Design Analysis of Transportation Refrigeration Container with Photovoltaic and Compatible to Electric Vehicle

I Dewa Made Cipta Santosa[a], I Gede Nyoman Suta Waisnawa, A. A. Ngurah Gde Sapteka and I Wayan Budiarta
Politeknik Negeri Bali, Jalan Kampus Bukit Jimbaran, Kuta Selatan, Badung, Bali 80364, Indonesia

Keywords: Container Truck, Refrigeration, Solar Technology, Electric Car Technology.

Abstract: The distribution system for fresh food and beverages at a certain distance requires a good cooling system to maintain good quality. At this time, the operating costs for conventional refrigeration trucks are still quite high, so the products refrigerated in cold distribution are becoming more expensive. The cooling system on light trucks with solar technology really needs to be developed to get cooling technology that is in accordance with the development of electric car technology. With the addition of a solar power system, this system can operate with cheaper energy and also equipment that is easily obtained domestically so that investment costs are also cheap. from fruit and vegetable producent, the food industry to consumers who are energy efficient, utilize solar power and are compatible with electric car technology. The expected results from this initial research are the results of the analysis of the cooling container system design which consists of the container body design, the tray arrangement design and air circulation, the calculation and selection of materials and the analysis of the use of Phase Changed Materials (PCM) in order to obtain a product design that is ready for processing. efficient further production.

1 INTRODUCTION

1.1 Refrigeration Truck Energy Saving

The basic logic of product delivery is very simple, namely transporting fresh vegetables directly from the garden to the market by cart. However, travel time, ambient temperature, and risk of spoilage often make transportation with a temperature controlled system necessary. Since some commodities are sensitive to humidity (RH), this condition may also need to be controlled. In current developments, many commodities require transportation systems to markets or consumers that are long distances intermodally (that is, by some combination of road, sea, and rail). Compared to other refrigeration system applications, the refrigeration system in the transportation system experiences a relatively higher load due to environmental conditions and changing loads caused by the movement of the transportation system, thus energy demand in refrigeration transportation is very urgently analyzed to determine cope with this condition (Rai, 2017). The refrigeration transportation system is unique compared to other refrigeration systems. Thus, it is also necessary to develop the use of *phase changed materials* (PCM) to cope with fluctuations in load and loading due to infiltration and high heat transfer rates from the environment. It was found that the development of PCM to anticipate the opening of container doors has been able to save energy significantly (Rai and Tassou, 2017). The saving method by reducing leakage in containers can save emissions to the environment by 14% for fresh food storage (Ben Taher et al., 2021). Another study with the development of air-cycle refrigeration to increase the efficiency of the heat exchanger but this is still being studied further to be able to replace or even not use refrigerant (Li, 2017). The development of an alternative system for the truck refrigeration system has also been carried out with a combination of a vapor compression system and themochemical resorption with this system able to save energy with an index of 1.4 (Spence et.al.,2005). Various materials and types of PCM have been tried to be

[a] https://orcid.org/0000-0002-9912-629X

Santosa, I., Waisnawa, I., Sapteka, A. and Budiarta, I.
Design Analysis of Transportation Refrigeration Container with Photovoltaic and Compatible to Electric Vehicle.
DOI: 10.5220/0011819800003575
In *Proceedings of the 5th International Conference on Applied Science and Technology on Engineering Science (iCAST-ES 2022)*, pages 541-546
ISBN: 978-989-758-619-4; ISSN: 2975-8246

added to containers and combined with variable speed trucks, and it was found that higher speeds will have higher total heat transfer coefficients (Gao et al., 2001). By using the modeling of the air curtain mechanism when opening the cooling container door, it was found that the air infiltration when opening the door on the refrigeration truck was 34% of the total cooling load, and by modeling the optimum air flow velocity for the air curtain was 3.1 m/ s and can reduce energy consumption by almost 48% (Mousazade et al., 2020). Another model was also developed to test the thermal performance of the truck cooling container body and it was found that the cooling load is very dynamic and is greatly affected by the absorption of solar heat from the heat coefficient from the wall to the cooling load on the refrigeration truck system (Rai et al., 2019). The infiltration rate at the time of opening the container door of the refrigeration truck system and the cooling load from this infiltration can be simulated with the buoyancy flow model and also with the natural convection model with the classical method which can also produce good estimates (Artuso et al., 2019). Micheaux et al.,(2015)recommends and classifies the factors for designing a truck refrigeration system, namely: a) extreme exterior conditions: temperature, relative humidity, wind, and solar effects, b) desired interior conditions: temperature and relative humidity, c) insulation properties: thermal conductivity, permeability and moisture retention, chemical and physical stability, adhesion, uniformity of application, fire resistance, material and application costs, and presence of structural members, d) air and moisture infiltration, e) trade-off between costs construction and operating costs. This classification is indispensable for determining the required design and effective calculations for the cooling load and its cooling capacity.

