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Article

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Energy efficiency on the reefer container storage yard; an analysis of thermal performance of installation roof shade

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Abstract

This study aims to estimate the effect of energy efficiency by installing roof shade in the reefer container storage. A cross sectional of reefer container was simulated by using thermal simulation to investigate thermal performance and estimate the energy efficiency. The roof shade is used to reducing heat penetration on the container surface caused by strong load of solar radiation during the day. Since the thermal performance is difficult to estimate on measurement experiment because the effects are not always so much and have strong deviation, thermal simulation provides a useful tool to predict the temperature distribution. The current thermal simulation model consists of thermal radiation and conjugate heat transfer. Measurement of solar radiation was carried out to provide thermal boundary condition and temperature measurement was carried out to validate the simulation model. The simulation result confirms 9% energy efficiency by installation of roof shade during the day.

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Keywords: Reefer container; Container yard; Roof shade; Thermal simulation

1. Introduction

In recent years a performance of container terminal operation in terms of energy consumption has been a trend to compete of infrastructure services [1,2]. Reduction of energy consumption has direct impacts on emissions, minimize the environment effect and reduces operational costs [3,4]. Focus on electricity consumption, reefer facility has been contributed the most energy consumption in container terminal [5,6]. Power consumption used to run the refrigeration system and expel heat from the inside condition of the compartment [7,8]. The measure of energy consumption that is consumed by the reefer container will change contingent upon numerous outer factors. [9]. These include the ambient air temperature and humidity, location of the reefer container, the age of the container, the refrigerant used and any new or specific refrigeration technologies used [10–13].

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Nomenclature

ϕ	: General flow variable such as velocity component and temperature
ρ	: Fluid density
U	: Fluid velocity vector
$\Gamma_{\phi,eff}$: Turbulence model
S_{ϕ}	: General source term could include transient, convection and diffusion
k_1	: Temperature dependent conductivity of the fluid medium, and defined as Eq. (3)
T_3	: Radiation temperature of the solid
σ	: Stefan Boltzmann constant ($5.67 \times 10^{-8} \text{ W/m}^2 \text{ K}^4$)
a	: Absorptivity of the fluid medium
s	: Scattering coefficient of the fluid medium
$WGAP$: Distance between adjacent walls

Hakata Island City Container Terminal (HICT) in Fukuoka introducing set up the roof shade over two bay of reefer container storage yard as demonstration equipment Since 2011 [14,15]. Installing the roof shade over reefer container stock yard will enable improvement to protect thermal condition of reefer container from bad thermal effect by solar insolation [16]. Presenting these strategies could be powerful in energy efficiency, however, these are hard to gauge a measure of impact in energy efficiency in light of the fact that the impacts are not generally so much and have solid deviation.

To get a better understanding of reduction the heat penetration from the solar radiation a computer model would be very useful. In this paper aim to simulate a thermal simulation using computational fluid dynamic (CFD) concerning the effect of roof shade over storage yard in reefer container storage yard. The installation of roof shade will provide an energy efficiency estimation and evaluate temperature distribution to drive a more significant energy saving.

2. Thermal simulation model

2.1. Geometry model

Reefer container storage yard are large-scale phenomena in which the temperature increase during the sunny day [17]. The main cause of the increasing temperature is the absorption by and emission of radiation by solid material i.e. storage yard, roads, and building. To catch whole phenomena on this location is difficult to understand since many external variable i.e. ambient air temperature, weather condition, wind velocity and also the specification of the container [18,19]. In this simulation model we used a cross sectional area of reefer container with considering the environment effect. A cross sectional area is considering the most representative area to understand the temperature distribution. In order to realize the actual condition, we used parameter data which taken using data from previous study was conducted by Shinoda & Budiyanto [20]. The parameter data consists of location information, reefer container specification and also weather data. Fig. 1 illustrates the schematic view of proposed simulation model.

The thermal simulation is conducted by using a general purpose CFD software packages by CHAM PHOENICS [21]. Simulation model is constructed with Cartesian grid in order to get fast convergence. The grid of whole model has number of 59 200 cells ($80 \times 74 \times 10$) and the discretization of transient time is 12 h divided into 168 time-step start from 6:00. Table 1 lists the parameter data and the boundary condition for the simulation input.

