International Journal of Technology (2017) 7: 1182-1190
ISSN 2086-9614 © IJTech 2017

STACK EFFECT ON POWER CONSUMPTION OF REFRIGERATED CONTAINERS IN STORAGE YARDS

Muhammad Arif Budiyanto[1*], Takeshi Shinoda[2]

[1]*Department of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia, Kampus UI Depok, Depok 16424, Indonesia*
[2]*Department of Marine System Engineering, Faculty of Engineering, Kyushu University, 744 Motooka Nishi-ku Fukuoka, 819-0395 Japan*

(Received: January 2017 / Revised: June 2017 / Accepted: October 2017)

ABSTRACT

This paper investigates the stack effect on the power consumption of refrigerated containers. The investigation is based on measurement experimentation that was conducted in Hakata Island City Container Terminal, Fukuoka, Japan. Experimentation was carried out over summer 2015, using three stacks of high cube refrigerated containers. Several sensors and devices were employed to ascertain parameters, including pyranometers, thermocouples, and power analyzers. Five units of pyranometers were set on a horizontal and vertical plane, facing all cardinal directions. Thermocouples were installed inside and outside of walls at a total of twenty points. Power meters employed to measure energy consumption were set on the power plug station nearby the measurement object. Measurement results showed that the stacking position of refrigerated containers affects the distribution of surface temperatures and power consumption. The average surface temperatures obtained on the top tier, middle tier, and bottom tier were 45°C, 41°C and 38°C at noon, respectively. Consequently, the average power consumption from the top tier, middle tier, and bottom tier were shown as 7.7 kW, 7.4 kW and 7.5 kW, respectively. From these results it can be concluded that the stacking effect of containers provides thermal benefit to the power consumption of refrigerated containers that are located on the middle tier and bottom tier.

Keywords: Container terminal; Green port; Refrigerated container; Solar radiation; Stack effect

1. INTRODUCTION

In recent years, the issue of energy consumption has been widely investigated with regard to the performance of container port operations. Reduction of energy consumption has a direct impact on emissions, minimizing environmental impact and reducing operational costs. The green port concept has emerged among container port operators as a way to implement some measured to control and reduces greenhouse gas emissions. Efforts in the development of green port technology have garnered more interest for terminal operators and container-handling manufacturers. Reduced power consumption is one approach for the reduction of greenhouse gas emissions, and this can been applied through various strategies in port operation.

Despite the fact that power consumption contributes to total energy consumption in container ports, there is a paucity of energy-efficient measures and strategies in this area. There is also

*Corresponding author's email: arif@eng.ui.ac.id, Tel: +62-21- 7270032, Fax: +62-21- 7270033
Permalink/DOI: https://doi.org/10.14716/ijtech.v8i7.771

scant literature and research about efficiency measures at container ports. Extant research indicates that energy used in container ports is concentrated in container handling equipment and refrigerated container storage yards (Wilmsmeier et al., 2013). Energy mapping in three Spanish container terminals has been investigated through research collaborations by the container handling company itself. Statistical data collected from three container terminals resulted in the same trend: the share of energy consumption was contributed predominantly by reefer containers and quay cranes (Greencranes, 2013). According to Shinoda and Budiyanto (2014), the power consumption in container ports is mostly contributed by reefer container storage yards, the latter comprising approximately half of the total power consumption. This consumption is mostly through electricity used to run refrigeration systems and remove heat from the internal environment of the container.

The energy consumption of refrigerated containers under given conditions for a fixed time has been investigated by Jolly et al. (2000), Wild (2009), Fitzgerald et al. (2011) and Shinoda and Budiyanto (2016). Jolly et al. (2000) conduct an experiment using temperatures ranging from −18 to +13.4°C, which gave energy consumption values between 4.42 kW and 8.63 kW, respectively. In Wild's study, the overall mean rate of energy consumption from 20 foot and 40 foot reefer containers was around 3.6 kW per TEU (Wild, 2009). Fitzgerald's study assumes the mean energy consumption rate of reefer containers to be 2.7 kW/TEU and indicates potential variations of around 60% due to various factors (Fitzgerald et al., 2011). Shinoda et al. (2016), measuring the high cube reefer container under exposed of solar radiation, calculated energy consumption at 7.2 kW/h.

