CROSS-VENTILATION APPROACH BY UTILIZING GREEN DESIGN FEATURES IN RESIDENTIAL BUILDINGS

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ABSTRACT
The nation of Japan is currently facing an arduous problem in energy shortage, especially during summer, after the incident of Fukushima in 2011. Active cooling by means of air-conditioning, which was generally used in the hot blazing summer, is now discouraged. Insufficient air movement within indoor environment gives a stuffy/stale perception to occupants and may cause serious health problems eventually. On the utilization of natural resources and renewable energy, incorporating green features into building design to moderate energy use in buildings can be significant. This paper gives an overview of the latest research and development work related to envelope design of residential buildings worldwide for enhancing their environmental performance and sustainability, and identifies the most promising façade feature which would have the potential for application to residential housings in Japan. A preliminary evaluation of the effectiveness of the potential feature to enhance cross-ventilation is also given.

Keywords: Green design features, residential building, cross ventilation, CFD, façade

1. INTRODUCTION
International efforts have been made to combat with climate change and to promote sustainable development since 1988 United Nation Environment Programme (UNEP), the 1992 Earth Summit at Rio de Janeiro, the 1997 Kyoto Protocol and the 2002 Earth Summit at Johannesburg.

In line with population growth, rapid urbanization is taking place in many places. In order to accommodate a larger population due to rapid population growth, a large quantity of buildings are necessary. Buildings are considered to be one of the main reasons for the urban heat island (UHI) effect as building masses increase the thermal capacity which has a direct bearing on the city temperature. Climate changes (regional or local) bring about by urbanization through different human activities and give various impacts on the physical environment, cf. Figure 1.

In the Tokyo Metropolitan area, about half of the land is occupied by buildings and about half of the anthropogenic exhaust heat generated during summer in this area comes from the building facilities. The increase in annual mean temperature can be attributed to global warming as well as local effects such as urbanization. The existence of UHI around Tokyo should not be ignored. In addition, the incidence of heat-related disorders such as heat exhaustion and heatstroke is increasing during hot weather period due to various factors including climate change, co-morbidities and drug usage.

Following the Fukushima earthquake and tsunami in March 2011, many nuclear power plants are shut down for

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Low wind velocity due to the high density of urban structures

Increase of anthropogenic heat releases from air-conditioning, automobiles, etc.

Change of land surface covering (decrease of green and water space, but increase of hard surfaces such as buildings and roads)

Decrease of evaporation from ground surface

Land surface covering
Anthropogenic heat
Urban ventilation

Figure 1. Various causes modify urban climate.

safety reasons which lead to energy shortages. Active cooling means using electrical devices such as air-conditioning or electric fans (concerning energy shortage these days) are commonly used in Japanese residential buildings for indoor thermal comfort control. In view of this, it is necessary to seek for another alternative in order to solve the problem. The building façade design is significantly more important to residential buildings, as they are far less extensively equipped with active environmental control systems than other types of buildings. Good façade design can minimise the reliance on active means for environmental control in residential housing and is also effective in reducing impacts due to consumption of non-renewable energy sources. Residences can also benefit directly from lower expenditure on energy use. This is especially essential to households that belong to the lower-income class in the society and is also particularly important to the chronically ill, unstable, disabled and frail, and retired elderly. This paper, based on an ongoing project, gives briefly an overview of various design features proposed, evaluated and implemented worldwide, and the most promising potential feature which has the greatest capability to conserve energy consumption is reported.

2. BUILDING DESIGN BETWEEN OVERSEAS AND JAPAN

Ventilation in buildings, especially for massive structures that accommodate many residents, has been an important issue to building designs in European countries. Rooms in buildings can gain adequate fresh air to ensure good indoor environment as airflow can easily move around the garden spaces and around the estate blocks as well as inside the housing units. In Europe, wide open spaces are typically provided in front and behind housing blocks so that outdoor fresh air can flow into the house units and leave without affecting the neighbourhood. In addition, European buildings blocks are generally much shorter than the buildings in Asian countries and residential units typically have larger indoor spaces as well as window openings. These imply that the important issues of natural ventilation and daylight were duly considered in housing designs in European countries. However, housing designs in Asia are rather different, which is largely due to expensive lands for large populations.

