COMPUTER SIMULATION ON NATURAL VENTILATION DESIGN OF A WAREHOUSE

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requirements for the award of the degree of
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To my beloved father and mother,

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ABSTRACT

A typical warehouse has metal cladding-steel frame structure and overheating can easily occur due to solar radiation and stratified space especially in region with hot and humid climate such as Malaysia, The studied warehouse is located in Johor Bahru and can be regarded as a typical warehouse. Temperature measurements had been made on a windless afternoon and the indoor has an average of 32°C. Diesel powered forklift was operating and mechanical ventilation system is absent to exhaust the pollutants out of the warehouse. Thermal Comfort and minimum airflow rate may not be fulfilled as stated by ASHRAE. This thesis is aim to study the effect of natural ventilation on the warehouse via computer simulation. The software used is ANSYS FLUENT. From the simulated results, it has shown that when wind is absent, the stack effect natural ventilation took place in the warehouse. However, stack effect is ineffective to remove heat from the compound. While cross ventilation takes place when there is presence of wind. Cross ventilation had greatly improve the condition but still unable to fulfil requirements stated by ASHRAE. Three more natural ventilation strategy are then integrated into the existing warehouse, namely: increasing window-to-wall ratio (WWR) close to 0.24, lengthen the roof ridge and installing the turbine ventilators and the former case shows greatest improvement in airflow.

ABSTRAK

Gudang tipikal mempunyai struktur bingkai besi dan mempunyai lapisan logam sebagai pelindung. Kejadian pemanasan yang melampau boleh berlaku dalam ruang gudang disebabkan radiasi matahari dan berlakunya stratifikasi. Terutamanya gudang yang terletak di rantau khatulistiwa yang mengalami iklim panas dan lembap seperti Malaysia. Gudang yang dikaji terletak di Johor Bahru dan boleh dianggap sebagai gudang tipikal . Pencatatan suhu di dalam ruang gudang telah merekodkan suhu dengan purata 32 ° C pada waktu petang petang dalam situasi tanpa angin. Jentera “Forklift" berkuasa Diesel didapati beroperasi dalam gudang. Tetapi. sistem pengudaraan mekanikal tidak wujud dan bahan pencemar dari enjin jentera tidak dapat dibuang dari gudang degan efektif. Keselesaan dan kadar aliran udara minimum mungkin tidak dapat dipenuhi seperti yang dinyatakan oleh ASHRAE. Tujuan tesis ini adalah mengkaji kesan pengudaraan semula jadi di dalam gudang melalui simulasi komputer. Perisian yang digunakan adalah ANSYS FLUENT. Hasilan simulasi telah menunjukkan “stack effect” mendominasikan aliran udara dalam gudang. Walaubagaimanapun, kesan ini tidak berkesan untuk menghilangkan haba. Bertentangan dengan itu, “cross ventilation” mendominasi aliran udara semasa kehadiran angin. “Cross Ventilation” telah memperbaiki keadaan dalam gudang tetapi keperluan yang dinyatakan oleh ASHRAE tidak dapat dipenuhi. Tiga lagi strategi ventilasi semulajadi kemudian diintegrasikan ke dalam rekabentuk gudang yang sedia ada, iaitu: meningkatkan nisbah jendela ke dinding (WWR) ke hampir 0.24, memanjangkan rabung bumbung dan memasang ventilator turbin dan modifikasi pertama menunjukkan peningkatan yang terbaik dalam aliran udara.

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LIST OF ABBREVATIONS

CO_2	-	Carbon Dioxide
SBS	-	Sick Building Syndromes
CFD	-	Computational Fluid Dynamic
HVAC	-	Heating, Ventilation and Air-Conditioning
3D	-	3-Dimensional
CAD	-	Computer Aided Design
WWR	-	Window-to-wall Ratio
ACH	-	Air Change per Hour

LIST OF SYMBOLS

W	-	Watt
mm	-	Millimetre
m	-	Metre
m^2	-	Square Metre
m^3	-	Cubic Metre
CFM	-	Cubic Feet per Minute
ft^2	-	Square Feet
atm	-	Atmospheric Pressure
kg	-	Kilogram
K	-	Kelvin (Temperature)
°C	-	Degree Celcius (Temperature)