1.2 Electric Car Truck Development

Regarding electric cars in the form of trucks, ASHRAE, (2016) stated that the target number of electric cars is 30% and this number is growing in line with infrastructure developments such as charging stations, etc. At this time the development of electric cars has been rapid which began in developed countries. And in a country with a large population. A study on the feasibility of heavy trucks using electric power (battery) found that it was very difficult to manufacture electric batteries with the same capacity as diesel trucks. If electric trucks could be charged quickly in the same way as private electric vehicles, the range required would be dramatically reduced and electrification would be much more realistic. if fast charging is available, the competitiveness of battery electric trucks compared to diesel trucks may actually increase with larger trucks (Osieczko et al.,2019). While the study for light trucks focused on electrical energy (ELT) or batteries and the results were that ELT could replace diesel light trucks to reduce carbon emissions after increasing the battery attenuation coefficient by 15% when ELT was used for 4 years. Compared to increasing the battery weight to reduce the value of energy consumption per unit load, increasing the energy density of the battery system to reduce vehicle weight can basically reduce carbon emissions (Nykvist et al., 2021). So, the development of battery technology makes battery electric heavy trucks technically and commercially feasible and several manufacturers have introduced battery electric trucks recently. To estimate the potential of electric trucks as much as 71% of Swiss ton-kilometer road freight can be electrified using battery electric trucks but Finland has a very limited potential of 35%, due to the use of long and heavy truck-trailer combinations. In both countries, the electrification potential varies widely between commodities, although in Finland it is more than in Switzerland. Increases annual electricity consumption by only 1-3% (Li and Yang, 2020). The photovoltaic potential for electric cars installed in the parking lots of shopping centers however, has shown for the first time the results that shop owners can increase profits by providing free PV-EV charging to their customers with multiple charging mechanism options (Liimatainen et al., 2019). While the feasibility study of solar power to drive the cooling system (AC) of electric cars for thermal comfort in electric cars and simulated air velocity and can be effectively used for several cooling system equipment such as fans and other electrical equipment (Sanjay et al., 2021). Converting a conventional car to a hybrid system using the ALC (annual life cycle) method and it was found that this conversion is very beneficial in terms of reducing energy consumption and emissions from greenhouse gases (Yan et al, 2012 and Tiano et al., 2018). Sathre and Gustavsson, (2021) examine the synergy of solar energy and electric vehicles (EV). Photovoltaic (PV) solar energy is already an important energy source globally, but due to its intermittent nature, energy storage is required to balance high and low production times. At the same time, a global push is underway in the transportation sector: the shift from internal combustion engines to EVs. power its complete energy system on PV only, using EV as the only energy storage resource (Bostrom et al., 2021).

From the literature review above, it was found that the feasibility of photovoltaic energy for the needs of refrigeration trucks is very good and has begun to be developed in various countries. But in particular, research on refrigeration truck containers that simultaneously use photovoltaic has not been found by the author. Thus this research will make an excellent contribution to the development of refrigeration trucks in the era of electric cars in the future.

2 METHODOLOGY

The method developed in this research is a simulation design and field survey in the container truck manufacturing industry. At this design stage, the technology that will be developed in this research product has novelty, urgency and uniqueness in the form of special applications on light trucks, both conventional and electric motor engines, which are in accordance with environmental and road conditions in Indonesia. Figure 1. is a schematic of the refrigeration container on a combined solar refrigeration truck.

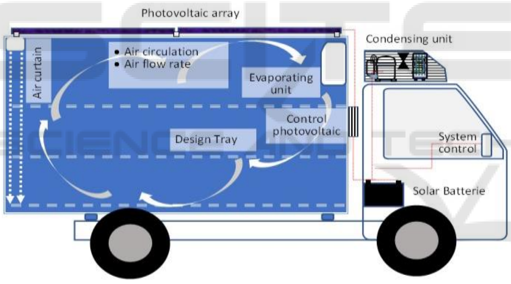

Figure 1: Refrigeration Design with DC Motor for Refrigeration Mini Truck Application.