Most of Japan’s major cities are located in Honshu and most of these cities are situated in the regions of Kansai, Chubu and Kanto. These regions normally have a long hot and humid summer as well as a mild winter throughout the year. On hot summer days, the use of air-conditioning would be inevitable. Nonetheless, good cross-ventilation is still of paramount importance for maintenance of adequate indoor air quality and for minimising use of air-conditioners. As building designs become more bio-climatically and ecologically conscious, buildings tend to become “skin” dominated. It is important to recognize that the skin of a building should be considered as part of a living organism and that it should be flexible, adaptive and dynamic rather than static in existence\(^3\).
3. GREEN BUILDING FEATURES

An extensive literature survey has been conducted to tap worldwide research and application experience in using façade design features to enhance the sustainability or environmental performance of residential buildings. Relevant information was sourced from the open literature such as academic journals, conference proceedings, websites of relevant research institutes, and government agencies, etc. The characteristics of the façade design features are summarized in Table 1.

4. EVALUATION OF BUILDING DESIGN FEATURE: WING WALLS

As found in the literature survey of the project, the ‘wing wall’ (cf. Figure 2(a)) is a highly cost-effective, green façade feature to residential buildings in hot and humid climates such as Japan. Thus, a preliminary study on wing wall application was commenced by using CFD simulation and it was believed that a simple two-dimensional model would be adequate; with the aims to show the improvement in cross-ventilation that would be achievable, the effect of wind direction on the cross-ventilation rate that a wing wall can effect, and to identify the effective range of the incident angle of wind relative to the façade. These are reported hereafter.

Flowfield analysed and test cases

The modelled geometry was a two-dimensional (2D) single-sided room. Two different model configurations were investigated in the preliminary study, one with wing wall and the other without. Figures 2(b) shows an example of the case with wing wall. The physical size of the entire flow domain is 140m × 66m. The dimension of the room is 5m × 12m, with two windows in one of the wider walls of the room. The width of the window is 1m and the distance between the two windows was 4m. The thickness and the length of the wing wall used are 0.2m and 1.5m respectively, protruding from the external wall of the room at mid-way between the two windows. The wind speed at the entrance of the flow domain was assumed to be uniform, at 4.1m/s, over the entire entrance, which is the average wind speed (meteorological data) over the summer season in urban spaces.

In both models, the orientation of the room was varied in order to investigate the effect of wind direction on cross-ventilation. The orientations studied including 0°, 22.5°, 45°, 67.5°, 90°, 135° and 180° for both room configurations (with and without the wing wall), however, only the results of 4 orientations are shown here. The orientation refers to the incident wind angle with reference to the outward normal vector from the windows.

Numerical prediction by means of Large Eddy Simulation (LES) and k-ε model are commonly used to simulate flow around bluff bodies in various fields of engineering. The k-ε model is still favourable due to its simplicity and cost effectiveness. In the current work, Standard k-ε turbulent model was used. All variables at the upstream of the flow domain were set according to the principles of Dirichlet boundary condition. The quantities of k and ε at the inlet were based on the mean flow characteristics at the inlet section, i.e. the uniform inlet velocity. The values of k and ε are 0.25215 m²/s² and 0.0045 m²/s³ respectively, which are obtained based on the software manual. The wall function was employed to describe the turbulence properties in the near wall regions. Free boundary conditions were applied at the outlet of the flow domain to satisfy mass conservation.

Results of analysis

Figure 3 and Figure 4 shows the pressure contours of the CFD simulation for various room orientations; 0°, 45°, 67.5° and 135° of the case of room without wing wall and room with wing wall respectively. For the room orientation with 0°, in both model configurations of with/without wing walls, there was no flow entering the room because the entire configuration considered was symmetrical and thus the two windows were subjected to identical wind pressure.
Table 1. Summary for comparison of the façade design features.