The amount of energy that is consumed by reefer containers changes is contingent upon many different external variables. These include the ambient air temperature and humidity, the location of the reefer container, the age of the container, the refrigerant used, and any new or specific refrigeration technologies used. In one thermal study of the environmental effects of international transport containers, the ambient temperature – particularly solar effect – has a significant impact on indoor temperatures. The average sun-shade difference for outdoor temperatures reaches more than 7°C, and walls exposed to sun radiation show clearly differentiated thermal patterns compared to shaded ones (Rodríguez-Bermejo et al., 2007). Another study has investigated the fixed position of reefer stacks, highlighting that terminal operations are highly influenced by the size and position of reefer stacks. After testing several terminal layouts (including reefer stacks), the distribution of reefer stacks over the whole stacking area of a terminal was proven to be more efficient than the centralized layout currently used, whereby all reefers are stacked together (Hartmann, 2013). Thus the essential factor in thermal exchange processes is the environmental condition, in particular the heat source from the sun which affects ambient air and the temperature of surfaces. Research on the effects of solar radiation to reefer containers has been conducted by Shinoda and Budiyanto (2014). Their results confirm that the maximum temperature occurs linearly with the maximum solar energy received by container surfaces; the intensity of solar radiation – about 700 W/m^2 – caused the surface temperature to reach up to 35°C, and power consumption subsequently reached 7.5 kW/h at noon. The simulation study of reefer container has been conducted by Budiyanto and Shinoda (2017).

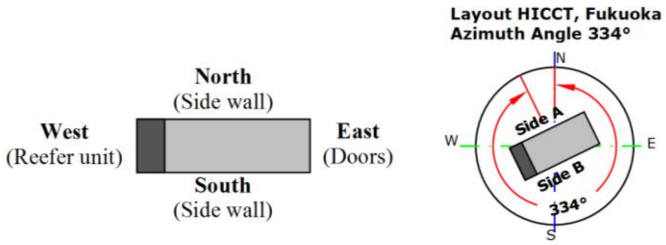
This paper investigates the stacking effect on power consumption from three stacks of refrigerated containers. The study is based on measurement experimentation conducted in Hakata Island City Container Terminal in Fukuoka, Japan. Results of the study proffer points of consideration around the location and positional arrangement of refrigerated containers in container ports. These findings around correct locations and positions have the potential to contribute to the reduction of energy consumption, and can be adopted as measures in the development of green port technology.

2. MEASUREMENT EXPERIMENTATION

To investigate the stack effect of reefer containers, measurement experimentation was conducted to provide necessary data related to energy consumption. Data are based on measurement conducted in situ during the summer of 2015 in Hakata Island City Container Terminal, Fukuoka, Japan. The layout of the reefer container storage yard has an azimuth angle of 334.185° from north, and the placement of the reefer container is set facing to the west (Hakata Port Terminal Co. Ltd., 2014). The orientation of the reefer container complies with industry guidelines: the reefer unit is facing the west, the door is facing the east, one side wall is facing the south and one side wall is facing to the north. Details of the experimentation location and orientation are shown in Table 1.

Table 1 Location and orientation of the measurement experimentation

Place	Hakata Island City Container Terminal
Degree of longitude	130.40° (130°24'04.24"E)
Degree of latitude	33.65° (33°39'31.15"N)
Altitude above sea-level	2.5 m
Time zone	Universal Time Coordinated (UTC) +9h
Orientation of container	334.185° from North (Wall Azimuth)
Detail orientation	



Several sensors and devices were employed to ascertain circumstantial parameters, including pyranometers, thermocouples, and power analyzers. Five pyranometer units were set on a horizontal and vertical plane facing all cardinal directions. Thermocouples were installed inside and outside of the walls at a total of 20 points. On the inside walls, 5 sensors were attached to the middle surfaces, including the floor, sidewall, ceiling, and the center. On the outside surface, 15 sensors were attached to each wall surface at the middle point, including fan and compressor surfaces. Power meter were employed to measure energy consumption, and were set on the power plug station nearby measurement objects. The parameter data from all devices recorded consumption every minute in various weather conditions. Details of measurement devices and the arrangement of sensor locations are shown in Figure 1.