The technology that will be developed in this research product has an overall prototype design at the time of carrying out the research, a very detailed design will be produced based on the results of the design of each part of the system, photovoltaic will be installed on the roof of the container where the energy will be supplied in a hybrid way. from solar power and car batteries with a control system that is compatible with electric car technology. Photovoltaics are designed with high efficiency so that with the available space the energy is supplied significantly for the operational needs of cooling containers.

The refrigeration system consists of one outdoor unit or condensing unit which is designed to be placed on the car cap and one indoor unit. All driving motors use a DC motor system so that they can directly use energy from solar energy without an inverter. And also use the battery installed in the car in a hybrid way if the supply from photovoltaic does not meet the required energy consumption. The connection of pipes and main lines from indoor to outdoor uses flexible pipes which are very strong against vibration and shock.

3 RESULTS AND DISCUSSION

3.1 Truck Refrigeration Design

In the design of the cooling container that will be designed to have the same dimensions as conventional trucks in general, where the design that will be used can be universally used on pick up cars that operate on the road today, the design that will be made follows the chassis capacity of 1,300 cc. and container specification is shown Table 1 as follow.

Table 1: Specification of the container.

length	250 cm
width	175 cm
height	160 cm
10 cm thick density floors and walls are given a lightweight construction as an intermediary for the load	
Paneling press molding system	
Rear door 1 (one) wing model	
4-point piping installation with led lamp	
Equipped with plastic curtain, and automatic air curtain	

The process of making cold containers for refrigeration trucks with a combination of solar power, it is carried out by making designs and calculating capacity so that the assembly process gets good results and the use of materials and cooling capacity can work optimally. And the 3D design with isometric view and top view is shown in Figure 2.

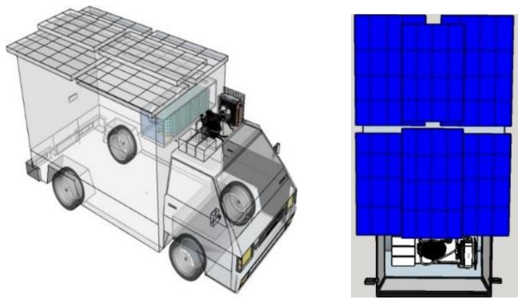

Figure 2: 3D Drawing of Refrigeration Mini Truck Applications.

3.2 Truck Container Cooling Load Calculation

First of all, some design conditions are defined according to rial condition as follows.

a. Indoor air condition design (depend on Indonesia circumstances), the dry bulb temperature (T_{db}) is 24ºC and Average relative humidity (RH) for fresh products is 80%, the average humidity ratio is 0.0105 kg/kg'
b. Design outdoor air conditions is found that the hottest month is May – September, the average dry bulb temperature (T_{db}) is 32ºC, daily temperature change is 30ºC, the average humidity ratio is 0.020 kg/kg' and the specific volume of outside air is 0.892/kg'

In Figure 3 is shown the schematic of heat transfer from environment to the container room and become reference to apply heat transfer equations.

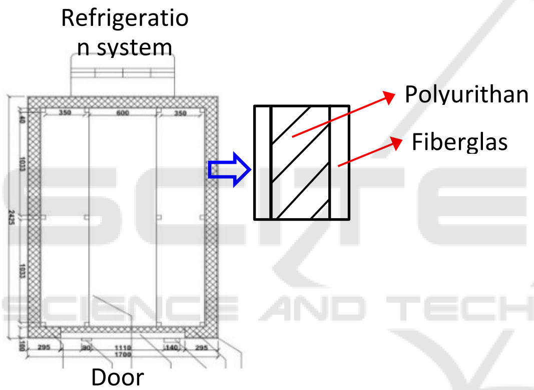

Figure 3: Schemtic of heat transfer from ambient to the room container.

Cooling load is calculated by the basic method of heat transfer from the surrounding air, heat load from stored products and infiltration factors, as well as the load from latent heat that occurs, namely high air humidity and adding humidity with a humidifier.

The results of the calculation of the cooling load on the container are shown in the following table.

Table 2: Heat load calculation results.

Sensible heat	Q	Latent heat	Q
Heat from environment to wall	876 kcal/h	Latent heat from indoor	449,16 kcal/h
		Latent heat from infiltration	90,882 kcal/h
Heat load from products/interior	1135 kcal/h		
Heat load from infiltration	403 kcal/h	2.414 kcal/h	
Heat load total		2.954 kcal/h	
		11.715 Btuh/h	

3.3 Refrigeration Components Capacity Calculation

The basis for calculating the capacity of the refrigeration system is the design that has been determined and the calculation results of the cooling load are used as cooling capacity. And design of layout refrigeration system shows in Figure 4 as follow.

