can be generated with a ventilated roof system can be employed to reduce the pollution occurs in a kitchen.

M. Hadavand et al. [6] studied the vaulted roofs to the flow of wind and solar radiation flux. In addition, heat transfer observed from ceiling to floor.

As for formulation and application of analytic models, Sodha MS, et al. [7] had a theoretical study, deriving an explicit expression of the periodic variation of the heat flow through a hollow multilayer insulated roof which has a face exposed to the solar radiation and ambient air another is in contact with the room air at a constant temperature. For optimal placement of insulation and spacing, numerical calculation is made of the heat flux through the roof multilayer insulated hollow for a typical hot day (May 26, 1978) in Delhi. Here it is seen that for a given total thickness of concrete, the best stored thermal load leveling, when the outer layer is as small as possible. Also discusses the effect of a film of hot water flow within the building.

Nelson and Wood [8] presented a numerical study of the combined transfer of heat and mass, natural convection fully developed flow between parallel plates inclined with boundary conditions symmetric and asymmetric. The fluid motion is generated by the buoyancy effect due to the difference of temperatures and concentrations between the channel and the fluid. The results show the correlations of the local Nusselt and Sherwood numbers for both walls.

Palomino [9] presented a numerical study of natural convection for a roof solar radiation shield inclined, for two types of boundary conditions: constant temperature and constant heat flux. The model was solved for the region near the upper plate of the channel, where the equations are determined by the finite difference method to obtain the velocity and temperature profiles. The two-dimensional model results when compared with experimental results of Al-Arabi (1969) under conditions of constant temperature, of Vliet (1979) under conditions of constant heat flux, there is a maximum difference of 12%, which validates the solution and the possibility of using the correlations of boundary layer on walls and ceilings shield.

Zhai et al. [10] propose two analytical models for HDS in ceilings, where the heating is one-step and two step when compare both systems and get a difference of 10 percent of the double-pass system with respect to a step.

In the experimentation, Shih Jason and Fairey Philip [11] presented an experimental study on ventilated walls and ceilings "cold house", they consist in bringing additional covered walls and ceilings between the traditional surround the building and the outside environment, the deck is separated the building envelope to allow circulation of air. The purpose of this construction is to eliminate or drastically reduce the effects of solar heat load in the building envelope. Therefore, the authors presented recommendations for the design of new buildings and the retrofitting of existing structures.

Samano et al. [12] presented a study, experimental and theoretical, airflow within the cavity formed by the arches are built with roofs of cubicles Energy Research Center in Temixco, Morelos, this cavity is kept ventilated to download it receives heat from the roof top plate due to solar radiation. We present the results of the analytical approach, tables and graphs of the measurements made on the prototype and weather data temperature, solar radiation and relative humidity where the study was developed.

Morales [13] presented theoretical and experimental study of the roofs of the stalls of the Solar Energy Laboratory, beam and vault constructed. In this system, the upper plate of the roof is in contact with solar radiation and ambient air periodically, and bottom plate (which forms the ceiling) is in contact with the air inside the cubicle. Between the plates allowing air circulation to achieve heat discharge. Morales introduced heat flow analysis and a numerical study to determine the temperature and air velocity within the channel, and the charts and tables of the measured temperatures at different points in the system.

Morillón et al. [14] present experimental results of a double top, as a shield to solar radiation in a room for the summer weather in Guadalajara, Jal. The results allow comparing the effect of damping shield roof internal temperature, and the impact of natural ventilation on thermal comfort conditions, and the effect of heat gains obtained through a window by its orientation in the internal temperature.

A. Dimoudi et al. [15] carried out an experimental study with a roof made up of roofing, thermal insulation, air space and concrete for the winter in Greece and Chi-ming Lai et al. [16] varied the spacing among panels as well as the inclination of the plates that simulated a double roof, to learn the correct spacing.

From the previously mentioned background, it can be said that the analytical models found do not contemplate the temperature of the air in the interior of the building to be ventilated and the heat storage set in the aluminum plate. In the first case, they consider that the space to be adapted has an air entrance from the environment and that it is enough to replace the system exiting hot air and in the second case, the topic is avoided because of its scope or because it is considered that the air carries all the heat from the internal plate. Based on the former problems, we propose an analytical model that considers both, room temperature, difference from the environmental, (because at the beginning of its function the internal temperature is higher than the environmental) and the heat storage in the storing plate.

## 3. Theoretical foundation

The analytic model considers that the solar radiation and environmental temperature vary with time, and the form of calculating them is as follows:

### 3.1. Solar radiation G

To determine the solar radiation values that require the analytical models described in this document, the ASHRAE [17] method is applied as follows:

The solar radiation that falls over a surface can be calculated with:

$$G = G_{\max}\cos\theta \tag{1}$$

where $G_{\max}$ is the maximum value of solar radiation that falls over a surface and it is calculated with:

$$G_{\max} = 950\left(1 - e^{-0.075h}\right) \tag{2}$$

where:

$$h = arc\sin\left[(\cos\Phi\cos\delta\cos\omega) + (\sin\Phi\sin\delta)\right] \tag{3}$$