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Preliminary design method for naturally ventilated buildings using target air change rate and natural ventilation potential maps in the United States

Kyosuke Hiyama [a, *], Leon Glicksman [b]

[a] *Faculty of Engineering, Yamaguchi University, 2-16-1, Tokiwadai, Ube-shi, Yamaguchi 755-8611, Japan*
[b] *Department of Architecture, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

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ABSTRACT

Natural ventilation design is one of the most effective strategies for designing green buildings. The cost-effectiveness of this strategy should be considered to balance its benefits with its higher initial costs. In addition, it is becoming increasingly important to discuss the potential energy savings. For this purpose, quantitative evaluations are valued during the early stages of building planning and design because a building's shape can have large impacts on the performance of natural ventilation. However, few studies have fully examined the criteria for this type of evaluation. In this paper, a target air change rate is proposed as a desired criterion. The target air change rate is defined as the point where the gradient of the increase in the cooling effect from natural ventilation reaches a maximum. Above this point the rate of improvement in building comfort is more modest. In addition, this paper provides maps of indices for the United States. The maps help architects obtain a clear understanding of their design directions, e.g., a carefully designed natural ventilation strategy is highly recommended for building projects in warm-dry climates, where the internal gains are moderate, and for building projects in cold climates, where the internal gains are very high.

1. Introduction

Natural ventilation is one of the best strategies for reducing energy consumption related to building use. In addition, natural ventilation increases occupant satisfaction and improves indoor air quality (IAQ) [1,2]. However, it is difficult to design natural ventilation systems due to variations in climate conditions [3–7]. The cooling effects obtained through natural ventilation depend on the differences in enthalpy between the outdoor and indoor air. Therefore, if the difference is small, the change in the amount of air must be large to offset the heat generated indoors. When cooling through the ventilation is not sufficient for offsetting the heat inputs, "mixed-mode ventilation", an operation in which the air-conditioning system and operable windows operate in the same space and at the same time [8,9], is required to maintain a comfortable indoor environment. Mixed-mode buildings offer several advantages and, in most cases, are necessary for maximizing energy-saving effects through natural ventilation. However, these systems also have several disadvantages. First, their installation is expensive because of the integration of automatic and manual control strategies for HVAC and building fenestration systems [8]. In addition, designs of mixed-mode systems are complex; thus, architects must be familiar with their design methods [10]. The complexity of mixed-mode systems increases the design time, which increases the design cost. Added complexities may also cause operational errors that result in wasted energy from conflicts between air-conditioning and natural ventilation systems. Increased risks of overcooling resulting in lower thermal comfort from operational errors have been reported in some instances [11]. To avoid these errors, environmental monitoring systems should be installed. Concurrently, building managers must be trained to understand how to read monitoring data and operate air-conditioning systems and operable windows to achieve the energy-saving effects intended by the designers. This training results in added costs. Currently, no studies are available that have conclusively determined which situations would result in wasted energy [8]. In some

* Corresponding author. Present address: 4-2-201, Gojumeyama-cho, Ube-shi, Yamaguchi 755-0005, Japan. Tel.: +81 836 85 9711; fax: +81 836 85 9701.
E-mail addresses: hiyama@yamaguchi-u.ac.jp (K. Hiyama), glicks@mit.edu (L. Glicksman).

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cases, wasted energy in mixed-mode buildings may be unavoidable; thus, architects should consider this risk.

Consequently, naturally ventilated buildings should be designed to achieve desirable and measurable effects while only requiring simple operations, e.g., opening operable windows when the outdoor air is suitable and when air-conditioning is not needed to maintain indoor comfort. Next, complex operations, including mixed-mode operations, should be considered to maximize the effects of cooling with the associated risks of energy waste and discomfort. In this sense, night-purge ventilation also should be considered as an optional strategy to maximize the effects of cooling because of its limitations related to climate, security and usability factors.

In real design practices, architects typically consider how much air must be exchanged by natural ventilation to achieve measurable effects. As mentioned above, the measurable effects must be achieved using only simple operations. Generally, the cost-effectiveness of the operations should be discussed. The initial cost increases and the operating cost decreases due to energy savings and occupant productivity must be examined. Concurrently, the extent at which a building can utilize natural ventilation potential should be discussed. Considering current global environmental problems and demands for net zero energy buildings (nZEB) [12,13], the effective utilization of the natural ventilation potential should be considered. These two criteria (cost-effectiveness and the high-energy performance for nZEB) must be considered together in future building deigns [14]. In this paper, a natural ventilation design method for estimating the later criterion during the early design stage is discussed. This methodology is based on a rational target air change rate during the early design stage, which is also proposed in this study. In addition, maps of the target air change rates are shown to discuss climatic suitability [15,16] during the preliminary design stage, where only a building's location and rough usage are known.

