Numerical Simulation of The Impact of Natural Ventilation on Fire Safety in Green Buildings

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ABSTRACT
Green buildings, also known as ecological buildings or sustainable buildings, are said to be environmentally symbiotic in the Asian region. Some results of research literatures showed that there were many functions and products of green buildings that singly or together may have an impact on fire safety unless there are some appropriate design approaches to mitigate those effects. Natural Ventilation effect is also included in two indicators of green building certification, energy saving and indoor environment quality, in Taiwan. However, The inappropriate ventilation strategy in emergency situation will produce some fatal impacts on fire safety of buildings, such as causing stack effect. In this study, Fire Dynamics Simulator (FDS) software was used to assess the impact of the natural ventilation on fire safety of green buildings. The results indicated that smoke accumulation phenomenon is significant since the stack effect of the natural ventilation. In the existing natural ventilation model, if the upper natural smoke vent is incorporated, the evacuation time can be increased.

KEYWORDS:
Green building, indoor environment quality, natural ventilation effect, Fire Dynamics Simulator (FDS), stack effect

1. INTRODUCTION

1.1 General concepts of environmental protection and energy saving for green buildings

Green buildings, also known as ecological buildings or sustainable buildings, are said to be environmentally symbiotic in the Asian region. Environmental protection and

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reduction of energy consumption are the two key factors for green buildings. Many countries have established various green building evaluation systems to be used as empirical guidelines. Figure 1 shows the global green building assessment indices (He et al., 2012).

In 1990, the British Building Research Establishment (BRE) proposed the first green building evaluation system in the world, BREEAM (Building Research Establishment Environmental Assessment Method), a method which evaluates the environmental load of buildings. The American LEED (Leadership in Energy and Environmental Design) system was subsequently proposed in 1996, with the Canadian GBTool system being created in 1998. In Taiwan, the EEWH evaluation system was proposed in 1999. More recently, the Japanese CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) system was established in 2002 (Ding, 2012).The evaluation methods provide a range of criteria for building designers to design buildings which are more environmentally-friendly and energy-efficient (Hansen et al., 2013; Mang and Reed, 2013).

Figure 1. *Global Green Building Assessment Indices* (He et al., 2012)

1.2 Green Building Index in Taiwan – EEWH system

In Taiwan, green buildings are publically promoted as being more ecologically sound, energy-efficient, and economical than conventional buildings. The EEWH evaluation system implemented in 1999, is characterized by the assessment of architectural and cultural criteria of buildings specifically for tropical and subtropical climates.

The Architecture and Building Research Institute (ABRI) promotes and oversees the evaluation criteria of green buildings in Taiwan and issues the related official certification. The four key significant factors of the EEWH evaluation system include ecological impact, energy saving, waste reduction, and health. (Lin et al., 2008).

1.3 Effects of ventilation on the fire safety of buildings

For a building, "safety" and "energy saving" are equally important criteria. Some studies in the research literature have analyzed fire safety issues in green buildings, including the fire resistance of construction materials, roof fire prevention, and the safety of glass curtain walls (Chow, 2003; Tidwell and Murphy, 2010). It has been shown that many functions and features of green buildings may have an impact on fire safety, either individually or in concert, unless appropriate design approaches are adopted to mitigate these effects.

When green buildings incorporate natural ventilation, the indoor temperature and humidity can be reduced effectively, and energy can be saved. The designs which make extensive use of natural ventilation can be assessed highly according to the aforementioned evaluation indicators. On the other hand, natural ventilation may hasten the spread of damage or increase the intensity of fires as a result of, for example, the strengthened stack effect. The ventilation effect in emergency fire scenarios has previously been addressed by the designers of buildings during the Edo period of Japan. Figure 2 (A) and (B) show the fire suppression stones used in barns of Takayama City, Gifu County, Japan. The fire suppression stone effectively blocks the ventilation opening when the barn is on fire.