<table>
<thead>
<tr>
<th>Category</th>
<th>Façade design features</th>
<th>Benefit</th>
<th>Cost</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Innovative window and related systems (e.g. [6-11, 12]) Glazing system (e.g. reversible glazing)</td>
<td>Reduce cooling energy use</td>
<td>Incremental glazing cost; increase lighting energy use; maintenance and cleaning costs are high as required skilled person</td>
<td>Flexibility in response to the conflicting demands of winter and summer conditions in many locations</td>
<td>Rotating the glazing system is rather risky when suddenly strong gust comes, especially difficult and inconvenience for the aged and the disabled</td>
</tr>
<tr>
<td>2</td>
<td>Solar chimney (12-13)</td>
<td>Reduce cooling energy use</td>
<td>Construction cost is high but running costs are low</td>
<td>Significant in its ability to self-balance; the hotter the day, the hotter the chimney and the faster the air movement</td>
<td>Complex automatic system is suitable for application to commercial buildings, the cost-effectiveness of the system applying to residential buildings is doubtful</td>
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<tr>
<td>3</td>
<td>Trombe walls (14, 15)</td>
<td>Reduce cooling energy use</td>
<td>Construction cost is high and for midrise to tall buildings, the construction cost may be significantly increased; little to no maintenance is required</td>
<td>Simple and relatively effective; easy to incorporate into building structure as an external or external wall; it provides winter space heating and draws cool air through the house in the hot season</td>
<td>Required carefully designed as it is often in conflict with the requirements for view and access and may therefore be difficult to implement in a design</td>
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<td>4</td>
<td>Trickle ventilators (16-18)</td>
<td>Increase background ventilation (pecuniary value will not be quantified)</td>
<td>Increase construction cost; maintenance is simple and can be done by the residences</td>
<td>Allow air to trickle inside in order to improve indoor air quality without significantly affecting energy costs</td>
<td>Ventilation openings should be adjustable and located typically 1.75m above floor level to avoid discomfort to occupants from cold draughts</td>
</tr>
<tr>
<td>5</td>
<td>Turbine ventilators (19-20)</td>
<td>Reduce cooling energy costs; improve internal environment</td>
<td>Installation cost is required but no maintenance cost and running costs require</td>
<td>Require no electric power source; the feature is suitable for low-rise buildings</td>
<td>Noise generation affecting neighbourhood</td>
</tr>
<tr>
<td>6</td>
<td>Wing walls (21-22)</td>
<td>Reduce cooling energy use due to greater use of natural ventilation system</td>
<td>Increase construction cost initially but is significantly low; no maintenance and running costs require</td>
<td>Provide better airflow distributions inside rooms under various wind directions; simple and easy to construct</td>
<td>Aesthetic problem</td>
</tr>
<tr>
<td>7</td>
<td>Plant roofs and planted walls (23-26)</td>
<td>Reduce cooling energy costs; increased aesthetics</td>
<td>Installation cost is high but require less maintenance over their lifetime</td>
<td>Reduce heat sink phenomenon created by the vast areas of urban constructions</td>
<td>Greatest concerns are the control of pest and disease as well as leaks problems</td>
</tr>
<tr>
<td>8</td>
<td>Sky garden (27)</td>
<td>Reduce heat generated by hard surfaces and cooling energy use</td>
<td>Construction cost is high; maintenance is required frequently by professionals; extra costs may need to minimize high wind</td>
<td>Reduce heat generated from hard surfaces and mechanical systems; enhance the amenity of building occupants in terms of view sharing and ventilation</td>
<td>Caution is required to be taken for high wind speed at high building altitude; safety for young children should also be taken into account</td>
</tr>
<tr>
<td>9</td>
<td>Climate façade (28-30)</td>
<td>Reduce cooling energy use due to reduce heat gain; tempering indoor climate of individual apartments</td>
<td>Too costly to build, running and maintenance; extra costs are required to employ specialists for servicing computer systems</td>
<td>Act as a climate sensitive regulator that helps to take advantage of the hot and humid climate</td>
<td>Too costly; the benefits in Japan would be far smaller than in Europe due to the different climatic conditions</td>
</tr>
</tbody>
</table>

Figure 2. Wing wall model configuration for computation.