CHAPTER 1

INTRODUCTION

1.1 Natural Ventilation as Effective Passive Design Strategy

In early twentieth century, a building had narrow floor plans or has large spaces with high ceiling. Both of these configurations is favourable for natural ventilation due to proximity of windows for wind-driven natural ventilation or the provision for a warm stratified upper air layer to accumulate and exhaust indoor pollutants in the case of stack-driven natural ventilation. In early 1950's buildings evolved into deep plan spaces with lower ceiling heights and this change has been consolidated in 1960s with the extensive use of fluorescent lighting and air conditioning (Arnold, 1999). These had aid the adoption of deep building plan that eliminates internal courtyards and light-wells, maximizing the total leasable space in a given plot. In 1980s, the increasing common use of personal computer had resulted in a rise in internal gains which is nearly tripled for the same occupation density in the former case (Arnold, 1999).

With the increasing momentum of the use of mechanical ventilation and air conditioning during second half of 20th century, existing knowledge on the integration of natural ventilation systems as a design and architectures features had become obsolete (da Graca & Paul, 2016). Meanwhile, the increasing of expectations and thermal comfort and indoor air quality standards had urged designers and building owners to choose the more reliable mechanical ventilation option making natural ventilation a scarce building feature in modern non-domestic buildings.

Hence, it is not surprising to find a non-domestic building using mechanical ventilations even when an optimised natural ventilation system could fulfil its cooling and fresh air requirements.

Study by others had pointed out that typical mechanical ventilation fan energy consumption is similar to the indoor lighting, ranging power densities of 5 to 15W/m^2 (Westphalen & Scott, 1999). Whereas, the mechanical cooling system in hot and humid climate region can consume about twice as much energy and compounding 50% to 60% of total building energy consumption (Perez-Lombard, Jose, & Christine, 2008).

However, Yau had reported that majority of the occupants had been feeling uncomfortable from unpleasant odour resulting from the returning air circulation inside the building itself. This is due to design failure in HVAC systems in fulfilling the requirement of our distinctive hot and humid climates (Y.H., 2008). Bad HVAC design could also lead to sick building syndrome (SBS). This is due to high concentration of CO_2. The prevailing main symptoms could include headache, lethargy, and dryness in body mucus (S., M., & R., 2007).

Bear in mind that natural ventilation brings in fresh air and can easily overcome the above problem. Moreover, Haw et al. had suggested that natural ventilation can be quite cost-effective in term of capital, maintenance and operational costs. In addition, it also does not need any plant room space (Haw, Saadatian, Sulaiman, Mat, & Sopian, 2012).

In Rio Summit 1992, the urge of integrating passive design into buildings had been brought out once again and natural ventilation can be considered as most effective passive design strategy. For example, flats that utilises natural ventilation could reduce air-conditioning energy by 24% without compromising thermal comfort (F.W.H & Y.T., 2010).

1.2 Overview of Natural Ventilation

Natural ventilation is an effective passive strategy to improve indoor air quality. It is capable of providing fresh air into a space and dilutes the indoor pollution concentration (Haw, Saadatian, Sulaiman, Mat, & Sopian, 2012).

Natural ventilation is also known to have capability to replace mechanical cooling systems, reducing energy demand related to ventilation and cooling by half and reduce sick building syndrome (da Graca & Paul, 2016). Evidence had also shown that worker productivity is improved when buildings' CO_2 level is low. This can be easily achieved in a building that characterise natural ventilation by letting occupants to gain control over their environment with operable windows.

Yet, design practitioners and sustainable architecture consultants struggle to integrate natural ventilation in modern designs despites of all the benefits mentioned above. This is mainly due to the late involvement of energy efficiency consultants, low fees to support a complex design analysis, lack of natural ventilation design experience and risk of destroying the aesthetic value of the exterior look (Linden, et al., 2014).

Hence, the process of integrating natural ventilation shall be carried out in the early design stage so adequate external shading and natural ventilation features can have significant impact in the final design (Linden, et al., 2014).

Besides, natural ventilations may require advanced control system that is able to vary the openings area throughout the year. The system shall be well commissioned and user friendly to the building occupants. This had also hindered the use of natural ventilation in new non-domestics buildings even in places with ideal climates (da Graca & Paul, 2016).