Figure 2(A). *The design of a Japanese barn during the Edo period*

Figure 2(B). *Fire suppression stone used in the Edo period barns*

It was found in this study that the assessment indices of present green buildings in Taiwan do not take into account the impact of ventilation in an emergency and that, similarly, fire safety laws and regulations do not incorporate the ventilation effect in their assessment criteria. It is a subject worthy of study due to the human and material cost of fire. This study used Fire Dynamics Simulator (FDS) to analyze a representative green building which exhibited high energy efficiency. This building is used as a convention hall where large crowds gather and incorporates a variety of combustible materials within. This study discusses the changes in airflow in the interior space when the air-conditioning system design model is replaced by natural ventilation. The hot smoke diffusion is also analyzed during a fire scenario.

2. METHODOLOGY

2.1 Numerical simulation software

The "Zone Model" and "Field Model" are two commonly-used simulation methods. The Zone Model is characterized by dividing the building space into several sections or zones. Although it is simpler and faster than the Field Model in terms of calculation, the Zone Model cannot forecast detailed air flow fields and temperature field distributions for different interior positions during a fire event. Cai and Chow, 2014; Su et al., 2014). The FDS software is a fire behavior simulation tool developed by the Building and Fire Research Laboratory (BFRL) of the U.S. National Institute of Standards and Technology and has been widely used for fire analysis around the world. This software has been approved by fire research units globally and is officially accepted in Taiwan (Shen et al., 2013).

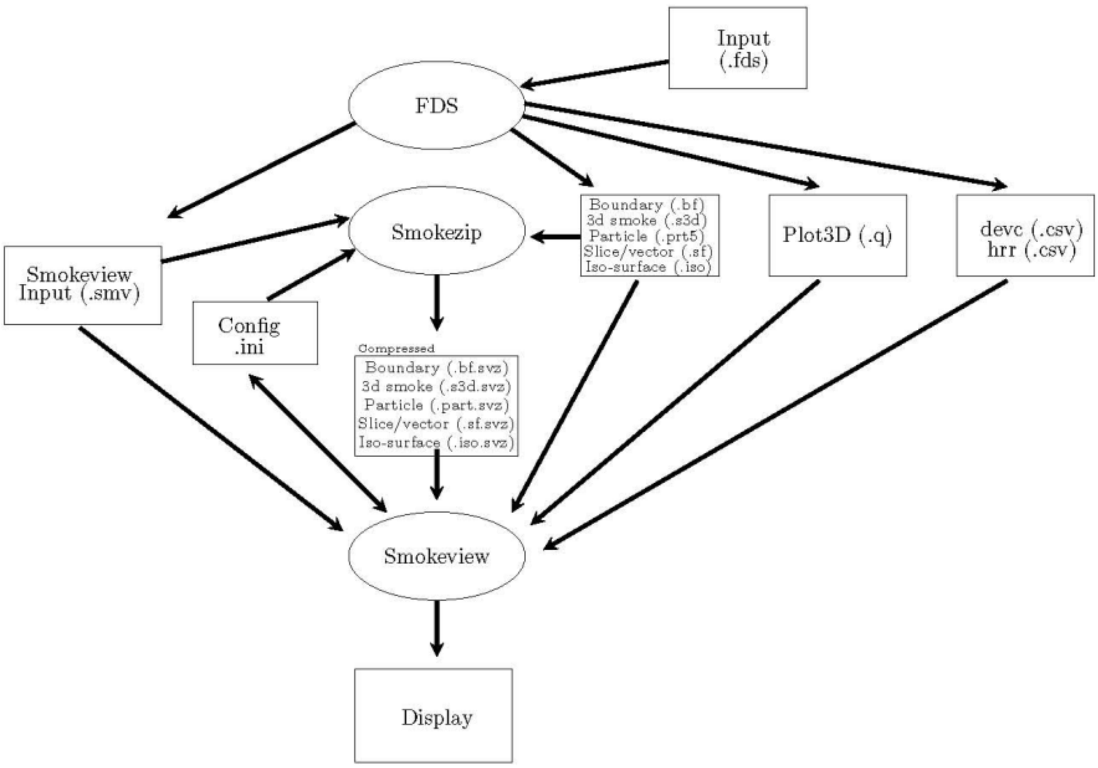

Figure 3. *The FDS and Smokeview framework*

Using the results of FDS simulations, Smokeview software can also be used to export the spatial and fire simulation data to the screen in 2D and 3D animations. The simulation results in terms of temperature, heat transfer, thermal radiation, heat convection, air velocity and wind direction at the scene of a simulated fire can all be displayed using this technique. The FDS and Smokeview architectures are shown in Figure 3 (Floyd et al., 2013).

