Airflow and temperature modelling of sustainable buildings at the design stage can prevent unintended consequences of passive features

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Abstract

The integration of passive features during the design/construction of sustainable buildings requires thorough modelling at the design stage as some features may have unintended consequences resulting in occupant dissatisfaction, and resulting in the building using more energy to maintain comfort. This paper reports the outcome of an investigation into the thermal performance of a recently built ‘sustainable science building’ in a school located in South Australia. The building consists of a 115 m² atrium which is naturally ventilated by a solar chimney integrated into a high pitch roof with low level and celestial window openings at the outlet of the chimney.

The experiment was undertaken in January to monitor the airflow pattern and air temperatures at different location of the atrium. A mathematical model was used to predict the performance for comparison with experimental data.

At some hours, it was observed that flow reversal in the chimney led to unwanted hot air entering into the building thus increasing the building cooling load. The model was able to predict the flow reversal at those times. The use of such a model at the design stage can help develop an improved chimney design which avoids the undesired flow reversal and demonstrates the potential value of modelling of passive features before construction.

Keywords: Passive building features; passive building design; mathematical modelling; sustainable building
1. Introduction

Integration of passive strategies into a building is fundamental in the design of sustainable buildings. Passive features are components that can be integrated as part of the building at the design stage to induce ventilation, cooling and heating with the aim of replacing/complementing mechanical systems. These elements may include solar chimneys, earth air tubes, wind towers, evaporative cooling, or Trombe-walls. The most challenging aspect at the initial design stage is to make sure that their intended purpose will be achieved. Most often the integration of these features into the design will be done by intuition and not supported by the use of simulation or decision support tools. As Attia et al [1] noted, among the main barriers of the decision making during the design of a sustainable building is the understanding of building physics and performance by architects. The same authors emphasized that in spite of the remarkable performance of some existing pre-decision evaluation tools, the tools are hardly used by architects who participate in the early design stage. Post occupancy evaluation of some sustainable buildings supported the evidence provided above.

Zion National park visitor centre (located in Utah, USA) incorporates passive features such as two cooling towers and clerestory windows [2] to provide natural ventilation and cooling. Two years post occupancy survey indicates that the cooling energy intensity was 77% less than a typical building in the region. Long et al. [2] recommended exhaust path consideration for improvement of the performance of cool towers. Lack of building integrated modelling on the design of passive evaporative cooling towers was found as the limiting factor faced at the initial design stage. Ford et al.[3] carried out performance evaluation of the combination of wind tower, evaporative cooling and thermal chimneys in a three storey mixed ventilated laboratory buildings in the Torrent Research Centre in Ahmedabad, India. The passive evaporative system uses micronisers for spraying water. Results from the first summer in operation indicate that internal temperatures are 10- 15°C below the peak external air temperature. In the top layer of the building however, air bypass was observed at the beginning of operation which could have been identified at the design stage if modelling was used.

An interactive learning centre at Charles Sturt University, Dubbo, Australia, includes four passive evaporative shower towers to provide cooling to 1600m² floor in combination of thermally massive walls and ceiling [4]. Its overall performance was found to be better than a conventional evaporative cooler while it is reported that the tower had performed poorly due to positive pressure developed in perimeter rooms which prevented the cool air from entering. This problem might have been prevented by modelling at the initial design stage.

This paper provides a case study on a recently built ‘Sustainable Science Centre’ in South Australia which was part of Building the Education Revolution program funded by the Australian government. Among the sustainable passive features in this building is a solar chimney integrated into the atrium of the building which acts as both internal shading device and promoting natural ventilation. The main aim of this study is to examine the actual operation characteristics of the solar chimney and to demonstrate how the use of modeling can lead to an improved design. In the previous publication [5], the details of the model used in this study has been presented.

1.1. Building description

The building consists of a 115 m² atrium which is naturally ventilated by passive airflow components and mechanical fans. The building is a light weight building mainly made of face brick and plasterboard. The atrium includes a manually operated low-level louver, a BMS (Building Management System) controlled high-level motorized louver, a built-in solar chimney which helps both to shade the transparent polycarbonate sheet roofing and to enhance natural ventilation, and finally, two BMS controlled variable speed axial fans. The solar chimney is constructed using polycarbonate sheets and six black painted sandwich panels filled with expanded Polystyrene (each with 2.7 m length, 1.7 m width and 75 mm thickness). The whole chimney is inclined at 35° from the horizontal as shown in Figure 1. The polystyrene panels are operable and act as a roof shade. When they are closed, the whole channel acts as a solar chimney and they attenuate the light and radiation passing through the polycarbonate sheet. When they are open, they let daylight through the polycarbonate sheet roofing.
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