In addition to the above design issues, opening windows in city environments can be discouraging due to air and noise pollution.

Undeniably, implementation of natural ventilation in non-domestic buildings poses significant challenges. Nevertheless, continuous development of software models had increased precision and reliability during design phase predictions of natural ventilation system performance. 3D CAD-based tools will be able to provide a better collaborative environment and important feedback during early design phase (Martins & Guilherme, 2016).

Generally, there are two main driving forces for inducing natural ventilation: wind and stack (buoyancy) which can be generated by solar and internal gains.

1.3 Research Background

In the year 2014, Tetsu & Hooi had carried out field measurements to investigate traditional timber Malay houses and masonry Chinese shophouses in Malaysia. The buildings' indoor thermal environments and passive cooling techniques were determined and analysed. In their findings, they found out that Malay house sites had generally 1.7 °C lower temperature when compare to the terraced house site due to various microclimates and less urban heat island effects. Similarly, shophouses that have small courtyards will experience 5-6 °C lower than the outdoors temperature during daytime. Small courtyards are also effective in enhancing night ventilation and nocturnal radiant cooling. They concluded that night ventilation is the most promising passive cooling strategies, able to cool down 2 °C for high thermal mass structures. They also pointed out the importance of roof insulation and window/wall shadings as Malaysia has high solar altitude and solar radiation can increase indoor heat (Tetsu & Hooi, 2014).

Another field study had also been done to study the influence of single-sided ventilation of high-rise building in Kuala Lumpur (Aflaki, Mahyuddin, & Baharum, 2016). According to their findings, units that face windward side (0.52 m/s) have the potential to reach 90% thermal acceptability in certain areas. They also concluded that indoor air temperature and relative humidity were influenced by building orientation and height.

Researchers from University Science Malaysia had also done case study on natural ventilation of a traditional Malay House in Penang. The Malay House has double roof system that induces stack effect whereas the overall openings on the building surfaces had created high air intakes when wind is presence emphasising cross ventilation. In their research, they also categorised outdoor wind speed level according time and found out that air velocity increases from light air in the early morning and developed into fresh breeze with peak recorded velocity of 10.7m/s in the evening. The average indoor humidity can ranged from 70 to 82.7% during 6 to 10am and drop to 61 to 70.5% at 11am to 6pm. However, the most discomfort recorded is at 2pm (Sanusi Hassan & Ramli, 2010).

Chan, et al. had study the correlation of passive design and users thermal comfort and expectation for schools around Negeri Sembilan. In their study, respondents do agree that passive designs do contribute in sustaining thermal comfort levels but the contribution is not significant. Futhermore, most of the respondents did not show interest in the addition of passive design elements to further enhancement of natural ventilation (Chan, Che-Ani, & Nik Ibrahim, 2013). However, this perception is refutable as researchers from Germany (Wang, et al., 2014) and Portugal (M. Mateus, Nunes Simões, Lúcio, & Carrilho da GracaInstituto, 2016) had showed natural ventilation can be improved by integrating appropriate passive design into classrooms.

In Thailand, researchers explored the potential of using natural ventilation as passive cooling system for new house design in Thailand. They also developed comprehensive guidelines for that via computational fluid dynamics and the deisgn is capable of providing thermal comfort in suburb 20% of the year (Tantasavasdi, Srebric, & Chen, 2001). Meanwhile, Benni and his team from Italy had ran numerical simulation on configurations of roof vents in a greenhouse and the maximum heat removal achievable via natural ventilation is 64% (Benni, Tassinari, Bonora, Barbaresi, & Torreggiani, 2016).

Kendrick, et al. assess a typical modern portal frame, day-lit rooflight warehouse building's annual heating loads and summertime thermal comfort in the south of UK. The warehouse experience overheating when unventilated and introducing natural ventilation can eliminate that. In their findings, they stated that mechanical was less effective when compare to open cargo doors in conjunction with ridge vents. Their findings also shows that thermal stratification can easily occurs at mezzanine level (Kendrick, Wang, Walliman, & Ogden, 2011).