2.1. Design and Specification of Refrigerated Container

This study used a 40 feet high cube reefer container as its measurement object. The design and specification of the high cube reefer container is shown in Figure 2. The dimensions of the high cube reefer container are: 12.1 meter length, 2.4 meter width, and 2.8 meter height. The container's structure consisted of ceiling wall, side walls, floor, and corner metal casting foundation. The internal space of the reefer container predominantly serves as the cargo hold. The floor is equipped with T-grating which functions to circulate air from the refrigeration system and is attached at the ends of internal spaces. The container walls are composed of three material layers – aluminium, polyurethane and stainless steel – with thicknesses of 0.8 mm, 90 mm and 0.9 mm, respectively.

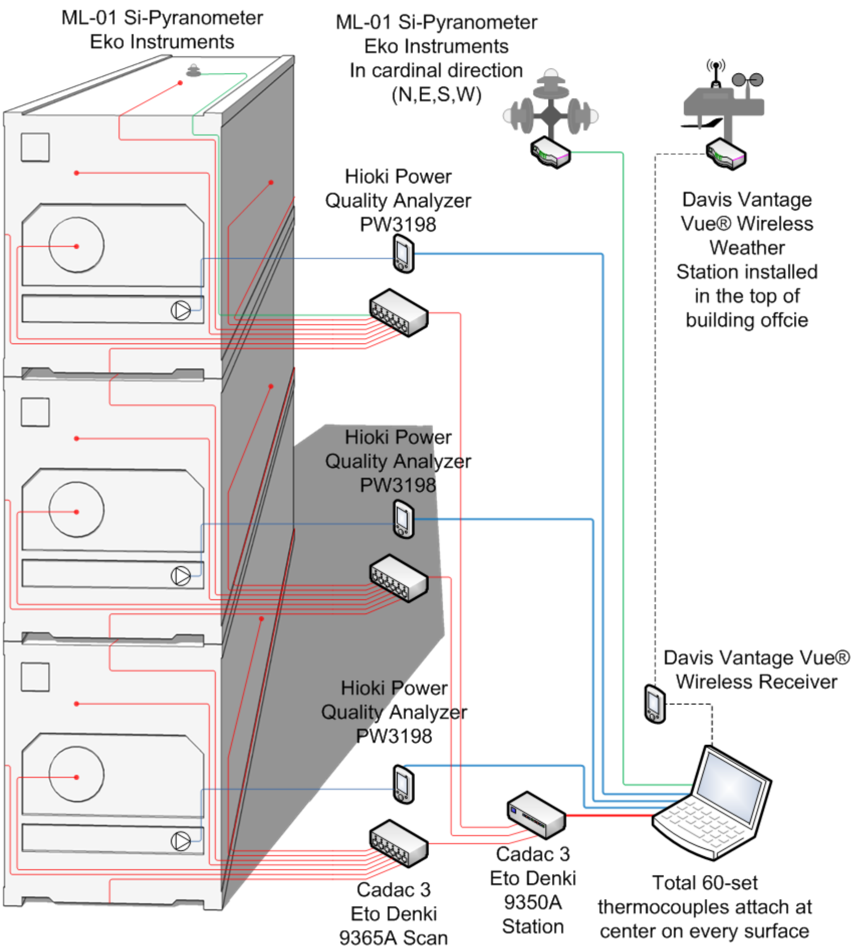
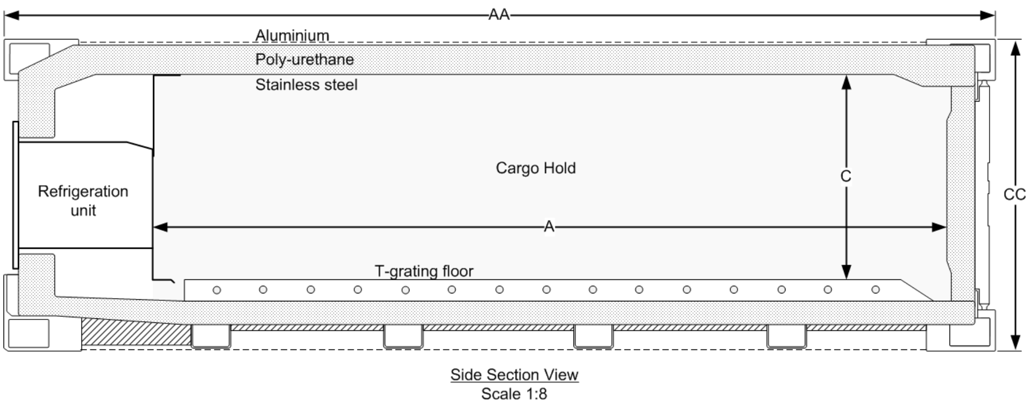
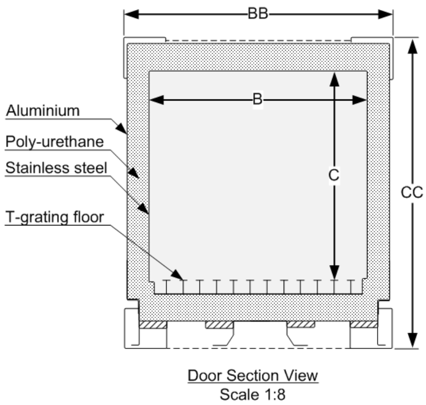


