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Investigation on the appropriate floor level of residential building for installing balcony, from a view point of energy and environmental performance. A case study in subtropical Hong Kong

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ABSTRACT

In a residential building, a balcony of an upper floor can act as an overhang; and provide solar shading and reduction in electricity consumption of air-conditioner (A/C) for a flat on the underneath floor. However, some residential flats located on the lower levels may receive substantial self-shading effect from some adjacent flats in the same building block, leading to an insignificant shading effect from a balcony. As there is substantial amount of energy consumed and pollutant generated during the production and disposal of a balcony, it is vital to investigate the energy and environmental performance of residential flats installed with balconies at various floor levels. The objective of this study is to investigate an appropriate floor level of a residential building above which balconies should be incorporated. A 21-story residential building was modeled using EnergyPlus. Simulation results indicated that, for a west-facing flat, only the flats located on 15/F to 20/F can give acceptable environmental payback periods, ranging from 58.3 years to 40.7 years, i.e. within the lifespan (60 years) of a building. The corresponding annual savings in A/C consumption range from 234.9 MJ (2.60%) to 336.7 MJ (3.57%). The research methodology and findings are presented in this paper.

1. Introduction

In the past decades, there is an increasing demand on the fossil fuel and its associated adverse impact on the environment is becoming a great challenging problem to most people around the world. As buildings account for a major portion of the total electricity consumption at end-use level in a modern city, promoting energy efficiency in buildings is definitely an effective measure to achieve energy conservation and help retard the rate of environmental pollution and climate change.

In recent years, there is a trend that balcony is constructed in the living room of residential flat in the private housing development. There are a number of merits of incorporating a balcony over a traditional window design such as provision of a panoramic view, planting space, enhanced natural ventilation (by enlarged size of window opening), etc. From the view point of energy saving, a balcony of an upper floor can provide solar shading to a building flat on the underneath floor so that the solar heat gain as well as the energy consumption of air-conditioning unit can be reduced, leading to a contribution to green building design and mitigation of greenhouse gas emission.

There is a number of previous research works carried out by various researchers on the performance of buildings installed with balcony. In the aspect of acoustic performance, Dien & Woloszyn [1] had investigated the effect of balcony configurations, including the ceiling design with different inclined angles (5°, 10° and 15°) and balcony depths, on the acoustic performance of tall building façades closed to roadway by using a Pyramid Tracing model. The result showed that a maximum reduction in noise level was obtained at the high floor levels and at a balcony depth of 2 m or more. Scale model was adopted by Lee et al. [2] to study the efficiency of different balcony forms in noise reduction. The research work revealed that the installation of parapet in a balcony can achieve a maximum noise reduction of 23 dB which was more effective than a lintel in reducing exterior noise. Kim & Kim [3] applied a method of field measurement, conducted in accordance with ISO 140-5, to evaluate the effectiveness of sound insulation provided by the installation of balcony windows in nine apartment complexes in Korea. The study found that the measured results considerably depended on the test methods, noise sources, angles of incidence

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and areas of specimens. Tang [4] had similar work on a noise screening effect of balconies at a building façade where the noise source is not parallel to the façade. The findings indicated that, when compared to a parallel noise source, less amount of noise amplification was observed from the cases with inclined sound source, under the presence of balcony ceiling reflection. Moreover, regression formulas had been developed for prediction of balcony insertion loss. Acoustic design guidance on optimized selection of balcony acoustic treatment was developed by Naish et al. [5]. Various balcony types with different acoustic treatments were assessed and multi-variable linear equation including modified exponential equations on nine deciding variables had been derived.

Naish et al. [6] extended their research work of acoustic design to estimate the potential saving in annoyance and sleep disturbance related health costs due to the provision of balcony in residential buildings located near the traffic noise. Regional road traffic noise mapping data and standard dose–response curves were applied to estimate the population exposure levels. Naish et al. found that balcony acoustic design could offer a significant merit for reducing the health related cost which was incurred from road traffic noise.

In South Korea, the government has changed the building regulation to allow alteration of balcony in residential buildings. The balcony space can be remodeled as an enclosed living space. Choi et al. [7] studied the association between balcony alternation and children's allergic symptoms in South Korea. The study revealed that 36% of participants had a balcony alternation in their apartments in which the living room area was enlarged. Moreover, a risk of floor moisture and condensation was discovered. About 61% of home owners with an alternated balcony had a problem of mold and condensation. Frequent rhinitis symptoms were also reported among the children who lived in the residential flats with balcony alternation.