Whereas another findings based in Malaysia researchers had showed that warehouse without proper air ventilation can cause congregation of high indoor temperature and humidity. This can lead health hazards. They proposed the installation of wind driven turbine ventilator and increasing openings in warehouse's surfaces to increase windward and leeward winds. The proposal may reduce the indoor temperature by 4 °C, increasing thermal comfort (Muhieldeen, et al., 2015).

1.4 Problem Statement

From above, we had seen experimental and simulation work has been done on domestics and commercial building but no detailed simulation work has been carried out on warehouses in hot and humid climates.

Most warehouses where loading/unloading doors are open during the working day will not usually require any special ventilation arrangements. However, specific ventilation requirements may be necessary for the storage of some materials or where equipment such as oil- or gas-fired heaters and lift trucks with internal combustion engines are used inside the warehouse (DOSH Malaysia, 2015).

The other main issues in a warehouse also included:

(a) Contaminant source control
(b) Appropriate level of fresh air ventilation
(c) Filtration of air to remove particulate and other contaminants
(d) Humidity management

There are air quality issues in warehouses are covered by ASHRAE Standard 62-2001 Ventilation for Acceptable Indoor Air Quality.

In short, the problem statement is as follow.

Natural ventilation has been study extensively via experiment and CFD in commercial & residential buildings but not warehouse in hot and humid climate. Typical warehouse has metal cladding-steel frame structure, overheating can occur easily via solar radiation and stratified space. Furthermore, the stated below also cannot be fulfilled.

(a) Thermal comfort cannot be achieved.
(b) Pollutants emitted via diesel-powered forklift truck is not exhausted effectively.
(c) Area outdoor air rate of 0.06 CFM/SQFT as covered by ASHRAE Standard 62-2001 Ventilation for Acceptable Indoor Air Quality may not fulfilled (ASHRAE, 2003).

1.5 Research Objectives

The purpose of this project is to propose an optimal natural ventilation strategy for a typical warehouse that provide storages for non-chemical reactive, non-hazardous, non-organic inventories in hot and humid climates such as Malaysia.

(a) To identify the existing ventilation strategy and heat load in a typical warehouse
(b) To evaluate different natural ventilation design strategies that can reduce warehouse indoor temperature and increase air exchange rate.

1.6 Research Questions

(a) What are the existing ventilation strategy and the source of heat load in a typical warehouse?
(b) Is the existing ventilation design able to fulfil the required air exchange rate as stated in ASHRAE regulation and provide thermal comfort?
(c) Can we utilise Computation Fluid Dynamic (CFD) software to solve the problem?

1.7 Scope of the Project

(a) The warehouse being studied provide storages for nonchemical reactive, non-hazardous & non-organic inventories.
(b) The warehouse is located in Kawasan Perindustrian Tebrau III, next to Pasir Gudang Highway.
(c) The warehouse has a floor area of 5,800m^2.
(d) The maximum height of the warehouse is 11.7m whereas the minimum height is 8m.
(e) ANSYS FLUENT is used as a CFD tools to solve the problem.

REFERENCES

Aflaki, A., Mahyuddin, N., & Baharum, M. (2016). The influence of single-sided ventilation towards the indoor thermalperformance of high-rise residential building: A field study. Energy and Buildings(126), 146–158.

Ahmed Ameer, S., Nasarullah Chaudhry, H., & Agha, A. (2016). Influence of roof topology on the air distribution and ventilationeffectiveness of wind towers. Energy and Buildings, 733–746.

ALSYNITE. (n.d.). Industrial Turbine Ventilators. Retrieved from Alsynite New Zealand: http://www.alsynite.co.nz/assets/Uploads/Products/Files/DIMENSIONS-Industrial-Vent-Specs-Brochure-180913-WEB.pdf

Arnold, D. (1999). The evolution of modern office buildings and air conditioning. ASHRAE Journal 41, No. 6, 40.

Aynsley, R. (2007). Natural ventilation in passive design. BEDP Environment Design Guide Tec 2.

Baghaei Daemei, A., Khalatbari Limaki, A., & Safari, H. (2016). Opening Performance Simulation in Natural Ventilation using Design Builder (Case Study: A Residential Home in Rasht). 3rd International Conference on Power and Energy Systems Engineering (pp. 412-422). Kitakyushu, Japan: Energy Procedia.

