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Indoor Thermal Comfort Assessment of Industrial Buildings in Singapore

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Abstract

In a tropical climate such as Singapore, as compared to fully air-conditioned buildings, naturally ventilated (NV) buildings tend to have lower Thermal Comfort (TC) condition. This research investigates and develops a thermal comfort assessment method for naturally ventilated industrial buildings.

Data was collected through field survey which consisted of environmental measurement and questionnaire of the thermal perception of several industrial buildings' occupants. From statistical analysis of the field survey data, thermal comfort prediction model was developed. The acceptable range to achieve thermal comfort for industrial buildings was also analyzed.

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Keywords: Thermal Comfort; Thermal Sensation; Naturally Ventilated; Industrial Building

1. Introduction

Building and Construction Authority (BCA) sets the Green Mark (GM) scheme standard in 2005.

Throughout the years, the criteria used for Residential Buildings (RB) have been adopted for Non-Residential Buildings (NRB), and the passing criteria of area weighted wind velocity of ≥ 0.6 m/s [1] for developments with higher GM rating is deemed to be not sufficient to assess the natural ventilation (NV) design for NRB.

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In Singapore, as compared to fully air-conditioned buildings, NV buildings tend to have better Indoor Air Quality (IAQ), but worse Thermal Comfort (TC) condition. So far, there is no research study that specifically focus on industrial buildings, therefore, this study looks into the TC of industrial buildings. This study will help BCA to further ensure sustained building performance, which key strategy would be to minimize energy consumption through the optimization of design.

The objectives of this study are as follows:

1. To develop thermal comfort model, analysis and validation; and
2. To recommend the optimum requirement and assessment method to achieve thermal comfort in industrial buildings.

2. Methodology

2.1. Objective and subjective measurement

Data was collected through field survey, and used to develop and validate the TC model. Field survey allows "first-hand" data that help to capture occupants' TC perception in their actual daily environment. The in-situ environmental measurement also records the characteristics of NV buildings, which are dynamic and unpredictable. These NV characteristics such as intermittent wind, solar radiation and high humidity cannot be simulated easily by mechanical means in a chamber, thus field survey is considered as the best method for the data collection.

The measurement protocol for the field survey followed Class II protocol of thermal comfort field research [2]. There are two groups of data required, i.e. objective and subjective measurement data. Since the human perception is not as simple as "stimulus-response" (cause-effect) phenomenon, the field survey attempted to observe and collect data to comprehend better the complex human perception, behavior and background.

The objective measurement measured the air temperature, wind speed, relative humidity and globe temperature near each occupant (respondent), and noted the activity and the clothing level of the respondent while the respondent did the subjective assessment. The objective measurement was conducted at around 0.8 – 1m high from the floor. The measurement was conducted using handheld equipment of Testo 445 as shown in Fig. 1(a). During the indoor field survey, a weather station was installed on the roof of the building to measure the micro-meteorological condition. Fig. 1(b) shows the HOBO weather station. The monitored environmental parameters included ambient temperature, wind speed and wind direction, relative humidity, and solar radiation.

The subjective assessment was formulated into questionnaire form. Some standard questionnaires (response scales) for TC studies such as ASHRAE scales for thermal sensation vote and Bedford scales for thermal comfort vote [3, 4] are used. By using both scales, the consistency of response between thermal sensation (hot to cold) and perception (uncomfortable-comfortable warm or cold) can be further verified.

2.2. Thermal comfort survey

For each building, the survey was conducted in two sessions daily, i.e. in between 10AM to 12PM (morning session) and in between 2 to 4PM (afternoon session), in order to capture the thermal perception of different parts of the day. The data collected from the field survey was compared between external and internal environment.

The surveys were on three different types of industrial buildings in Singapore, and were conducted on the occupant/worker inside the buildings. Fig. 2 shows the floor plans of the buildings surveyed. Fig. 3(a) shows the weather station installation on the rooftop, while Fig. 3(b) and Fig. 3(c) show the TC survey conducted within the units.