Figure 1 Devices and sensors location of measurement experimentation





Dimension			
External	Length	AA	12,192 mm
	Width	BB	2,438 mm
	Height	CC	2,866 mm
Internal	Length	A	11,583 mm
	Width	B	2,272 mm
	Height	C	2,545 mm

Classification	Material	Thickness
Outer frame	Alumuminum	0.8 mm
Insulation	Poly-urethane	90.0 mm
Inside panel	Stainless steel	0.9 mm

Figure 2 Design and specification of a high cube reefer container

The thermal conductivity of these materials are obtained from the manufacturing catalog and comprise 204 W/mK, 0.03 W/mK and 16 W/mK, respectively. Container design data available from the manufacturer give a minimum inside temperature of -0°F (-18°C) and maximum outside temperature of 100°F (38°C). The overall heat transfer rate is 7,556 BTU/hour (1,904 kcal/hour) with a U-Factor of 75.0 BTU/hour °F (34 kcal/hour °C). The exterior surface is composed of a flat surfaced aluminium panel, and all surfaces are painted in a white color.

2.2. Procedure of Measurement Experimentation

The measurement experimentation, procedure and performance test was carried out according to the guidelines of ISO 1496-2:2008 Series 1 'Freight Containers - Specification and Testing, Part 2: Thermal Containers' (ISO, 2008). In this study, measurement experimentation was performed to verify the stack effect of reefer containers at one specific period of time continuously. The experiment used three refrigerated containers with the same manufacturer and production year. The measurement data were acquired from devices and sensors attached in each container from the 19th to the 22nd of October 2015. The procedure of the stack experimentation is described sequentially, as follows:

1. Preparation of the reefer container: cleaning of the cargo hold, installation of measurement devices.
2. Arrangement of three reefer containers into one stack and placement on empty space, with minimum possibility of a shadow effect from another object.
3. Testing of the refrigeration system by consideration of the cooling performance of the refrigeration units.
4. Setting of temperature of the cooling performance to a constant 0°C, then monitoring of the fluctuation in energy consumption and temperature change of each reefer container.
5. Beginning of data acquisition and monitoring of required parameters. Data are acquired and saved according to weather factors. The main factor to be considered is the strong intensity of solar radiation, which must be measured in a day with continuous clear sky conditions.
6. The procedure is finished when a one-day measurement in clear sky conditions is obtained.

3. RESULTS AND DISCUSSION

The results of the stack experimentation performance test are presented here. Measurement data are categorized into solar radiation, surface temperature, and energy consumption. Intensity of solar radiation monitored during the measurement day is used to assess the performance of reefer container. Additionally, weather parameters are recorded as supplementary data for climate analysis. Weather data parameters e.g. wind speed, wind direction, ambient temperatures, and humidity, are obtained from the weather station that was installed at the top of the office building.

