Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 156 (2019) 207–211

Energy Procedia

www.elsevier.com/locate/procedia

2018 5th International Conference on Power and Energy Systems Engineering, CPESE 2018, 19–21 September 2018, Nagoya, Japan

Simulation study using building-design energy analysis to estimate energy consumption of refrigerated container

Muhammad Arif Budiyanto [a, *], Nasruddin [a, *], Fariz Zhafari [a]

[a] *Department of Mechanical Engineering, Universitas Indonesia*

Abstract

Refrigerated containers account for half of the total electricity consumption by storage yards and that this is expected to increase continuously each year. A refrigerated container is a special cargo container equipped with an integral refrigeration unit. The amount of power consumption of the refrigerated container will change depending on many external variables. Environmental factors mainly solar radiation received on the container walls caused surface temperatures increase will then affect the power consumption. This paper provides a simulation study on the estimation of energy consumption of refrigerated container. The simulation model performed on the building-design energy analysis used Integrated Environmental Solution (IES) software packages. The geometry of simulation model considers the actual dimension of refrigerated container consists of insulation walls in the three-dimensional analysis. Physical properties of the insulation walls and environmental factors used weather data are applied to the simulation model as parameter inputs. Estimation of energy consumption of the model based on the calculation of cooling load from the object considers the thermal effect from the sun energy. The measurement data from the experimentation was conducted by Shinoda and Budiyanto (2016) used as validation of simulation model. The comparison of energy consumption from simulation and measurement shows in shows in good agreement.

Selection and peer-review under responsibility of the 2018 5th International Conference on Power and Energy Systems Engineering, CPESE 2018, 19–21 September 2018, Nagoya, Japan.

Keywords: Refrigerated container; Energy simulation; Energy consumption; Energy analysis; Environmental factors

* Corresponding author. Tel.: +62 821 1394 2255
E-mail address: arif@eng.ui.ac.id; nasruddin@eng.ui.ac.id

Selection and peer-review under responsibility of the 2018 5th International Conference on Power and Energy Systems Engineering, CPESE 2018, 19–21 September 2018, Nagoya, Japan.
10.1016/j.egypro.2018.11.129

Nomenclature

c	Specific heat capacity of the solid *(J/kgK)*
h_c	Convective heat transfer coefficient
I_g	Total solar flux *(W/m^2)* on the horizontal plane
I_{df}	Diffuse sky solar flux *(W/m^2)* on the horizontal plane
I_b	Solar flux *(W/m^2)* measured perpendicular to the beam
T	Temperature *(ºC)* in the solid at position
T_a	Ambient air temperature *(ºC)*
T_s	Mean surface temperature *(ºC)*
t	Time
W	Heat flux *(W/m2)* from the air to the surface
λ	Conductivity of the solid *(W/m^2K)*
ρ	Density of the solid *(kg/m^3)*
α	Solar altitude

1. Introduction

The growth of container traffic pushes container port to develop port infrastructure towards performance improvement. Some methods for greenhouse gas reduction has been implemented, such as electric power supplied system to rubber tired gantry crane, hybrid model straddle carriers instead of conventional straddle carriers and a trial system of roof shade for refrigerated container to reduce a load of solar insolation [1]. Related to electricity consumption, refrigerated container facility has contributed the highest energy consumption in container terminal [2]. Electricity is used to run refrigeration system and to remove heat from the internal environment of the container. The amount of energy consumed by refrigerated will change depending on the ambient air temperature and humidity, location of the refrigerated container, the age of the container, refrigerant used and refrigeration technologies used [3].

Several studies has been performed to measure energy consumption of refrigerated containers under given conditions for a fixed time [4,5,6]. Jolly et al. (2000) measured the energy consumption of refrigerated containers has values between 4.42 kW and 8.63 kW depend on the inside temperature setting. Wild (2009) was performed measurement experience of 20 feet and 40 feet refrigerated containers estimated the energy consumption was around 3.6 kW per TEU. Shinoda & Budiyanto (2016) was measured the high cube refrigerated container under the exposed of solar radiation consumed energy about 7.2 kW/h. Looking from these various values of energy consumption by refrigerated container, the estimation study by simulation will take benefit for further energy analysis in container terminal operation. In order to predict energy consumption of refrigeration container, numerical analysis using building-design energy simulation will provide an overview of the thermal performance of the circumstances object therefore calculation of energy consumption in various condition can be estimate. This paper aims to estimate the energy consumption of refrigerated container in the fixed condition by simulation model. The validation of simulation result uses measurement data from the experimentation was conducted using other computational fluid dynamic method [7].

