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A review: Natural ventilation performance of office buildings in Japan

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ABSTRACT

Natural ventilation is an effective strategy for reducing energy use in buildings. The effect is especially significant for buildings with high internal heat generation, such as commercial office buildings. Therefore, naturally ventilated office buildings are becoming increasingly popular in Japan. In this paper, monitoring and measurement results from Japanese studies are reviewed. Thirty buildings are selected for the review based on the search results obtained using a Japanese search engine for academic papers. To identify trends in the design of naturally ventilated buildings, the representative air change rates are compared. The values range from 1 to 10 ac/h, and no specific peak is observed. In addition, no strong correlation is found between the air change rates and floor areas. These results suggest that the natural ventilation performance depends considerably on the design. Additionally, the natural ventilation performance is highly dependent on the building shape, which is generally discussed during the early stages of building design. In this context, it is important to create a clear target air change rate within the range of achievable values for natural ventilation design in the early design stage and to consider this target throughout the building design process.

1. Introduction

Natural ventilation is one of the best strategies for reducing the energy consumption related to building usage. In particular, the effect is significant when it is applied to buildings with high internal heat gains, such as modern office buildings. Conversely, office workers require high-level thermal environments for intellectual productivity. Therefore, operable windows and air conditioning are generally combined in office buildings that use natural ventilation. Such methods are “mixed-mode” approaches. A well-designed mixed-mode building enables the integration a high-level thermal environment with air conditioning and energy savings when the outdoor air conditions are suitable for natural ventilation. In Japan, mixed-mode buildings are becoming increasingly popular [1]. In addition, many studies have been performed to monitor the real performance of naturally ventilated buildings in Japan, and their results have been reported in various research papers published in Japanese. Therefore, these articles should be reviewed, and the actual performance of office buildings in Japan that use natural ventilation should be statistically analyzed. In this paper, research papers regarding the monitoring or measurement of naturally ventilated office buildings in Japan were collected via searches using a Japanese database service called CiNii (Scholarly and Academic

Information Navigator). This system enables users to search for information on academic articles published in academic society journals, university research bulletins, and articles included in the National Diet Library's Japanese Periodicals Index Database. Searches were conducted using the search terms “Shizen-kanki” (“natural ventilation” in Japanese) and “Jissoku” (“measurement” in Japanese). The papers produced by the searches regarding the monitoring and measurement of office buildings, as well as other papers related to these papers, were selected for this review. First, an outline of the references is described. Next, the air change rate data are presented in figures based on floor area or building scale. Finally, trends in the real performances of naturally ventilated buildings in Japan are discussed based on the data.

In the early stages of building design, architects decide the outline of building shape. The building shape can limit natural building strategies. In this context, it is important to make architects sufficiently aware of the links between building type and natural ventilation performance during the initial stages of building projects to achieve green building goals. These links based on measured performance are far more compelling than qualitative views based on theories. The data presented in this review article can help architects create building outlines and promote natural ventilation strategies, especially during the initial stages of building projects.

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2. Outline of references

In this section, the data described in the reviewed papers are summarized. In addition, representative air change rates (representative ACH) are calculated from the data, allowing the natural ventilation performance to be compared among the buildings reviewed in this paper. This value is either directly obtained or calculated from each reference as follows:

- i. the mean air change rate when it is included in the paper (this approach, as the most preferable, is used when possible);
- ii. the mean of the maximum and minimum values when only the maximum and minimum values are included in the paper;
- iii. the intermediate value when some data in various spaces and measurement periods are included in the paper.

If only the amount of air change is given in the paper, the air change rate is calculated by dividing the amount by the floor area multiplied by the ceiling height. When the ceiling height is unknown, 2.7 m is used as a general height for office buildings.

