Thermal performance of reused shipping containers as building components

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\textbf{Abstract.} The era of disruption occurred influenced by innovations that emerged according to the needs and developments of the times. This occurs in various sectors, including the construction industry sector. One of the growing innovations in the construction industry sector is the reuse of shipping containers (SC) into buildings with various functions. The trend of using SC as buildings is quite significant. Several sectors have used a lot of SC as buildings, including: Offices, educational, commercial and residential. However, the reuse of SC as a building has several weaknesses, one of which is the thermal aspect. The structure of the container, which is generally composed of steel, should be considered in achieving indoor thermal comfort. The case study of the paper was SC buildings at Institut Teknologi Sains Bandung (ITSB). The aims of this study were to determine the contribution of design parameters of SC to indoor thermal comfort and its effect on energy efficiency. The method was model simulation on the thermal aspect using Sefaira software. The results showed that setting of design parameters considerably contributed to thermal comfort and energy efficiency.

1. Introduction

The use of shipping containers (SC) as buildings has tended to increase over the last 10 years. This has been influenced by the increase in shipments of goods using SC from countries in Asia to Europe and United States (US). On the other hand, in particular the US did not reuse SC for reexporting goods to Asia. This caused US have an excess of containers. Based on data from the Maritime Administration of the US Department of Transportation, there were more than 5 million unused of SC [1]. Meanwhile, to recycle these SC into steel products were very inefficient, because it has a large embodied energy impact [2-5]. Therefore, US prefers to move these SC to Asia for reuse. The trend of reuse of these SC is on the increase. Many of the world's architects have been reused SC into feasible and comfortable residential buildings [1]. This also affects the increasing demand for SCs. The modular shape of the container [7], the rapidity of construct, the sturdy steel structure [8], and the lower cost when compared to other constructions are the aspects that are considered in choosing a SC for a building. Some of these factors trigger disruption in the construction industry sector [9]. Several sectors, such as commercial, social and residential [6], even the education sector have converted many of these containers into buildings that are feasible, but still aesthetically attractive.

In terms of thermal aspects, thermal comfort is an important factor in designing buildings using SC. The structure of SC, which is generally made of steel, certainly has an impact on changes in indoor air temperature, because steel is a good medium for heat propagation. Artificial ventilation, such as Air...
Conditioning (AC), has been considered the most ideal solution to solve the problem of thermal comfort, but it certainly uses a lot of energy. The addition of insulation material to steel walls of SC, is one of strategy to create indoor thermal comfort [4,10,11]. Walls and roofs are components of thermal modifiers. The influence of openings and roof designs are important factors in designing SC buildings through a passive design approach. Thermal performance can be identified through several indicators, namely; Conductivity, u-values, air tightness, other measures [12]. Relating to the performance of passive building designs, it can be done through an approach of six basic principles, namely superinsulation, eliminating thermal bridges, airtight construction, ventilation, high-performance windows, and optimization of passive-solar gains [13].

The aims of this study are to determine the contribution of design parameters of SC in maximizing natural ventilation, to achieve indoor thermal comfort and its effects on energy efficiency.

2. Method

2.1. Case study

The case study is located in Bekasi 6°14′ S, 106°59′ E, at an altitude of 18 m. This study took the case of SC building at Institut Teknologi Sains Bandung (ITSB) Campus area which is planned to be used as a classroom for several study programs.

Figure 1. SC at ITSB
2.2. Temperature

ITSB is located in the Kota Deltamas area, Bekasi. The highest average air temperature in October was 33 °C, the lowest temperature was 22.6 °C, and the average temperature was 27.8 °C. In this case, the air temperature is warm. The following is the air temperature data for Bekasi area for the period January to December 2019 [14].

![Weather by Month](image)

**Figure 2.** Weather by month [14]

2.3. Building components and materials

The dimensions per unit of SC used were 12.192 m long, 2.4 m wide, and 2.9 m high [15]. The building components consist of a steel structure as a supporting frame, SC as a classroom. The floor is covered by tiles, for SC walls covered by insulation material gypsum. Spandex is used for roof coverings (figure 3).

![Building components and materials](image)

**Figure 3.** a. Construction process of SC, b. ceramic floor, c. glass wool, d. gypsum
2.4. Simulation
This study was an initial stage to determine the performance of SC with passive design approach. This study consists of 2 (two) stages, namely:
   a. Modeling using SketchUp software
   b. Simulation and analysis using Sefaira software based on ASHRAE standards [16]

The strategy conducted to optimize passive design aspects was through the setting of building orientation, u-value of wall components, window and roof design. However, the shading component was not simulated in this study.

![Modeling used sketchup software](image)

**Figure 4.** Modeling used sketchup software

![Simplified geometry for simulation](image)

**Figure 5.** Simplified geometry for simulation

2.5. Methodology flow chart
Figure 6 below is the steps conducted to examine the influence of design aspects on thermal comfort and energy efficiency.
3. Result and Discussion

3.1. Building Orientation

Figures below were comparison of energy consumption based on orientation between building with natural ventilation and building with natural ventilation + cooling. The orientation of the building was to the North. Figure 7 shows the annual energy consumption which is certainly lower than the building scheme that uses natural ventilation + cooling, which is 166.5 kWh / m² / yr. In this case, building with natural ventilation schemes certainly shows better projections regarding energy savings. The graph in Figure 8 shows a fairly high annual energy consumption, which is above 183 kWh / m² / Yr. The value should be lower than the set concept value of 181 kWh / m² / Yr.

