E3S Web of Conferences **3**, 01025 (2014)
DOI: 10.1051/e3sconf/20140301025

Relevant indoor ventilation by windows and apertures in tropical climate: a review study

Ardalan Aflaki[1], Norhayati Mahyuddin[2] , Zakaria Al-Cheikh Mahmoud Awad[3] , Mohamad Rizal Baharum[4]

[1,2,3,4]Center for Urban Conservation and Tropical Architecture (UCTA), Faculty of Built Environment, University of Malaya, Kuala Lumpur, 50603, Malaysia

Abstract. High temperature and humidity oblige occupants to use mechanical ventilation to regulate indoor temperature in tropical climate. Therefore, energy consumption becomes a challenge facing the designers in primary steps of design. Natural ventilation known as a passive design strategy in buildings is one of the innovative techniques in modern building to reduce operation costs and energy consumption. Although the advantages of natural ventilation are proved by previous studies, few studies have been done on application of openings and apertures designs to maximize indoor air velocity inside the buildings. This study reviews different ventilation methods and techniques which have been applied through openings to identify the most effective architectural elements for adequate ventilation inside the buildings. Comparison of study results shows that building orientation accompanying with apertures size are effective design strategies and techniques to increase indoor air ratio. Finally, the study recommends various form of openings and different form of louvered windows as research gaps for further study.

1 Introduction

Passive cooling systems are specific strategies in buildings to decrease energy load. They are categorize into four major methods including; radiative cooling, evaporate cooling, heat avoidance and ventilation cooling [1]. Although these strategies have been tested in buildings, few researches have been done on application of ventilation cooling through the window and aperture. Therefore, current study focuses on ventilation cooling in buildings to finalize the natural ventilation methods and architectural elements for acceptable air velocity inside buildings.

2. Review of literatures

2.1 Advantages of natural ventilation application on built environment

Ventilation cooling has been established in design of building in tropical climate to create at least more tolerable indoor environment if not perfectly comfortable. Review of studies show that thermal comfort in tropical climate can be achieved by application of ventilation cooling.

Chandra noted air exchanges at 5-500 air changes per hour is necessary to achieve thermal comfort within building [2]. Study by Kubota et. al [3] in Malaysia approves that natural ventilation

application through buildings decreases energy consumption and green gas emissions. Also, the study reveals that acceptable indoor temperature can be achieved in naturally ventilated buildings.A comparative study on application of natural and mechanical ventilation in building shows that high level of environmental quality and occupant control could be achieved in naturally ventilated spaces [4]. Moreover, the intensification of natural air through sick office buildings condition saves up to US$30 billion in the USA [5]. This concept can be applied in residential building where fresh natural ventilation improves thermal comfort and indoor air quality. In overall, natural ventilation as a passive cooling strategy in building is an opportunity to improve associated issues related to mechanically ventilated buildings where thermal comfort satisfaction and indoor air quality modification can achieve with lower operation costs.

2.2 Natural ventilation application by different methods

Air pressure ventilation and stack ventilation are considered as applicable methods for establishment of natural ventilation through buildings in previous studies [6, 7]. Building surfaces are the main element on creation of air pressure ventilation. In detail, air flow is blocked by windward side of the building and creates more pressure. On the other side of the building, called as a leeward side, the pressure is much lower than the windward side. Therefore, the wind flows from the higher pressure to the lower pressure. Moreover, the patterns of airflow through the building can be divided into single and cross ventilation. As it is presented in figure 1, single side ventilation occurs in same openings in the same side where the inlet and outlet for airflow are appointed in one side of the building. In opposite, cross ventilation is where the inlet and outlet are appointed in different side of building façade. Building corridors as an architectural element act as a channel to prepare cross ventilation in the buildings. As declared by Mohamed and Tahir [8], indoor corridors deliver outdoor wind by difference in air pressure. Also, study by Zhou, J., et. al [9] indicates that air pressure created by building corridors can be intensified by application of other passive design techniques in buildings.