According to the minimum length scale, nearby fire source, as defined by Baum et al. (Baum et al., 1994), the fire diameter D* is calculated as per Eq. (1).

$$D^* = \left[\frac{Q}{\rho_0 \cdot Cp \cdot T_0 \sqrt{g}}\right]^{2/5} \quad (1)$$

where Q: heat release rate (W), ρo: air density (kg/m3), Cp: air specific heat (J/kg-℃), To: ambient temperature (K), g: gravitational acceleration (m/s2). The result of Eq. (1) matches the experimental regression equation of Baum et al. This case is a public space, and the fire source is 600kW, already contained the safety factor of 1.2 times (Smardz and Novozhilov, 2006). The grid size of the model is 0.1m. The fire scene simulation parameters are shown in Table 1.

Table 1. *The parameters in FDS simulation*

Heat release rate (kW)	600	Fire location	In front of the podium
D* (m)	0.78	Ambient temperature (℃)	25
0.1 D* (m)	0.078	Average outdoor wind speed (m/s)	3.7
Grid size (m)	0.1		

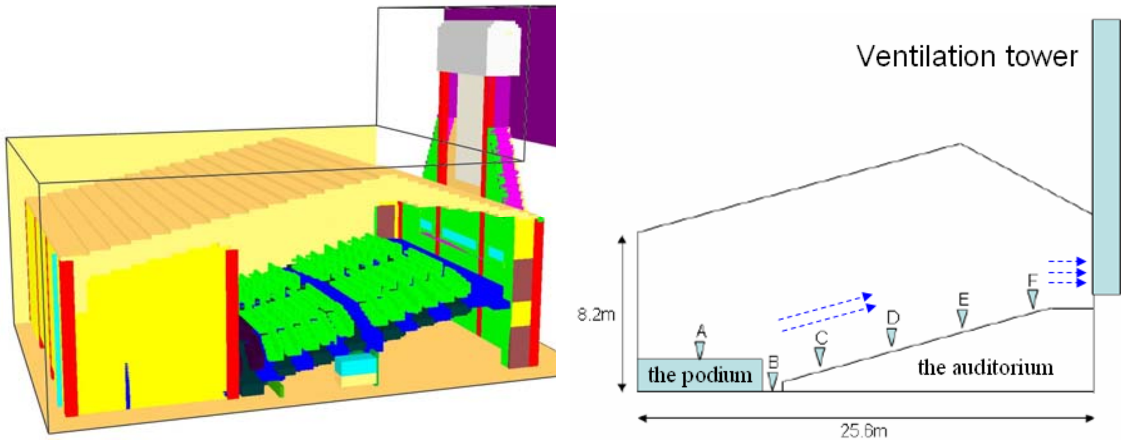

Figure 4. *Visual simulation model*

2.2 Outside conditions

The investigated building is located in a southern city in Taiwan. The simulated appearance of the structure is shown in Figure 4. According to the statistics of the Central Weather Bureau, the monthly average temperature of the region is 15 to 30℃, and the relative humidity is 75 to 80%. The outdoor average wind speed is 3.7m/s in spring and autumn and is mostly northerly, or in a north-northeastern direction. The building is designed to incorporate natural ventilation in spring and autumn taking advantage of moderate outside air temperatures to save energy consumption by reducing the need for air-conditioning systems.

2.3 Simulated fire scenarios

The spatial dimensions of the structure are 25.6m (length) x 16.7m (width) x 12m (height). 5 million individual grids was divided approximately. The growth model of fire adopts t square pattern, and the burn rate is assumed to follow a medium speed growth model. The burning rate α value is 0.01127kW/s2. The heat release rate reaches maximum after 300 seconds.