Figure 5. Mass flow rates of the room with/without wing walls.
The net effect was limited to a pressure build up inside the room but no wind could enter the room.

![Images](a) Wind angle at 0° (b) Wind angle at 45° (c) Wind angle at 67.5° (d) Wind angle at 135°

Figure 3. Pressure contour for various room orientations in the case without wing wall.

As the room orientation was increased to 45°, the rate of wind flow entering the room also increased. The effect of the presence of the wing wall became much more significant. The pressure differences between the room and its exterior surfaces can be seen in Figure 4(b). The effect of the wing wall in diverting wind to flow through the room was more significant when the room orientation was at 67.5°. Without the wing wall, the wind only led to a much smaller ventilation rate compared to the case with the wing wall (cf. Figures 3(c) and 4(c)). For the situation where the windows of the room were at the lee side, at 135° relative to the wind flow direction (cf. Figures 3(d) and 4(d)), showed that wind could still enter the room. This was due to the downstream backflow that pushed the wind to enter the room through the window at the far side. However, the amount of wind flow entering the room was less compared to those cases where the windows were facing the windward direction.

![Images](a) Wind angle at 0° (b) Wind angle at 45° (c) Wind angle at 67.5° (d) Wind angle at 135°

Figure 4. Pressure contour for various room orientations in the case with wing wall.

Figure 5 provides a summary for comparison of the mass flow rate of wind flow between the two model configurations and among the range of room orientations studied. It can be seen that the wind mass flow rate through the room with wing wall at the incident angles of 45°, 67.5° and 135° were much greater than those through the room without wing wall under the same wind environment. The highest flow rate would occur in the range from 45° to 67.5° (a smooth relationship was plotted, by Excel, between 45°, 67.5° to illustrate where the range of maximum mass flow rate would be). Wing wall building feature can produce extra pressure difference between the two windows, and increase the air speed inside the room in most wind directions. It is also interesting to find that wing wall may remain effective even when it is at the lee side, cf. Figure 4(d). It can be deduced that larger the wing wall or higher the wind speed creates larger pressure difference between two window openings, larger ventilation flow rate of the room and higher average air speed inside the room.

5. CONCLUSIONS

Due to the shortage of electricity supply is severe, after the Fukushima accident in 2011, during summer in Japan, the building indoor environment, human health and comfort, as well as well-being are also affected. The building façade is the interface between the outdoor and the indoor environments. An appropriate façade design features can help minimise the reliance on active means to maintain comfortable indoor environment which require the use of energy, and reduce the environmental burdens due to the consumption of non-renewable energy resources. Most
importantly, households that belong to the lower-income class in the society or those chronically ill, unstable, disabled and frail, and retired elderly can benefit directly from lower expenditure on energy use. Thus, not only can a large reduction in the overall electricity use in Japan be realised, reduced household expenditure on energy use would also translate into much greater improvements in living standards of low-incomes families than of higher income families.

In view of this, this paper gives an overview of various design features proposed, evaluated and implemented worldwide and identifies the most promising façade feature which would have the potential for application to residential housings in Japan. A preliminary evaluation of the effectiveness of the potential feature to enhance cross-ventilation is also given. Further investigation will include impacts on the availability of natural ventilation due to: wind from a range of directions with various speeds; different combinations of open/closed status of windows; locations of the wing walls, sizes of the wing walls etc, using 3D CFD simulation and wind tunnel experiments. Predicted results will compare and validate with experiments.

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REFERENCES