Table 2 Summary of weather condition for stack experimentation

Measurement period: 19th – 22nd October 2015
All parameter indicated in table measured at 12 PM

Date	Weather	Wind Speed (m/s)	Wind direction	Temperature (°C)	Humidity (%)
19-Oct-2015	Sunny -Cloudy	2.7	N-E	22.0	67
20-Oct-2015	Rainy	2.7	N-N-W	21.2	73
21-Oct-2015	Sunny	3.6	N-E	23.2	70
22-Oct-2015	Sunny	2.7	E-N-E	24.1	51
23-Oct-2015	Sunny-Cloudy	2.7	N-N-W	23.0	64

Table 2 gives a summary of weather conditions during the performance test. Generally, the weather condition can be categorized as either sunny or rainy. Sunny conditions convey clear skies with solar irradiance exposing the earth surface to maximum intensity. Contrastingly, rainy conditions give a minimum intensity of solar irradiance exposed to the earth surface. In the course of one measurement experimentation, it is difficult to get a continuously sunny condition for a whole day, owing due to various climatic factors, including cloud condition, rainfall, and wind. As a result of this, the present investigation of stack effect on refrigerated containers used data from 22nd October 2015, owing to the high ambient temperature and low wind speed on this day.

3.1. Features of Solar Radiation

Solar radiation was measured on a horizontal plane and vertical plane in four cardinal directions i.e. east, south, west and north. The features of solar radiation in sunny conditions captured on 22nd October 2015 are shown in Figure 3. The maximum solar radiation occurs on the south and west surface. Highest solar radiation reaches up to 820 W/m^2 on the south surface at 10:00 AM, while on the west surface highest solar radiation occurs at 03:00 PM. The horizontal surface received maximum solar radiation of approximately 750 W/m^2 at noon. Peak solar radiation on the east surface was approximately 480 W/m^2 at around 8:30 AM. The north surface received the lowest solar radiation, at about 100 W/m^2. The intensity of solar radiation for every surface has a different trend line depending on the solar position and orientation of the surface. Fluctuation occurs in the intensity of solar radiation during the measurement, owing to various factors from cloud condition and the effect of rainfall to wind speed and wind directions (Maxwell et al., 1986).

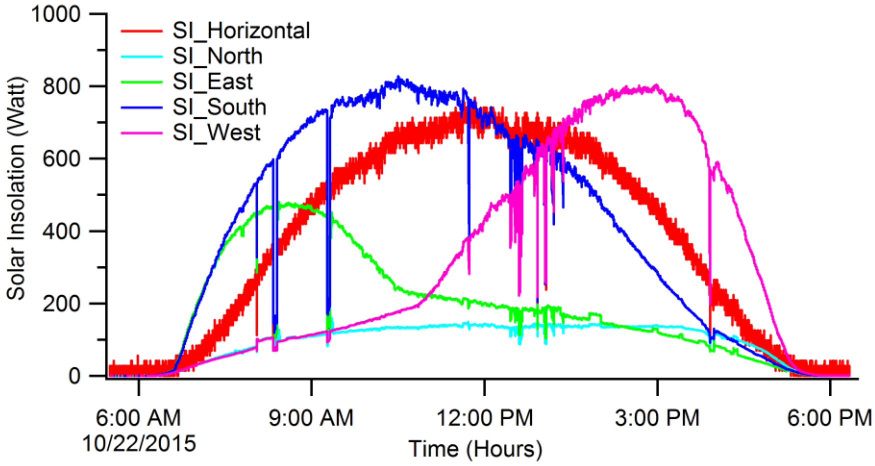


Figure 3 The feature of solar radiation in Hakata port

3.2. Temperature Stratification

Various thermal exchange processes enable transfers between containers to other containers. The stack effect of refrigerated containers provides thermal exchange processes that exhibit temperature stratification. Due to word count limitations, not all surface temperature data are shown in this paper. Figure 4 shows the temperature stratification on a stack of refrigerated containers. Thermal stratification is clearly observed from the top tier into the bottom tier on the south surface of reefer containers. Surface temperatures on the top tier are highest, with a maximum temperature of about 45°C at noon. Thus the surface temperatures on the middle tier and bottom tier lie on the next thermal strata, with average temperatures of 41°C and 38°C at noon, respectively. Surface temperatures therefore experienced thermal stratification from the top tier to the bottom tier. Thermal stratification occurs because of the thermal buoyancy of the air space; warm air tends to rise owing to buoyancy forces, which result in a positive vertical temperature gradient between the bottom floor and the ceiling (Saïd et al, 1996; Menchaca Brandan, 2012).