Interior decoration materials are used throughout the majority of the meeting hall, with a heat release rate of 600kW. The fire source is in a fixed range and takes 300 seconds to reach the peak heat release rate. The fuel chemical reaction is polyurethane. The total simulation time is 9 minutes. Considering the actual height of Asian people, the smoke layer is set at 1.8m above the ground. The elapsed time when the visibility in the monitoring points is lower than 10m is recorded, as well as the change in the air flow of the outlet at the top of the tower.

3. RESULTS AND DISCUSSION

The fire source was assumed to be the front platform and the spread of smoke in the convention hall was simulated under natural ventilation conditions. The visibility at 1.8m above the floor in three specific positions was observed. The elapsed time when visibility was lower than 10m and the change in the air flow through the ventilating tower were recorded. An additional simulated parameter is a natural smoke vent in the upper part of the wall behind the auditoria.

The results show that the detector is actuated after 119 seconds of burning. However, the recorded values as shown in Table 2 show some significant variations in the visibility data. When there are no natural smoke vents, the visibility is lower than 10m at 1.8m above the ground at the rearmost point of the auditorium after 180 seconds of burning while the figure was 157 seconds at the left rear position, and 166 seconds at the right rear.

Table 2. *Comparison of smoke layer descent with and without smoke ventilation*

	Activation time of detector (s)	The descent time of smoke layer to 1.8 m height (s)		
		Left rear	Center rear	Right rear
Without smoke vent	119	157	180	166
With smoke vent	119	252	240	243

When there are natural smoke vents in the rear wall, the detector is also actuated after 119 sec of burning. At this point, the natural ventilation holes under the ventilation tower and behind the auditoria are closed, and the upper natural smoke vent is opened. In this case, the visibility at 1.8m above the ground is lower than 10 m in the rearmost position after 240 seconds of burning, 252 seconds at the left rear point, and 243 seconds in the right rear.

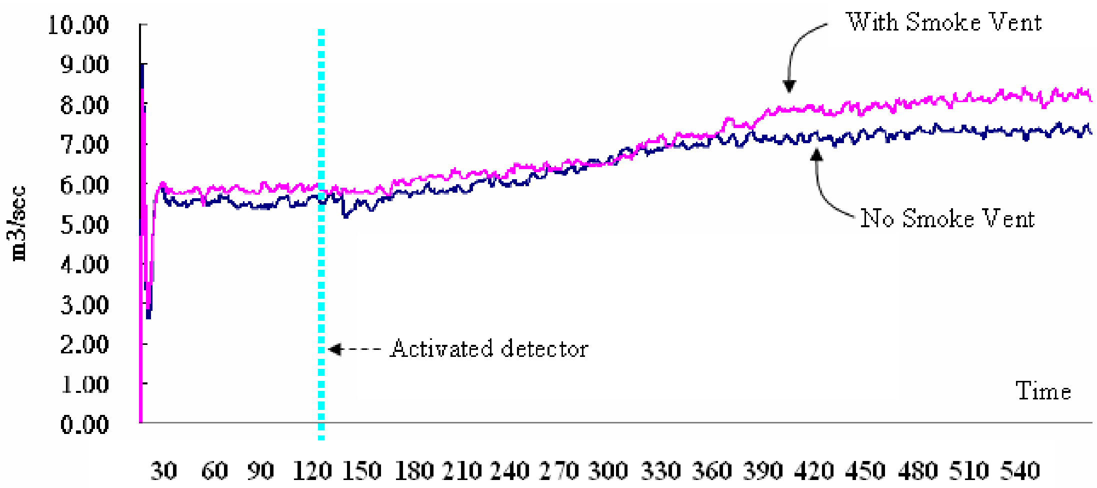

Figure 5. *Flow volume of the ventilation tower*

In the existing natural ventilation model, if the upper natural smoke vent is incorporated, the evacuation time can be increased by 60 seconds. The times for the left and right sides increase by 95 and 77 seconds respectively, which would be valuable in any evacuation scenario.