2. Simulation model

The estimation of energy consumption was performed by means of a building energy modeling using Integrated Environmental Solution – Virtual Environment (IES-VE) software packages. IES-VE simulation is a dynamic thermal simulation program based on first principles mathematical modelling of the heat transfer processes occurring within and around a building. The simulation results provide an environment for the detailed evaluation of building and system designs, allowing them to be optimized with regard to comfort criteria and energy use. The calculation process of this simulation study shown in the Fig. 1.

2.1. Governing Equations

The heat transfer processed such as conduction, convection and radiation for each element of the building fabric are individually modelled and integrated with models of container heat load. The set of governing equations of the simulation models describes as follows:

$$\nabla \cdot (\lambda \nabla T) = \rho c \frac{\partial T}{\partial t} \quad (1)$$

$$W = h_c (T_a - T_s) \quad (2)$$

$$I_g = I_{df} + I_b \sin \alpha \quad (3)$$

Eq. 1 is the heat diffusion, Eq. 2 is the heat convection and Eq. 3 is the solar radiation. In this study the simulation model is driven by real weather data measurement. For these purpose, the value of diffuses sky solar flux and beam solar flux was deliberately taken from the analytical calculation. Previous study about estimation of energy consumption has been done validated using experimental measurement on the certain time [8,9,10].

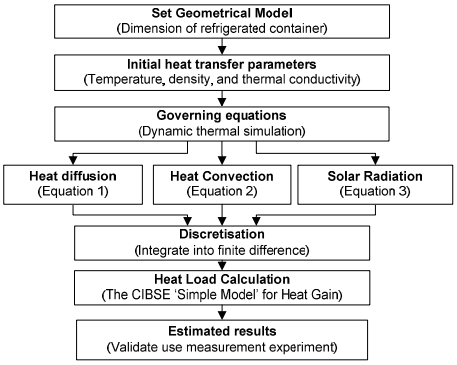

Fig. 1. Calculation process of the simulation study

2.2. Geometrical model and parameter inputs

The geometry of simulation model considers the actual dimension of high cube refrigerated container with the dimension 12.1 meter length, 2.4 meter width and 2.8 meter height. The structures is consisted ceiling wall, side walls, floor, and corner metal casting foundation. Inside space of refrigerated container mainly serves as the cargo hold, with the floor is equipped with T-grating functioned as air circulation from the refrigeration system which attached at the end of the spaces. For the instance of physical parameter inputs uses the design specification obtained from manufactured catalogs. Refrigerated container are constructed from the container walls are composed from three material layers that are aluminium, polyurethane and stainless steel with the thickness is 0.8 mm, 90 mm and 0.9 mm, respectively. The thermal conductivity of these material are 204 W/mK, 0.03 W/mK and 16 W/mK, respectively. Container design data available from the manufacturer is 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 is 75.0 BTU/hour °F (34 kcal/hour °C).

3. Results and discussion

The results of simulation model are presented here. Simulation results are provide the estimated value of energy consumption in one day and one year operation for a high cube refrigerated container. The estimated result of energy consumption in one day operation was compared with the measurement experiment data by Shinoda & Budiyanto (2016). The measurement data on 15th August 2015 has been chosen as comparison since the weather condition on this day has clear sky condition which mean the global solar radiation emitted in the peak intensity.

3.1. Estimated energy consumption in one day operation

Energy consumption of a reefer container particular define as the electricity consumption in one day operation. Design of energy consumption of refrigerated container in one day operation prepare inside cargo hold in the empty

condition with set temperature into zero degree Celsius. The standard for energy consumption of refrigerated container following the rules of ISO 1496-2:2008 Series 1 freight containers - Specification and testing, Part 2: Thermal containers [11]. According this standard, both simulation model and measurement experiment set inside temperature into zero degree Celsius with empty cargo hold. The simulation model performed in the transient time during one day operation provided the estimation of energy consumption each one hour time step.