2.1. Building 1 [2,3]

Location: Utsunomiya City, Shimane Prefecture
 Date of completion: 8/2015
 Gross floor area: 7628 m²
 Naturally ventilated volume: 4609 m³
 Number of stories: 5 stories above ground and 1 story below ground
 Building use: Government office building
 Type of natural ventilation: Combination of cross-ventilation and stack ventilation
 Facilities for natural ventilation: Vertical shaft and light well
 Facility note: Water louver on lighting window at the top of light well
 Date of monitoring or measurement: 9/2015 (fall) and 4/2016 (spring)
 Outdoor air temperature: 0–30 °C (note 1)
 Outdoor wind speed: 0–9 m/s (note 1)
 Air change rate: 4.3 ac/h (fall) and 5.4 ac/h (spring)
 Amount of air change: 330 m³/min (fall) and 417 m³/min (spring)
 Representative ACH: 4.9 ac/h (mean value)
 Target ACH at the design state: 5.0 ac/h

2.2. Building 2 [4,5]

Location: Ueda City, Nagano Prefecture
 Gross floor area: 10,082 m²
 Naturally ventilated area: 3400 m²
 Number of stories: 3 stories above ground
 Building use: Office building (research center)
 Type of natural ventilation: Combination of cross-ventilation and stack ventilation
 Facilities for natural ventilation: High-side lighting windows
 Date of monitoring or measurement: 1/31~2/1/2015
 Outdoor wind speed: 0 ~ 11 m/s (note 1)
 Air change rate: 2.8 ac/h to 5.3 ac/h.
 Amount of air change: 36,697 m³/h to 70,042 m³/h
 Representative ACH: 4.1 ac/h (mean value)

2.3. Building 3 [6]

Location: Fujinomiya City, Shizuoka Prefecture
 Date of completion: 2012
 Gross floor area: 1373 m²
 Number of stories: 2 stories above ground
 Building use: Office building (research center)

Type of natural ventilation: Cross-ventilation
 Facilities for natural ventilation: Central courtyard
 Date of monitoring or measurement: 10/1~10/12/2013
 Temperature difference between outdoor air and indoor air: 0–8 °C (note 1)
 Outdoor wind speed: 0–10 m/s (note 1)
 Air change rate: 1.2–8.4 ac/h.
 Representative ACH: 5 ac/h.

2.4. Building 4 [7,8]

Location: Tokyo
 Date of completion: 1/2013
 Gross floor area: 16,906 m²
 Number of stories: 17 stories above ground and 1 story below ground
 Building use: University building (mainly graduate school)
 Type of natural ventilation: Stack ventilation
 Facilities for natural ventilation: Double skin façade
 Date of monitoring or measurement: 4/27-5/8/2013 (spring) and 10/21~11/4/2013 (fall)
 Outdoor air temperature to open the windows: 15–25 °C
 Air change rate: 2–5 ac/h.
 Representative ACH: 3.5 ac/h (mean value)
 Target ACH at the design state: 6.0 ac/h

2.5. Building 5 [9]

Location: Saitama City, Saitama Prefecture
 Date of completion: 1/2011
 Gross floor area: 9030 m²
 Number of stories: 4 stories above ground and 1 story below ground
 Building use: University building
 Type of natural ventilation: Stack ventilation
 Facilities for natural ventilation: Double skin façade and solar chimney
 Facility note: Hybrid system of natural and mechanical ventilation
 Date of monitoring or measurement: 10/9/2012
 Outdoor air temperature: 14–24 °C (note 1)
 Air change rate: 1.2–4.8 ac/h (note 1)
 Amount of air change: 600–2400 m³/h (note 1)
 Representative ACH: 3.0 ac/h (mean value)

2.6. Building 6 [10,11]

Location: Kitakyushu City, Fukuoka Prefecture
 Date of completion: 12/2010
 Gross floor area: 10,387 m²
 Number of stories: 5 stories above ground
 Building use: Commercial office building
 Type of natural ventilation: Combination of cross-ventilation and stack ventilation
 Facilities for natural ventilation: Vertical shaft and top light
 Date of monitoring or measurement: 4/1/2011 ~ 3/31/2013
 Air change rate: 2–4 ac/h
 Annual amount of air change: 9,900,000 m³/h (2011) to 35,220,000 m³/h (2012)
 Representative ACH: 3 ac/h

2.7. Building 7 [12]

Location: Osaka City, Osaka Prefecture
 Area per floor using natural ventilation: 2800 m²
 Number of stories: 38 stories above ground and 3 stories below ground
 Building use: Commercial office building

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