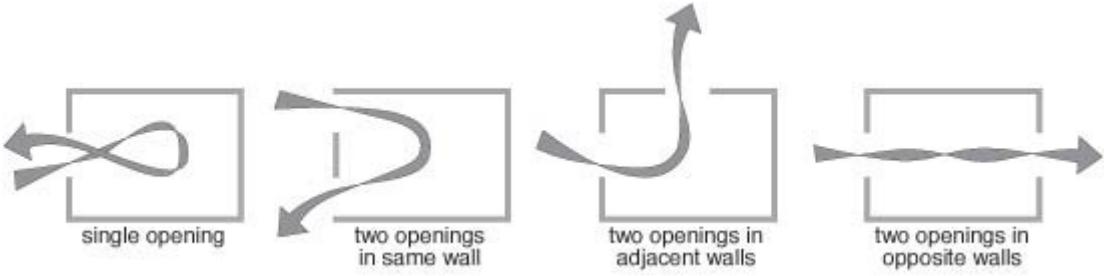

Figure 1: Single and cross ventilation methods

Stack ventilation as another air flow pattern in the building is the vertical movement of the wind (figure 2). Thermal force or stack ventilation occurs due to different densities between cool and warm air. Also, it happens in the regions where the there are more discrepancies between day and night temperature [10]. For stack ventilation effectiveness, study by Ismail and Abdul Rahman [11] shows that the differences in height between apertures and temperature differences between indoor and outdoor of building are imperative factors. The stack ventilation can be applied by wind catchers. The fresh air comes from the building façade flows through the building can be discharged by wind catcher [12]. Along this process, comfortable indoor condition could be reached while the hot air replace with cool and fresh air. However, specific focus on studies in tropical regions proves that cross ventilation is more applicable than stack ventilation in hot and humid climate where the difference between indoor and outdoor temperature ratios is almost trivial [7, 13].

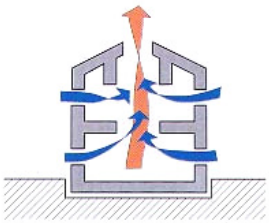

Figure 2: stack ventilation pattern in building

3 Research Methodology

The study provides an overview of the approach and methodology used to identify the relevant literature from the peer-reviewed research literature and a select number of web-based and practice literature. A structured approach was used to determine the source of materials for review. The peer-reviewed literature was the main source of information and data application of natural ventilation through ventilation openings especially in tropical climate.

3.1 Peer-Reviewed Literature: Search and Review Strategies

Searches for peer-reviewed journal articles and dissertations were conducted using the University of Malaya online databases in the area of sustainability and renewable energy. These searches are outlined below. The Google Scholar search engine was also used to conduct more general searches. All searches were limited to research with humans, published in English (Table 1). Key criteria were used in the decision tree for selecting articles in the literature review. It consists of data bases which have applied natural ventilation inside the buildings. Once abstracts had been identified as relevant to the criteria and worthy of further exploration, the full article was accessed. The articles were skimmed, after which a further selection was made based on criteria including the terms discussed in the literature review outline and proposal. As well, articles were included if they were relevant to natural ventilation.

Table 1: Data bases, terminology and amount of selected articles

Data based search	Terminology in abstract	Articles selected
Ovid with all search engines Science direct, Sage, Ebrary library center, Sage research method, Scopus, Springer link	Natural ventilation, passive cooling in buildings, tropical climate, natural ventilation operation, heat avoidance technique	65
ISI web of knowledge	Natural ventilation, passive cooling in buildings, tropical climate, natural ventilation operation	33
Google scholar	Natural ventilation, passive cooling in buildings, tropical climate, natural ventilation operation	28
All university of Malaya data bases	Natural ventilation, passive cooling in buildings, tropical climate, natural ventilation operation, heat	18

4 Results and discussion

A sufficient air flow inside the buildings depends on the architectural elements which induce outdoor wind into indoor environment. Review of previous studies guides to understand more applicable techniques and elements. Current study analyzes previous studies in different tables for relevant comparison among results of different studies in various hot-humid regions. Air flow through

the ventilation opening is divided into two tables where table 2 and 3 show application of cross ventilation and stack ventilation through the openings respectively. Furthermore, table 4 presents studies which applied ventilation openings accompanying with façade components to increase natural cross ventilation. Review of elements in the table 2 shows that elements such as window type and configuration, adequate layout of building, window position and louver angles are some significant variables in the ventilation openings. On the other hand, the table 3 present ventilation shafts and proper size of stacks as main components for stack ventilation.

Table 2: Studies on cross ventilation through ventilation openings

Architectural elements for N.V achievement/ Researcher	Evaluation criteria	Study results
• Relevant direction to prevailing wind, • Accurate aperture location in building Burrnet, et al, [14]	Cp(distribution of wind pressure coefficient on building envelope)	Proper cross ventilation (p= 1.63) could be achieved for head flats where y is equal to 0^, 45^ and 90^. For central side flats, potential for cross ventilation could be reached up to 1.57 while the y is 15^, 30^, 60^ and 75^.
• Louver angles • Outdoor air speed Chandrashekara, [2]	ASHRAE 55 standard,	Louver angles effect on the direction and amount of air flow inside the building.
• Apertures shape and form • Building direction • Prevailing wind in location Gao, [15, 16]	Mean age of air velocity and sensitive analysis	Window openings in opposite directions or perpendicular to each other for maximum ventilation Natural ventilation performance was most sensitive to change of windows positions, followed by building orientation and doors positions.
• Door and window size and position • Layout and shape of architectural plan Sahabuddin, [17]	Field study, thermal comfort indicators	Wide plan layout for more external surface for ventilation in tropical climate is compulsory. Louver windows above panels are suggested for maximum pressure and consequently better ventilation. Perpendicular windows for more cross ventilation

Table 3: studies on stack ventilation through ventilation openings

Architectural elements for N.V achievement/ Researcher	Evaluation criteria	Results of study
• Evaluation of passive and active stacks • Proper size and position of stacks • Active stacks by different speed test R. Priyadarsini et al, [18]	Thermal Comfort indicators	Active stack (application of small fan on top of stack) could achieve sufficient ventilation and comfort temperature in compare to passive stack. When the door closes, air velocity increase up to 550% and maximum velocity achieve up to 0.67m/s. this amount is approved for small size stack. Clearly larger stack in size could reach higher air velocity inside the room.
• Outdoor wind speed • ventilation shafts Prajongsan, et al, [19]	Comfort hours	Proposing ventilation shaft is an effective wind induce ventilation and it increases comfort hours from 37.5% in reference to 53.6% in test room.