Benni, S., Tassinari, P., Bonora, F., Barbaresi, A., & Torreggiani, D. (2016). Efficacy of greenhouse natural ventilation: Environmental monitoringand CFD simulations of a study case. Energy and Buildings(125), 276-286.

Brown, G., & Deekay, M. (2001). Sun, Wind and Light: Architectural Design Strategies 2nd Edition. New York: John Wiley and Son Inc.

Cardinale, N., Micucci, M., & Ruggiero, F. (2003). Analysis of energy saving using natural ventilation in a traditional Italian building. Energy and Buildings, 153-159.Chan, S., Che-Ani, A., & Nik Ibrahim, N. (2013). Passive designs in sustaining natural ventilation in school. International Journal of Sustainable Built Environment(2), 172-182.

Chu, C.-R., Chiu, T.-H., Tsai, Y.-T., & Wu, S.-L. (2015). Wind-driven natural ventilation for buildings with two openings on the same external wall. Energy and Buildings, 365-372.

Chung, L., Ahmad, M., Remaz Ossen, D., & Hamis, M. (2015). Effective solar chimney cross section ventilation performance in Malaysia terraced house. International Conference Green Architecture for Sustainable Living and Environment (GASLE), (pp. 276-289).

da Graca, G., & Paul, L. (2016). Ten questions about natural ventilation of non-domestic buildings. Building and Environment, 107, 263-273.

DOSH Malaysia. (2015). Guidelines on Occupational Safety and Health in Courier Services Industry. Department of Occupational Safety and Health (DOSH) Malaysia.

Driss, S., & Driss, Z. (2015). Numerical simulation and wind tunnel experiments on wind-induced natural ventilation in isolated building with patio. Energy, 917-925.

F.W.H, Y., & Y.T., L. (2010). Energy saving by utilizing natural ventilation in publichousing in Hong Kong. Indoor and Built Environment(19), 73-87.

Gaber Farea, T., Remaz Ossen, D., Alkaff, S., & Kotani, H. (2015). CFD modeling for natural ventilation in a lightwell connected tooutdoor through horizontal voids. Energy and Buildings, 502-513.

GBI Certified Buildings. (2011). Retrieved from Green Building Index: http://www.greenbuildingindex.org/organisation-certifiedbuildings.html

Haw, L., Saadatian, O., Sulaiman, M., Mat, S., & Sopian, K. (2012). Empirical study of a wind-induced natural ventilation tower under hot. Energy and Buildings, 28-38.

Hughes, B., & Cheuk-Ming, M. (2011). A study of wind and buoyancy driven flows through commercial wind towers. Energy and Buildings.

Jamaludin, A., Hussein, H., Mohd Ariffin, A., & Keumala, N. (2014). A study on different natural ventilation approaches at a residential college building with the internal courtyard arrangement. Energy and Buildings(72), 340-352.

Ji, Y., Cook, M., & Hanby, V. (2007). CFD modelling of natural displacement ventilation in an enclosure connected to an atrium. Building and Environment, 1158-1172.

Kannan, K. (2006). Implementing energy efficiency in buildings. SIRIM Standards & Quality News.

Kendrick, C., Wang, X., Walliman, N., & Ogden, R. (2011). Evaluation of Ventilation Strategies to Reduce Overheating in a Typical Metal Clad Building with In-Plane Roof-Lights. International Journal on Architectural Science, 8(2), 37-46.

KHP Kimdeck. (n.d.). KHP KIMDECK Metal Roofing. Retrieved from KHP KIMDECK.

Linden, P., David , B., Nick, D., Marc, F., Greg, G., Anoop, H., & et al. (2014). Natural Ventilation for Energy Savings in California Commercial Buildings.

M. Mateus, N., Nunes Simões, G., Lúcio, C., & Carrilho da GracaInstituto, G. (2016). Comparison of measured and simulated performance of naturaldisplacement ventilation systems for classrooms. Energy and Buildings, 185-196.

Martins, N., & Guilherme, C. (2016). Validation of numerical simulation tools for wind-driven natural ventilation design. Building Simulation, 9(1), 75-87.