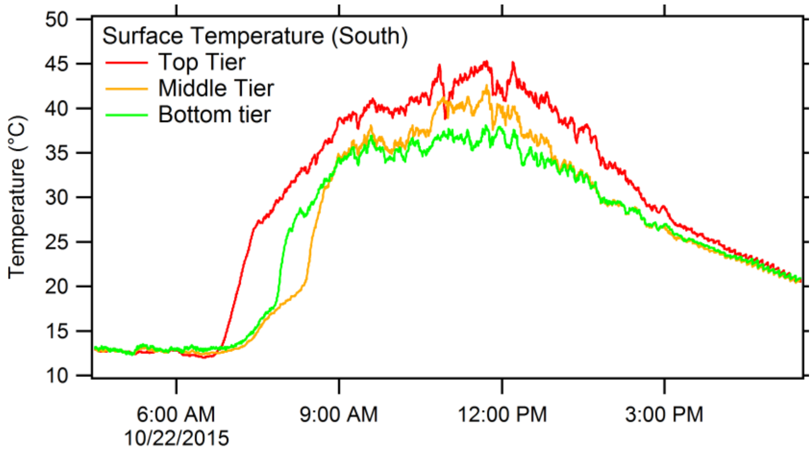


Figure 4 Temperature stratification on a stack reefer container

Increases in surface temperature are caused by the thermal energy from solar radiation received by container surfaces. The trend line in surface temperatures is related to solar radiation. On the south surface, the trend line of surface temperatures is concurrent with the intensity of solar radiation facing the south. The maximum solar radiation received on the wall – approximately 830 W/m^2 – caused the maximum surface temperature of around 45°C.

3.3. Stack Effect on Power Consumption

Figure 5 illustrates a comparison of the power consumption from all containers in a stack of refrigerated containers. The average initial power consumption ranges between 7.2–7.4 kW and the maximum power consumption ranges between 7.4–7.8 kW at noon.

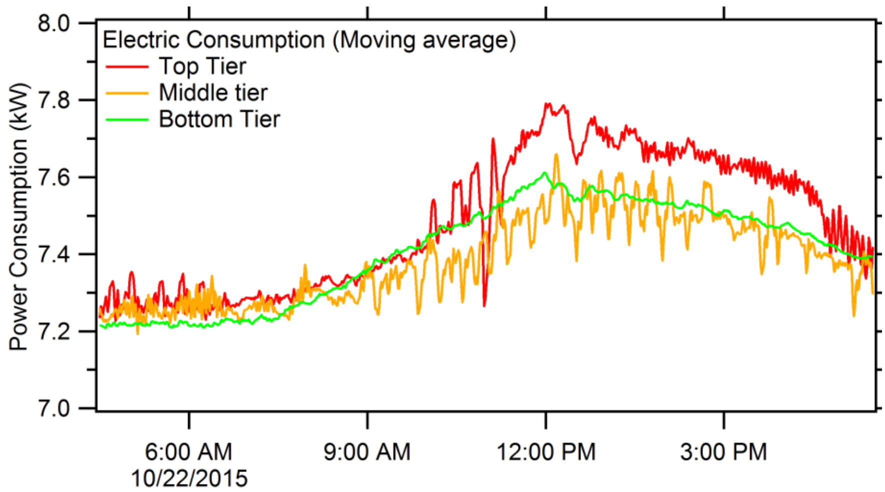


Figure 5 Power consumption on a stack reefer container

The power consumption of reefer containers increases from 07:00 a.m. then reaches maximum consumption at 13:00 p.m. The trend line of power consumption is concurrent with changes in surface temperatures of the container walls. However, the starting time of increasing energy consumption shifted slightly from the starting time of increasing surface temperatures. This disparity is owing to the temperature delay caused by the heat capacity of insulation materials

(Tadeu et al., 2014). Refrigerated containers at the top tier have higher ranges of energy consumption, with an average consumption of about 7.7 kW, followed by the bottom and middle tier, which have an average consumption of about 7.5 kW and 7.4. kW, respectively. Enlightening results are therefore found regarding the order of power consumption in a stack of refrigerated containers: the lowest energy consumption occurs in the middle tier, which receives thermal exchange advantages from the top and bottom. These results are subsequently consistent with the research of Shinoda and Budiyanto (2014).