5 Conclusions

Review of previous studies declares that building layout, size and location of apertures, windows and doors, building orientation, and some vernacular elements are most applicable architectural elements for ventilation opening. By comparison of results and outcomes of researches in tropical climate, it is proved that following elements are most effective elements and techniques on application of natural ventilation (N.V);

- Louver angles in apertures

- Window to wall ratio and window to floor ratio
- Building position and orientation

The evaluation of elements for increase of N.V in different studies shows that they are significant elements which rarely have been evaluated in previous studies as it is listed here.

- Different shapes of louvers for maximum ventilation
- Different shape and form of apertures for maximum discrepancy on pressure

It can be claimed these variables as research gaps in the field of ventilation through the aperture and openings for further researches. Findings from tables specify most prevalent indicators and standards for evaluation of ventilation. Based on these studies, assessment is carried out frequently and repeatedly by predicted mean vote (PMV), ASHRAE standards, mean age of air velocity, indoor to outdoor air velocity ratio and average velocity coefficient.

References

1. Cook, J., Passive cooling, 1989, Arizona State Univ., Tempe, AZ (USA).
2. Chandrashekaran, D., Air flow through louvered openings: Effect of louver slats on air movement inside a space, 2010, University of Southern California: United States -- California. p. 141.
3. Kubota, T. and S. Ahmad, Wind Environment Evaluation of Neighborhood Areas in Major Towns of Malaysia. J. of Asian Architecture and Building Engineering, 2006. **5**(1): p. 199-206.
4. De Dear, R., G.S. Brager, Developing an adaptive model of thermal comfort & preference. 1998.
5. Fisk, W.J., How IEQ affects health, productivity. ASHRAE Journal-American Society of Heating Refrigerating and Airconditioning Engineers, 2002. **44**(5): p. 56-60.
6. Szokolay, S.V., Climate analysis based on the psychrometric chart. International journal of ambient energy, 1986. **7**(4): p. 171-182.
7. Givoni, B., Passive low energy cooling of buildings. 1994: John Wiley & Sons.
8. Mohamed, M., D. Prasad, and M.M. Tahir. A Study on Balcony and Its Potential as an Element of Ventilation Control in Naturally Ventilated Apartment in Hot and Humid Climate. in Proceedings of International Conference on Construction and Building Technology (ICCBT 2008). 2008.
9. Zhou, J., et al., Coupling of thermal mass and natural ventilation in buildings. Energy and Buildings, 2008. **40**(6): p. 979-986.
10. Evans, M., Housing, climate, and comfort. 1980: Architectural Press London.
11. Ismail, M. and A. Abdul Rahman, Comparison of different hybrid turbine ventilator (HTV) application strategies to improve the indoor thermal comfort. International Journal of Environmental Research, 2010. **4**(2): p. 297-308.
12. Ghiaus, C. and F. Allard, Natural ventilation in the urban environment: assessment and design. 2005: Earthscan.
13. Siew, C.C., et al., Classification of Natural Ventilation Strategies in Optimizing Energy Consumption in Malaysian Office Buildings. Procedia Engineering, 2011. **20**(0): p. 363-371.
14. Burnett, J., M. Bojić, and F. Yik, Wind-induced pressure at external surfaces of a high-rise residential building in Hong Kong. Building and Environment, 2005. **40**(6): p. 765-777.
15. Gao, C., The Study of Natural Ventilation in Residential Buildings, 2011, Hong Kong Polytechnic University (Hong Kong): Hong Kong. p. 133.
16. Gao, C.F., W.L. Lee, Evaluating the influence of openings configuration on natural ventilation of residential units in Hong Kong. Building & Environment, 2011. **46**(4): p. 961-969.
17. Sahabuddin, M.F.M., Traditional Values and Their Adaptation in Social Housing Design: Towards A New Typology and Establishment of 'Air House' Standard in Malaysia', 2012, The University of Edinburgh: UK.
18. Priyadarsini, R., K.W. Cheong, and N.H. Wong, Enhancement of natural ventilation in high-rise residential buildings using stack system. Energy and Buildings, 2004. **36**(1): p. 61-71.
19. Prajongsan, P. and S. Sharples, Enhancing natural ventilation, thermal comfort and energy savings in high-rise residential buildings in Bangkok through the use of ventilation shafts. Building and Environment, 2012. **50**(0): p. 104-113.