2.2. Heat transfer process

Thermal performance of the reefer container is closed related with the heat transfer process i.e. radiation, convection and conduction. In this simulation considered thermal radiation, conjugate heat transfer and turbulent flow to know heat penetration process through the wall of reefer container. The governing partial differential

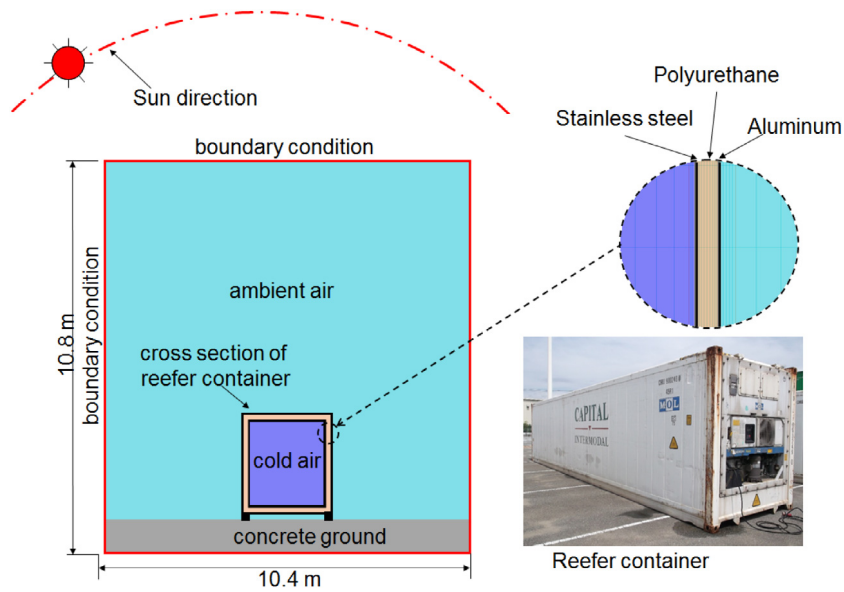


Fig. 1. Schematic view of simulation model.

Table 1. Geometrical data of reefer container.

Parameter	Value
Reefer container dimension	
Length × Width × Height	12.2 × 2.4 × 2.8
Insulation type	Polyurethane
Material inside	Stainless steel
Material outside	Steel
Location latitude	33.6
Average inside temperature	0 °C
Average outside temperature	30 °C
Average wind speed	3 m/s at 10 m
Wind direction	South east
Number of cell	80 × 74 × 10
Time dependence	Transient
Turbulence model	The standard k-ε model
Thermal radiation	Immersed solid

equations for conservation of mass, momentum, and energy in a turbulent flow system can be expressed by time-averaged 2nd order partial differential equations as is shown in Eq. (1) and solved with a common numerical algorithm in the code.

$$\frac{\partial}{\partial t} (\rho\phi) + \text{div} (\rho U\phi) = \text{div} (\Gamma_{\phi,eff} \text{grad}\phi) + S_{\phi} \quad (1)$$

In the current simulation, all the transport processes are modelled using standard k-ε model turbulence model and the Immersed solid (Immersol) thermal radiation [21]. Thermal radiation plays a critical role for heat transfer between the ambient fluid and the solid components. The Immersol model is a single heat-conduction-type equation that describes the influences of heat conduction within the solids and radiation in fluid domain between the solids on the distribution of immersed-solids temperature. The model is mainly dependent on position and conductivity of immersed-solids [22].

The Immersol radiation model can be described with the differential equation within the immersed solid per unit volume as in Eq. (2). This equation means that solar radiation will be stored by the solid component. The radiance

temperature T_3 is the temperature of the solid (body of reefer container).

$$\frac{\partial}{\partial x} \left(k_1 \frac{\partial T_3}{\partial x} \right) + \frac{\partial}{\partial y} \left(k_1 \frac{\partial T_3}{\partial y} \right) + \frac{\partial}{\partial z} \left(k_1 \frac{\partial T_3}{\partial z} \right) + q' = (a + s) \sigma (T^4 - T_3^4) \tag{2}$$

$$k_1 = \frac{16\sigma T_3^3}{3(a + s + 1/WGAP)} \tag{3}$$

In this simulation heat source per unit volume as a heat penetration generate from solar radiation, in this case we used measurement data as a parameter input. The parameter input from solar radiation using direct and diffused radiation via weather data from the sunlight object. The ‘sunlight’ object in PHOENICS can compute the intensity and direction of incoming radiation and its distribution upon surfaces, and the Immersol feature is ideally suited to handling their distribution of radiation between buildings by reflection and re-radiation.