4. CONCLUSION

This investigation of stack effect on reefer containers was conducted through measurement experimentation. Adequate equipment and procedures were utilized to collect parameter data of reefer containers, including surface temperature, air temperature, power consumption, and solar radiation. The measurement results clearly illustrate the stack effect of refrigerated containers influences temperature stratification in the container surfaces and causes different strata of energy consumption in each tier's containers. The order of energy consumption in a stack of refrigerated containers, from highest to lowest consumption, are therefore top tier, bottom tier, and middle tier, respectively. Placing refrigerated containers in the middle position will garner the lowest energy than any other position. These results therefore illustrate that the proper arrangement of containers can aid container port operators in energy-saving strategies.

5. ACKNOWLEDGEMENT

The authors would like to express our gratitude to the crews of Hakata Port Terminal Corporation for collaborative research in this experimentation, and for providing essential data during the research process, as well as suggestions for future related research. The authors would also like to extend thanks to the Department of Mechanical Engineering, University of Indonesia, and Department of Marine System Engineering, Kyushu University.

6. REFERENCES

Budiyanto, M.A., Shinoda, T., Nasrudin., 2017. Study on the CFD Simulation of Refrigerated Container. *IOP Conference Series: Materials Science and Engineering*, Volume 257, pp. 1–10

Fitzgerald, Warren B., Howitt, Oliver J. A., Smith, Inga J., Hume, A., 2011. Energy Use of Integral Refrigerated Containers in Maritime Transportation. *Energy Policy*, Volume 39(4), pp.1885–1896

Greencranes, 2013. *Report on Port Container Terminals Energy Profile: Mapping of Port Container Terminals Energy Profile*, Valencia

Hakata Port Terminal Co. Ltd., 2014. *Introduction for Island City Container Terminal*. Available online at http://www.hakatako-futo.co.jp/terminal/islandcity.html, Accessed on March 2017

Hartmann, S., 2013. Scheduling Reefer Mechanics at Container Terminals. *Transportation Research Part E: Logistics and Transportation Review*, Volume 51, pp. 17–27

ISO, 2008. *International Standard: Series 1 Freight Containers — Classification, Dimensions and Ratings*

Jolly, P.G., Tso, C.P., Wong, Y.W., Ng, S.M., 2000. Simulation and Measurement on the Full-load Performance of a Refrigeration System in a Shipping Container. *International Journal of Refrigeration*, Volume 23(2), pp. 112–26

Maxwell, E.L., Stoffel, T.L., Bird, R.E., 1986. *Measuring and Modeling Solar Irradiance on Vertical Surfaces*. SERI/TR-215-2525 No. 3738.10, Colorado, USA

Menchaca Brandan, María Alejandra., 2012. Study of Airflow and Thermal Stratification in Naturally Ventilated Rooms. *Ph.D Thesis*, Massachusetts Institute of Technology

Rodríguez-Bermejo, J., Barreiro, P., Robla, J.I., Ruiz-García, L., 2007. Thermal Study of a Transport Container. *Journal of Food Engineering*, Volume 80(2), pp. 517–27

Saïd, M.N.A., MacDonald, R.A., Durrant, G.C., 1996. Measurement of Thermal Stratification in Large Single-cell Buildings. *Energy and Buildings*, Volume 24(2), pp. 105–115

Shinoda, T., Budiyanto, M.A., 2014. Energy Saving Effect of Roof Shade at Reefer Container Storage Yard. *In:* Proceedings of the International Forum on Shipping, Ports and Airports (IFSPA): Sustainable Development in Shipping and Transport Logistics, pp. 455–460

Shinoda, T., Budiyanto, M.A., 2016. Energy Saving Effect of Roof Shade for Reefer Container in Marine Container Terminal. *The Journal of Japan Institute of Navigation*, Volume 134, pp.103–113

Tadeu, A., Moreira, A., António, J., Simões, N., Simões, I., 2014. Thermal Delay Provided by Floors Containing Layers That Incorporate Expanded Cork Granule Waste. *Energy and Buildings*, Volume 68, Part A, pp.611–619

Wild, Y., 2009. *Refrigerated Containers and CA Technology*. Container Handbook, The German Insurance Association, Berlin, Germany

Wilmsmeier, G., 2012. *Energy Consumption and Efficiency: Emerging Challenges from Reefer Trade in South American Container Terminals*, FAL 329, pp. 1–9