Currently, evidence-based design is becoming popular for designing better green buildings. The trend has increased the demand for building performance simulations during the early design stage. These approaches are called Design Performance Modeling (DPM), as defined by the American Institute of Architects (AIA) [17]. In the guidelines, DPM is defined as an energy model that is used to inform design decisions by predicting a building's performance. It is typically performed during the early stages of design, before engineering systems are incorporated. Therefore, architects or engineers must make assumptions for several parameters to perform DPM because multiple decisions are made after performing DPM. An initial natural ventilation strategy is also included in the assumptions that architects or engineers make before performing DPM [18]. The assumptions are conventionally made based on the architects' or engineers' experiences. Thus, there is a risk that architects or engineers may make inadequate assumptions that could result in inaccurate decisions due to their lack of experience. With this background, the preliminary design method proposed in this study is aimed to provide an initial natural ventilation strategy that can help architects or engineers input adequate values in DPM.

2. Definition of the target air exchange rate

In previous studies [19], the authors have referred to the importance of design targets during the early stages of building design, particularly for building designs with natural ventilation. During early design stages, e.g., schematic designs, the building's shapes and plans are typically sketched and discussed [20]. Those discussions include the atria and vertical ventilation shaft plans that will significantly impact the natural ventilation potential of the building [21]. Thus, it is very important to estimate how the final building design may reach its intended performance during the schematic design phases. However, time-consuming evaluations are not acceptable in practical design procedures because building design procedures generally occur within a limited periods. Furthermore, decision-making during early design phases should be conducted in a feasible and timely manner. Thus, rough targets that can be estimated in a timely manner should be described early in the design process. In this paper, an air change rate is proposed as the target criterion during the early design stage. Some simplified simulation software programs, such as CoolVent [22], which can be used for quick estimations of air exchange rates through natural ventilation, have recently been developed. Using these simplified tools, architects can continue their design process while checking to determine if their designs ensure that measurable effects will be attained through natural ventilation. However, the air change rates alone do not explain the effects of energy savings and environmental improvements that result from natural ventilation. Rather, the target air change rates should be considered with the environmental improvements. In this paper, the target air change rate is defined as a point where the gradient of the increase in the cooling effect due to natural ventilation reaches a maximum.

3. Detailed explanation of the target air change rate using energy simulation results

The case study of an energy simulation using a simple office model will be used to explain the target air change rate. The basic model building consists of a three-story office-building. Fig. 1 shows a rendering of the building. The area of each floor is 25×25 m^2, the floor height is 3.5 m and the ceiling height is 2.5 m. Table 1 lists the building conditions and Fig. 2 shows the activity schedule. The basic building model has windows of the same size on each wall. The air exchange rate is treated as a design variable between 0 ac/h and 10 ac/h. The amount of air change is defined as the zone volume multiplied by the air exchange rate. The zone volume is calculated by multiplying the floor area by the ceiling height. One zone without internal partitions is set for each floor, and the outdoor air intake is assumed to be well-mixed with indoor air in this simulation. Outdoor air is introduced when the indoor temperature is over 22 °C and the outdoor air temperature is lower than the indoor air temperature during business hours, 7:00–19:00. Night ventilation is not modeled. The weather data were obtained from Los Angeles (TMY3), and the simulation was performed using the Design Builder and Energy Plus [23].

In these simulation conditions, the cooling loads were calculated. The cooling effects from natural ventilation were estimated using the following equations with substitution of energy simulation outputs:

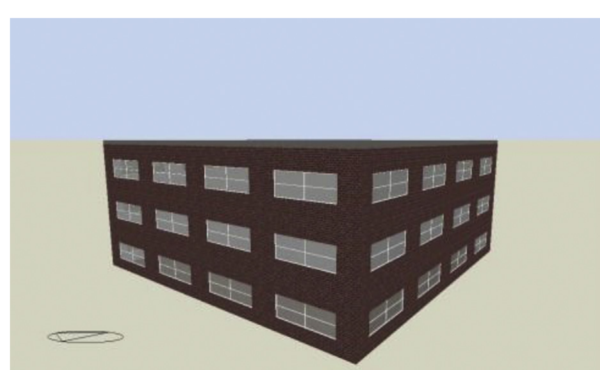

Fig. 1. Rendering of the basic building considered in this study.