In order to verify the accuracy of the simulation results, a measurement experimentation was performed according to the simulation condition. The measurement experimentation it is not be described in this paper and has published in preceding study [6,20]. Data to verification is consist of temperature and solar radiation. The temperature measurement counted every 30 s of each side in the centre of wall container. Solar radiation is measured in horizontal surface and vertical surface, in the vertical surface four direction has been set i.e. east, south, west and north. In this validation we use measurement data on 27 August 2013 as comparison since the maximum solar radiation and sunny weather has occurred on this date. Fig. 2 shown the comparison of measurement and simulation results. The trend line of simulation results have good agreement with the measurement data, can be seen in the simulation results that the trend line of the temperature fluctuation is following the fluctuation of solar radiation. Maximum temperature penetration occurs on the ceiling wall of reefer containers is 55 degree Celsius at the noon, this heat penetration is caused by the amount of solar radiation also at maximum conditions of 900 W/m². The results that showed the amount of solar radiation affected the wall temperature of the reefer container is consistent with the results of previous studies [23,24].

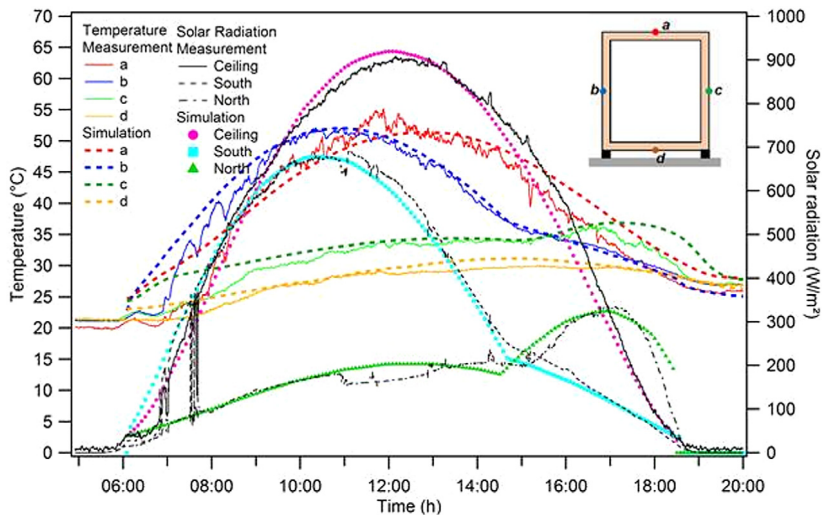


Fig. 2. Comparison of simulation results with measurement data.

3. Results and discussion

The thermal simulation was performed simulation for two conditions of reefer container. The first condition was performed simulation of reefer container without roof shade (NR0) and the second condition is the simulation of reefer container with the installation of roof shade (RS0). Fig. 3 shows the temperature distribution of this two condition. This figure illustrates the temperature distribution through the wall caused by a load of solar radiation at 12:05 PM, the highest position of the sun latitude. From the temperature, distribution clearly shows that the effect of roof shade appears on the ceiling side of the container.

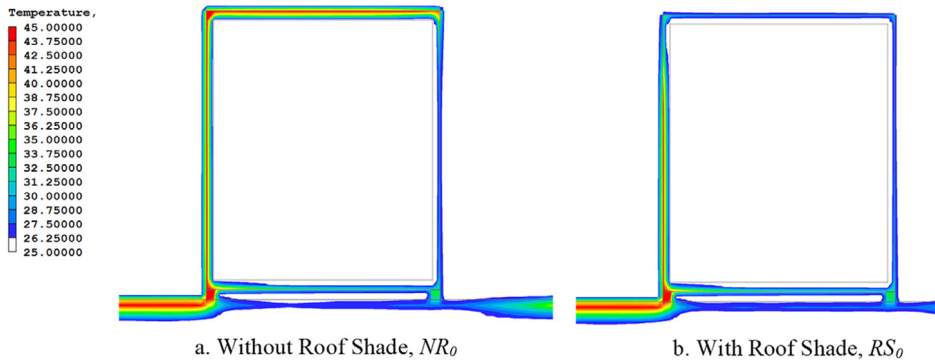


Fig. 3. Temperature distribution on the wall of reefer container.