In this study, the energy analysis for one day operation will use time range between 08:30 AM until 17:30 PM since the solar radiation take an effect to the heat load of the container during this time. Fig. 2 shows the comparison value of energy consumption of a high cube refrigerated container between IES-VE result and measurement data. Simulation results estimated the maximum energy consumption around 3.1 kW at 08:30 AM and minimum energy consumption is 2.7 kW at 17:30 PM. The value of energy consumption indicate the amount of energy to remove heat load from the inside cargo effect from the heat penetration due to solar radiation.

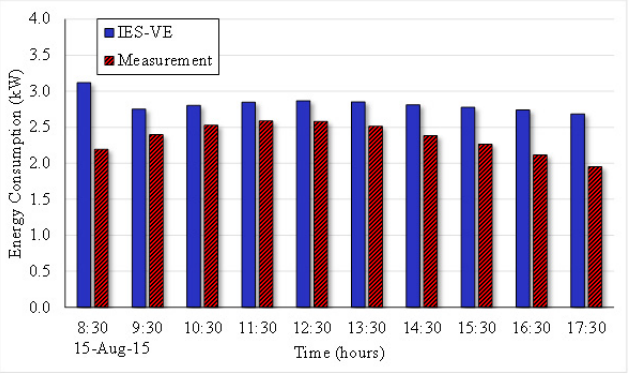

Fig. 2. Energy consumption of a high cube refrigerated container in one day operation

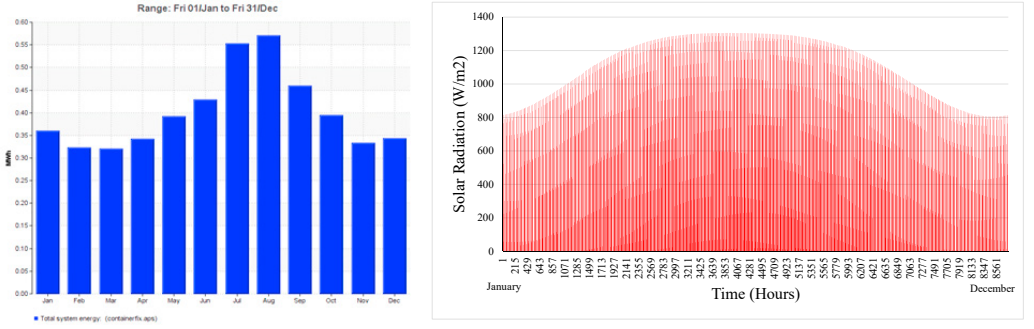

Fig. 3. (a) Estimated value of total energy consumption in a year operation and (b) the intensity of solar radiation in the simulation model

The average energy consumption by simulation during one day operation is 2.8 kW, this result consistent with the result conducted by Fitzgerald et al. [12]. The comparison of energy consumption per hour shows that the energy consumption by simulation model has various difference values with measurement data. The highest difference value found at the initial time at 08:30, this circumstances due to simulation model assumed the refrigerated container object prepared as container without pre-conditioning, therefore the heat to be remove in the first calculation higher than other time step. The lowest difference value of energy consumption found in the noonday 11:30 AM, this result give direction of suitable time for the further analysis in the estimation of energy consumption.

3.2. Estimated energy consumption in one year operation

In field of energy analysis in container terminal, the overview of energy consumption in one year operation will provide a direction for the further development of opportunity on energy saving in this area. Concerning this circumstances, in this paper provide the estimation energy consumption of a refrigerated container in one year operation. Fig. 3a. shows estimated value of total energy consumption of a high cube refrigerated container in one

year operation by IES-VE. The maximum of energy consumption of a refrigerated container in one year operation estimated around 0.57 MWh in August, thus the minimum of energy consumption estimated around 0.32 MWh in March. The profile of energy consumption in one year operation following the normal distribution of solar radiation. The trend of energy consumption following the trend of solar radiation which uses in the simulation model as shown in Fig. 3b. The trend of solar radiation imported from the weather data very influence to the calculation result as heat load from the environment, this result consistent with the result by Budiyanto and Shinoda (2017) [13,14].