Mat, S. (2005). Natural Ventilation in the Urban Environment: Assessment and Design. In C. G. Allards, Energy in the urban built environment: The role of natural ventilation. (pp. 1-19). London: Earthscan.

MatWeb. (n.d.). ASTM A525 Galvanised Steel. Retrieved from MatWeb: http://www.matweb.com/search/datasheet.aspx?matguid=abbf07b7f93a4c358a0ddd194f5c18be

Muhieldeen, M., Loi, D., Paramanandam, V., Wong, M., Arthimoorthy, B., Yeo, C., . . . Koh, G. (2015). Combined Ventilation Methods in a Large Scale Warehouse Building to Reduce Indoor Air Temperature. American Journal of Energy and Power Engineering, 5(2), 74-78.

Nejat, P., Kaiser Calautit, J., Abd. Majid, M., Richard Hughes, B., & Jomehzadeh, F. (2016). Anti-short-circuit device: A new solution for short-circuiting in. Building and Environment, 24-39.

Nishi, Y. (1981). Measurement of Thermal Balance of Man. Bioengineering, Thermal Physiology and Comfort, Cena, K. and J.A. Clark (Eds.)., 1st Edn., pp: 29-39.

Peren, J., van Hoofff, T., Leite, B., & Blocken, B. (2015). CFD analysis of cross-ventilation of a generic isolated building with asymmetric opening positions: Impact of roof angle and opening location. Building and Environment, 263-276.

Perez-Lombard, L., Jose, O., & Christine, P. (2008). A review on buildings energy consumption information. Energy and buildings(40), 394-398.

Reardon, C. (2008). Passive Design. Your Home Technical Manual, 4th Edn., pp: 69-70.

Rockwool Asia. (n.d.). Roofing Applications using ThermalRock Blanket and ThermalRock Slab Insulation. Retrieved from Rockwool: http://www.rockwool.in/files/RW-IN/pdfs/product_brochures/RW_ThermalRockB_IN_LR.pdf

S., G., M., K., & R., G. (2007). Sick building syndrome: a case study in a multistorycentrally air conditioned building in Delhi city. Building and Environment, 2797-2809.

Sanusi Hassan, A., & Ramli, M. (2010). Natural Ventilation of Indoor Air Temperature: A Case Study of the Traditional Malay House in Penang. American J. of Engineering and Applied Sciences, 3(3), 521-528.

Tantasavasdi, C., Srebric, J., & Chen, Q. (2001). Natural ventilation design for houses in Thailand. Energy and Buildings, 815-824.

Tetsu, K., & Hooi, D. (2014). Application of passive cooling techniques in vernacular houses to modern urban housese: A case study of Malaysia. International Conference Green Architecture for Sustainable Living and Environment (GASLE).

Utama, N., Muhammad Fathoni, A., & A. Kristianto, M. (2014). Passive Application through Solar Induce Ventilation on Sustainable Building in Equatorial Hemisphere. Procedia Environmental Sciences 20, (pp. 126-130).

Wang, H., & Chen, Q. (2015). Modeling of the impact of different window types on single-sided natural ventilation. 6th International Building Physics Conference, IBPC (pp. 1549-1555). Energy Procedia.

Wang, L., & Wong, N. (2007). The impacts of ventilation strategies and facade on indoor thermal environment for naturally ventilated residential buildings in Singapore. Building and Environment, 4006-4015.

Wang, Y., Zhao, F.-Y., Kuckelkorn, J., Liu, D., Liu, J., & Zhang, J.-L. (2014). Classroom energy efficiency and air environment with displacementnatural ventilation in a passive public school building. Energy and Buildings(70), 258-270.

Westphalen, D., & Scott, K. (1999). Energy consumption characteristics of commercial building HVAC systems volume II: thermal distribution, Auxiliary equipment, and ventilation. US Department of Energy.

Y.H., Y. (2008). A preliminary thermal comfort study in tropical buildings located in Malaysia. International Journal of Mechanical and Materials Engineering(3), 119-126.

Yang, X., Zhong, K., Kang, Y., & Tao, T. (2015). Numerical investigation on the airflow characteristics and thermalcomfort in buoyancy-driven natural ventilation rooms. Energy and Buildings, 109, 255–266.