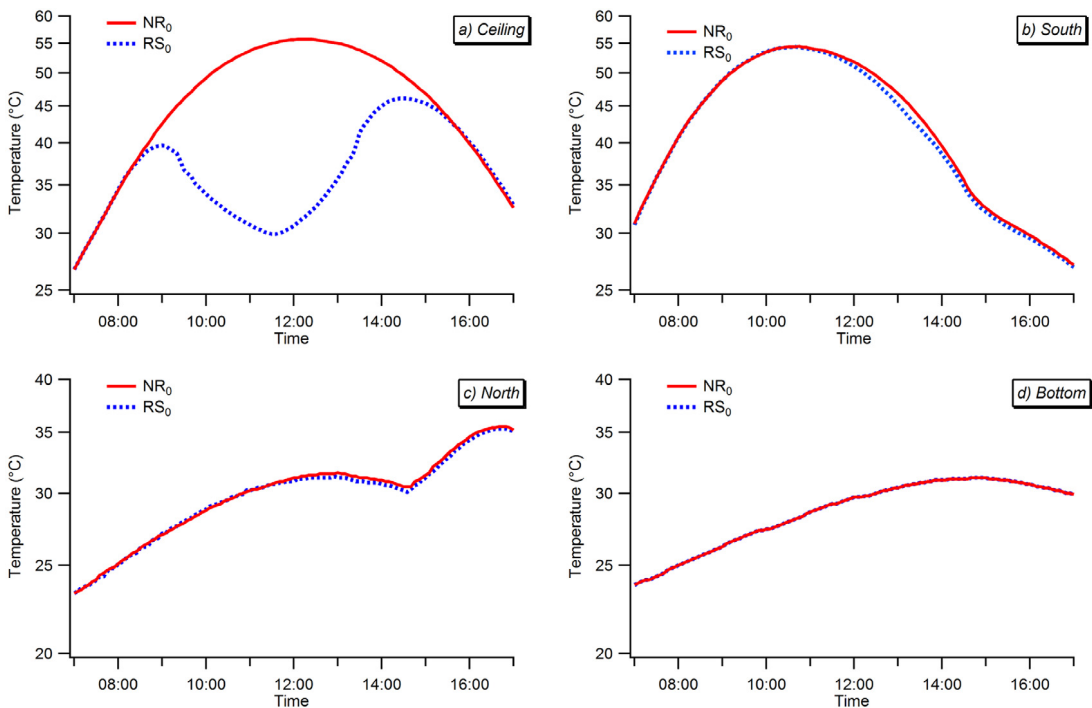


Fig. 4. Comparison of temperature profile of installation roof shade (RS0).

Fig. 4 shows the temperature profile on each side of the reefer container during the day. The effectiveness of roof shade in order cutting the heat penetration is clearly shown from the ceiling surface. The effect of roof shade to other side is not significant since solar radiation directly occurs due to the rotation of the sun direction. To estimate the energy efficiency of installation roof shade, benchmarking thermal performance is defined as the following [25]:

$$q = K \cdot S \cdot (\theta_o - \theta_i) \tag{4}$$

$$q_{Total} = q_a + q_b + q_c + q_d \tag{5}$$

$$\eta_q = 1 - \left(\frac{q_{RS}}{q_{NR}} \right) \tag{6}$$

Here, the value of q represents heat flow through the wall (W), K represents overall heat transfer coefficient of the container wall (W/m²K), S represents an area of the wall (m²) and θ represents temperature difference between inside and outside of the container. Eq. (4) is representing the total of heat flow from each side i.e. ceiling (a), south

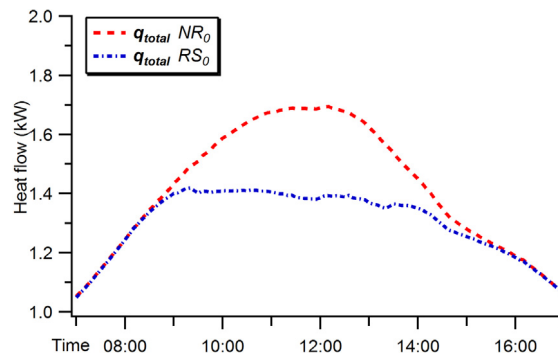


Fig. 5. Thermal performance of installation roof shade.

(b), north (c) and bottom side (d). The calculating of the thermal performance shown in Fig. 5. From this figure show the effectiveness of the roof shade start from 09:00 until 15:00, this result is quite reasonable since the strong load solar radiation starts on this time. By using Eq. (5), the ratio energy efficiency during this time is around 9% by the installation of roof shade. Furthermore, this energy efficiency is conformity with the preceding study that was conducted on a different day with the simulation condition resulted in 10% of energy efficiency [5,16]

4. Conclusions

Efforts to save energy consumption in the container terminal area are still very rarely studied. Installation of roof shade over the reefer container is aimed to reduce of power consumption of the refrigerated container. This study has been verifying the energy saving of the installation of roof shade by the CFD simulation methods. The CFD simulation using Cham Phoenics codes have been performed by considering the effect of solar radiation as a heat source to the container models. The energy consumption has been calculated using heat flow through the container walls from two models, with and without roof shade, and the results clarified the value of energy efficiency by the installation of roof shade. From the simulation show, the installation of roof shade is effectively reducing the thermal energy from the solar radiation with ratio energy efficiency during the day is around 9% energy savings. In addition, the container configuration in the container storage yard indicates an interaction of thermal effect from another container. Furthermore, with the amount of energy-saving by installation roof shade, provide future research on thermal distribution inside of reefer container in the empty condition and full load condition.

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