![Figure 6. Methodology flow chart](image)

![Figure 7. Orientation and natural ventilation scheme](image)
3.2. U-value of wall material

The graph in figures 9 below were comparison u-value of wall material to thermal comfort and energy efficiency. Material taken in Sefaira was exterior insulation with 0.20 W/m²·K. The simulation results related to the u-value of the wall based on natural ventilation and natural ventilation + cooling show that on the left graph, energy was low but comfort was not achieved, while on the right, when natural ventilation was not optimum, energy was needed to condition the room (natural ventilation + cooling). Thermal comfort was achieved but required around 7 kWh/m² to lower temperature of the room. Theoretically, lowering the u-value of wall material the output should be better.

Figure 8. Orientation natural ventilation + cooling scheme

Figure 9. Comparison schemes based on u-value of wall
3.3. Passive design schemes
Based on the graph, thermal comfort and energy used are also quite affected by differences in simulation schemes. The u-value of the wall was the same, but the passive parameter approach of the design was different. WWR and window type was influence the optimization of natural ventilation, and energy used could be reduced by 2 kWh / m² / yr. These results was preliminary findings and more iterations are needed on the design aspects in order to obtain optimum results. In previous studies conducted at the same location, but with different building, natural ventilation was sufficient to contribute to the indoor thermal comfort on a scale of 0-1 (neutral-slightly warm) [19, 20]

![Comparison of passive design schemes](image)

**Figure 10.** Comparison of passive design schemes

4. Conclusion
Thermal performance of SC through u-value of walls simulation and passive design parameters (natural ventilation only and natural ventilation combined with cooling) contributed to the indoor thermal comfort and energy consumption in the SC building. Based on the simulation, the contribution of walls and passive design parameters to the average of thermal comfort was 40% hrs. However, these result was not optimum. Thermal performance can be increased through optimizing the application of shading and window settings, both U-value setting and window operation. Therefore thermal comfort can be achieved and energy consumption can be reduced.

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6. References
[1] Discover containers. Shipping Container History: Boxes to Buildings; 2020; https://www.discovercontainers.com/a-complete-history-of-the-shipping-container/. Accessed on 29 April 2020.
[2] Abrasheva, G., Senk, D., and Häußling, R. Shipping Containers for a Sustainable Habitat Perspective, Revue de Métallurgie; 2012; vol. 109, pp. 381-389.

[3] Islam, H., Zhang, G., Setunge S., and Bhuiyan, M.A. Life Cycle Assessment of Shipping Container Home a Sustainable Construction, Energy and Building; 2016; vol. 128, pp. 673-685.

[4] Bernardo, L.F., Oliveira, L.A., Nepomuceno, M.C., and Andrade, J.M. Use of Refurbished Shipping Containers for the Construction of Housing Buildings: Details for the Structural Project, Journal of Civil Engineering and Management, 2013; vol. 19 pp. 628-646.

[5] Ismail, M., Al-Obaidi, K.M., Rahman, A.M.A., and Ahmad, M.I. Container Architecture in the Hot-Humid Tropics: Potential and Constraints, presented at the International Conference on Environmental Research and Technology (ICERT); 2015; Malaysia

[6] Smith, J.D. Shipping Containers as Building Components; 2006; University of Brighton, Department of the Built Environment

[7] Garrido, L. D. Green Container Architecture 3; 2015; Monsa

[8] Aktan, I. Reusing Shipping Containers: What are the Advantages and Challenges?; https://www.morethanshipping.com/reusing-shipping-containers-advantages-challenges/ (accessed on October 14, 2020)

[9] Romano, K. Construction Executive; 2019; https://constructionexec.com/article/fivemounting-forces-disrupting-the-construction-industry-dont-be-caught-by-surprise (accessed on October 14, 2020)

[10] Hidayat, M.S., Munardi. The Shipping Container as Commercial Building: The Process of Construction and Thermal Comfort Condition, International Journal of Recent Engineering Research and Development (IJRERD); 2018; pp. 181-189

[11] Adenaike, F.A. An Assessment of Thermal Performance of Office Units Built With Shipping Containers Around Lagos, International Journal of Scientific & Engineering Research; 2018; vol.9, issue 2.

[12] Designing buildings wiki. 2020; https://www.designingbuildings.co.uk/wiki/Thermal_performance_of_buildings. Accessed on November 6, 2020.

[13] Roetzel, A., Tsangrassoulis, A., Dietrich, U., Busching, S. A review of occupant control on natural ventilation, renewable and sustainable energy reviews; 2010; volume 14, issue 3, Pages 1001 – 1013.

[14] Climate-data.org. https://en.climate-data.org/asia/indonesia/west-java/bekasi-31803/ (accessed on October 14, 2020)

[15] Shen, J., Copertaro, B., Zhang, X, Koke, J., Kaufmann, P., Krause S. Exploring the Potensial of Climate-Adaptive Container Building Design under Future Climates Scenarios in Three Different Climate Zones

[16] Corney A., Bajic, V. How to improve ASHRAE 55 and Make it More Relevant, Conference and SimBuild co-organized by ASHRAE and IBPSA-USA; 2018; Chicagom, IL.

[17] Weather file source. https://www.ladybug.tools/epwmap/ (Accessed on, October 14, 2020)

[18] ANSI/ASHRAE/IESNA. Standard 90.1-2007 Normative Appendix B – Building Envelope Climate Criteria; Tables B-2, B-3, and B-4

[19] ASHRAE. Thermal Environmental Conditions for Human Occupancy, ANSI/ASHRAE; 2013; Addendum b to ANSI/ASHRAE Standard 55

[20] Risnandar, F.A.R. Kenyamanan Termal dan Kepuasan Pengguna Ruang Kelas di Gedung Kampus ITSB; 2019; Journal of Applied Science, vol. I, no. 1, p. 012–021.