4. Conclusions

The estimation of energy consumption from a high cube refrigerated container was done performed use IES-VE software packages. The simulation result for one day operation has been validate using measurement data carried out by Budiyanto (2016). From the comparison result shows the simulation results has good agreement with the measurement data with the mean absolute error about 0.47 kW. From the estimation result obtained the average amount of energy to remove heat load inside cargo from the effect of heat penetration due to solar radiation during one day operation is 2.8 kW. Thus, the estimation of energy consumption in one year operation for a cube refrigerated container predicted about 4.81 MWh. Furthermore, this result give a direction for estimation of energy consumption in a container terminal for whole capacity of refrigerated container

Acknowledgements

This research / article's publication is supported by the United States Agency for International Development (USAID) through the Sustainable Higher Education Research Alliance (SHERA) Program for Universitas Indonesia's Scientific Modeling, Application, Research and Training for City-centered Innovation and Technology (SMART CITY) Project, Grant #AID-497-A-1600004, Sub Grant #IIE-00000078-UI-1. Author also would like to thanks to Department of Mechanical Engineering, Universitas Indonesia for providing the IES-VE software packages.

References

[1] 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

[2] Greencranes, (2013), Report on Port Container Terminals Energy Profile: Mapping of Port Container Terminals Energy Profile, Valencia.

[3] Wilmsmeier, Gordon., (2012), Energy Consumption and Efficiency : Emerging Challenges from Refrigerated Trade in South American Container Terminals, FAL (329): 1–9.

[4] Jolly, P.G., Tso, Y.W., Wong, S.M. Ng., (2000), Simulation and Measurement on the Full-Load Performance of a Refrigeration System in a Shipping Container, International Journal of Refrigeration 23(2): 112–26.

[5] Wild, Yves., (2009), Refrigerated Containers and CA Technology. Container Handbook, The German Insurance Association, Berlin, Germany.

[6] Budiyanto, M.A., Shinoda, T., 2017. Stack Effect on Power Consumption of Refrigerated Containers in Storage Yards. International Journal of Technology, Volume 8(7), pp. 1182-1190

[7] Budiyanto, M.A., Shinoda, T., Nasruddin, 2017. Study on the CFD Simulation of Refrigerated Container. IOP Conference Series: Materials Science and Engineering 257(1),012042.

[8] Nasruddin, Budiyanto, M.A., Nawara, R., 2018. Comparative Study of the Monthly Global Solar Radiation Estimation Data in Jakarta. IOP Conference Series: Earth and Environmental Science 105(1),012111.

[9] Nasruddin, Budiyanto, M.A., Lubis, M.H., 2018.Hourly solar radiation in Depok, West Java, Indonesia (106.7942 Longitude, -6.4025 Latitude). IOP Conference Series: Earth and Environmental Science 105(1),012088.

[10] Study on the estimation of solar radiation: Case study: Jakarta, Indonesia. IEEE Xplore DOI: 10.1109/PGSRET.2017.8251792.

[11] ISO, (2008), International Standard: Series 1 freight containers — Classification, dimensions and ratings.

[12] Fitzgerald, Warren B., Howitt, Oliver J. A., Smith, Inga J., Hume, A., (2011), Energy Use of Integral Refrigerated Containers in Maritime Transportation, Energy Policy, 39(4): 1885–96.

[13] Budiyanto, M.A., Shinoda, T., Sunaryo, Nugroho, F.A., Wibowo, B. 2018. Estimated of energy saving from the application of roof shade on the refrigerated container storage yard. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 46(1), pp. 114-121

[14] Budiyanto, M.A., Shinoda, T., 2018. The Effect of Solar Radiation on the Energy Consumption of Refrigerated Container, Case Studies in Thermal Engineering 12 (2018) 687–695. doi.org/10.1016/j.csite.2018.09.005