The effect of balcony on reducing the spread of flame in high-rise apartment fire was investigated by Mammoser & Battaglia [8]. Large eddy simulations coupled with a mixture fraction combustion model was employed in the study and it was found that an increased balcony depth could reduce the heat flux to the surface and thus delaying vertical spread of fire. Moreover, it was revealed that a rectangular balcony with non-combustible balustrades and open separation walls could offer a better protection against vertical fire spread.

A new concept of second-skin façade installed on building balcony was proposed by Montazeri et al. [9]. This new design concept was initiated by the problem of wind discomfort and wind danger at balcony of residential flat located in high-rise building. 3-D steady Reynolds-averaged Navier–Stokes CFD (Computational Fluid Dynamics) simulations were conducted to evaluate the performance of building cases with and without a second-skin façade. The analysis indicated that a second-skin façade was effective in providing pressure equalization, reduction in pressure gradient and improvement in wind comfort at the balcony.

Yoshie et al. [10] introduced a new air-conditioning system with solar collector integrated in balcony handrail. Experimental and CFD studies had been carried out. It was found that, with an optimal control in the proposed system, a maximum reduction of 60% in the total annual heating and cooling loads could be achieved.

Goulouti et al. [11] investigated the effect of fiber-reinforced polymer which acted as a thermal break on the balcony connection of a typical residential building in Switzerland. A typical two-story residential building was selected for the study. The research revealed that the reduction percentage in heating demand of a building could be up to 41%. Similar study was conducted by Ge et al. [12] who applied a 2-D THERM heat transfer analysis program to find that the overall U-value of a balcony with thermal break could be reduced by 72–85% and the minimum floor surface temperature was increased from 6.1 °C to 12.5 °C. Moreover, it was revealed that the peak heating and cooling loads were reduced by 6–16% and 1–3% respectively for the scenarios simulated.

Song & Choi [13] had carried out study on the effect of balcony alteration on the indoor thermal environment and the heating and cooling demands of residential buildings in Korea by field measurement and simulation. Their results indicated that the indoor temperature of a living room without a balcony was 0.8 °C lower than that with a balcony in the winter season. Moreover, the heating and cooling loads of the living room space were 39% and 22% respectively higher than that of a flat with a balcony. The analysis showed that the change in building regulation by the Korean government caused an increase in building energy consumption. In addition to the effect on the thermal environment, Kim & Kim [14] evaluated the effect on healthy daylight environment caused by the elimination of balcony in some residential flats in South Korea. As the balcony (acting as an overhang) was removed, there was a loss in obstruction for blocking the excessive and intensive sunlight, leading to a problem of uncomfortable glare and ultraviolet penetration.

Song et al. [15] had investigated the effect of eave on energy consumption of a hospital and a hotel located at high latitude (Fairbanks, Alaska, USA (64.82°N)) and low latitude (Taipei, Taiwan, R.O.C (25.07°N)). Compared to a building case without eave, the average reduction percentages in energy consumption were found as 15.4% and 10.72% for hospital and hotel, respectively. Moreover, the study revealed that the reduction in energy consumption increased dramatically as the width of an eave increased, but the increasing trend became negligible when the eave-length was longer than 0.25 m.

The author of this paper has previous research work on investigating the energy performance of a balcony constructed in the living room of a typical residential flat in subtropical Hong Kong [16]. The study revealed that, based on the extra purchasing cost of a residential flat incurred by an additional balcony, the cost payback period was more than 100 years. On the other hand, an energy payback period of 22.4 years was found for a building case with a southwestern balcony and clear glass glazed window. The provision of balcony to the living room of residential flat was found environmentally feasible in Hong Kong.

Huang et al. [17] had similar study on energy and carbon emission payback analysis for an overhang shading option in an air-conditioned university campus building in Hong Kong. Through experimental and numerical investigation, it was concluded that installation of shading device on building façade was effective for reduction of building cooling demand caused by solar heat gain. The energy and carbon emission payback periods are 46.3 years and 63.8 years respectively, which were considered as unrealistically long by the campus management office.

Florides et al. [18] had estimated the energy saving as well as cost payback period of installing overhang in a model house in Cyprus. Simulation result by running TRNSYS computer program indicated that a range of saving in annual cooling load from 7% to 19% can be achieved for the model house. Moreover, the estimated cost payback periods range from 4.4 years to 16.5 years.

However, construction of balconies for residential flats located on the lower floor levels of a building may not be recommended due to high noise level and poor air quality when a residential building is located within a busy traffic area. An example is presented in Fig. 1, showing a photo of a residential building with balconies constructed in the living rooms of some flats located on high floor levels only. Moreover, security is another major concern for residential flats on the lower levels.