In terms of the causes, it is found that if the upper natural smoke vent is not included, the ventilation volume is 7.14m3/s after 560 sec of burning. As the opening in the ventilation tower is in a relatively low vertical position, the initial air outflow is fresh air while the dense smoke accumulates in the upper part of the interior of the building. If the natural smoke vent is set in the rear of the auditorium, as the smoke vent is opened, the ventilation volume increases to 8.34m3/s after 560 sec of burning, as shown in Figure 5. Since the rear opening is closer to the ceiling, the improved design not only increases the smoke extraction rate by 16.8%, but also allows the interior air to flow upwards. The dense smoke is therefore expelled at an earlier stage of the fire, effectively prolonging the evacuation time.

4. CONCLUSION

The natural ventilation effect can reduce the energy consumption of air-conditioning systems due to the effectiveness of the air exchange effect. This design concept is very similar to the barns used during the Edo period of Japan. Ventilation of architectural environments has a positive effect on "daily energy saving" and "indoor health and environment". However, it has been shown that the natural ventilation effect of green building can also influence the diffusion of dense smoke during a fire.

Considering both "safety" and "energy saving", this study used the FDS to simulate the indoor pressure, temperature, velocity and smoke flow at the fire scene. A natural smoke vent was set in the upper part of the wall behind the auditoria to evaluate the smoke discharge efficiency. The results show that when the fire occurs at the front platform, the rate of emission of smoke from a large building can be increased by 16.8% and that, as the smoke layer descends more slowly, the evacuation time on the left and right sides can be increased by 95 seconds and 77 seconds.

REFERENCES

Baum, H. R., McGrattan, K. B. and Rehm, R. G. 1994. Simulation of smoke plumes from large pool fires. In Symposium (International) on Combustion, 25(1), 1463-1469.

Cai, N. and Chow, W. K. 2014. Numerical studies on heat release rate in a room fire burning wood and liquid fuel. Tsinghua University Press. In Building Simulation, 7(5), 511-524.

Chow, W. K. 2003. Fire safety in green or sustainable buildings: Application of the fire engineering approach in Hong Kong. Architectural Science Review, 46(3), 297-303.

Ding, G. K. 2012. Environmental assessment tools. Handbook of Sustainability Management, World Scientific, Singapore, 441-471.

Floyd, J., Forney, G., Hostikka, S., Korhonen, T., McDermott, R. and McGrattan, K. 2013. Fire Dynamics Simulator User's Guide. Gaithersburg, Maryland, USA.

Hansen, K., Braungart, M. and Mulhall, D. 2013. Resource Repletion resource repletion, Role of Buildings. In Sustainable Built Environments. Springer New York, pp. 502-525.

He Ming Jin, Hsien-Te Lin, Zhuang Huiwen, Chen M, Zhang Yi from. 2012. Green Building Assessment Handbook: Accommodation category, ABRI, Taipei, Taiwan. (in Chinese)

Lin, L. W., Chen, C. H., Chang, H. C. and Chen, T. C. 2008. Applying the grey assessment to the evaluation system of ecological green space on greening projects in Taiwan. Environmental monitoring and assessment, 136(1-3), 129-146.

Mang, P. and Reed, B. 2013. Regenerative Development regenerative development and Design. In Sustainable Built Environments. Springer New York, pp. 478-501.

Shen, T. S., Chien, S. W., Li, C. Y., Chen, C. C. and Chen, T. Y. 2013. Fire Safety Analysis on the Historical Heritages with Southern Fukien Style: Example on Tainan Grand Matsu Temple in Taiwan.

Smardz, P. and Novozhilov, V. 2006. Validation of Fire Dynamics Simulator (FDS) for forced and natural convection flows. University of Ulster, 16-20.

Su, C. H., Tsai, K. C. and Xu, M. Y. 2014. Computational analysis on the performance of smoke exhaust systems in small vestibules of high-rise buildings. Journal of Building Performance Simulation, (ahead-of-print), 1-14.

Tidwell, J. and Murphy, J. J. 2010. Bridging the Gap: Fire Safety and Green Buildings. National Association of State Fire Marshals.