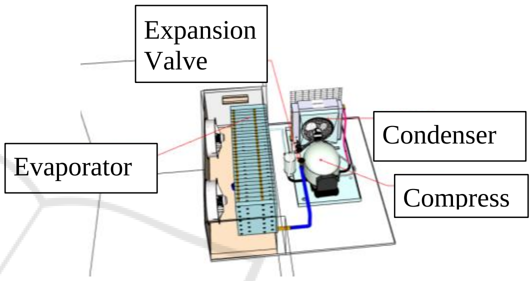

Figure 4: Design layout refrigeration system on truck container.

Furthermore, as the reference for capacity calculating some performance designs are defined as follows:

a. *Evaporating temperature design*
The desired room temperature is 2°C, then the evaporation temperature is determined = 2°C - 15°C where 15°C is empirical data on heat transfer losses from the evaporator to the room so that the evaporating temperature = 2°C - 15°C = -13°

b. *Condensing temperature design*
The cooling temperature is based on the average ambient temperature T_{amb}=30ºC, to produce the optimum heat transfer, the temperature difference ΔT=25ºC is determined (empirical data).
Condensing temperature = Ambient temperature + Temperature difference
= 30ºC + 25ºC = 55ºC

c. *Sub cooled temperatures* ΔT_{sc} *and Super heating* ΔT_{sh} are determined empirically based on the reference that the system works in the medium temperature zone, 2K and 10K , respectively.

d. *The type of refrigerant* used is environmentally friendly refrigerant and is available in the market, especially for Direct Current (DC) compressors, the refrigerant is defined R600a.

e. The compressor work is determined to have a thermal efficiency of 0.8 and the expansion process at the expansion valve is an iso-enthalpy process.

Furthermore, Calculations are carried out using *@coolpack software* and mass flow rate calculations are carried out by applying the energy balance equation in the evaporator and finally, capacity component of refrigeration system is tabulated in following table.

Table 3: Component capacity calculation results.

Refrigeration Components	Q (watt)	Type
Compressor	618	*Hermetic*
Evaporator	1103	*Finned tube*
Condenser	1721	*Finned tube*
Expansion valve	D=0,68 L= 185 cm	*Thermostatic expansion valve*

In summary, this research focuses on refrigerator design, which will be continued in further research by making prototypes of container systems and special refrigeration systems for this need. Detailed testing will also be carried out to obtain efficiency and effectiveness that can improve and validate the designs that have been produced in this study.

4 CONCLUSIONS

Depend to the results of the discussion that has been obtained in this study, it can be concluded as follows:

a. The container truck cooling system with an energy system from solar power that is compatible with electric car systems is very important to develop because it is a very feasible technology in the future.

b. From the design of a light truck system with a cooling container for working conditions at medium temperature, it is found that the cooling load and capacity of the refrigeration component are suitable.

c. This initial research focuses on the design of the refrigeration system and further research will continue with the manufacture of prototypes of the container system and the refrigeration system and the test results will also be used for improvement and validation of the designs that have been obte hope you find the information in this template useful in the preparation of your submission.

ACKNOWLEDGEMENTS

This research was supported by the Directorate of Academic, DIKSI, Ministry of Education, Culture and Research Technology, Indonesian Government, Grant No: 085/SPK/D4/PKK.01.APTV/VI/2022, SP DIPA-023.18.1690524/2022 tanggal 20 Juni 2022 Revisi ke 04 for the in cash contribution. The authors wish to acknowledge the contributions of The Mechanical Engineering Department-Bali State Polytechnic for the in-kind contributions. Also, Centre for Research and Community Service (P3M-PNB) for all administrative support.

REFERENCES

Rai, A., Tassou, S, A. (2017). Energy demand and environmental impacts of alternative food transport refrigeration systems, *Energy Procedia*, Vol. 123, Pages 113-120.

Ben Taher, M,A., Kousksou, T., Zeraouli, Y., Ahachad, M., Mahdaoui, M. (2021). Thermal performance investigation of door opening and closing processes in a refrigerated truck equipped with different phase change materials, *Journal of Energy Storage*, Vol. 42, 103097.

Li,G. (2017). Comprehensive investigation of transport refrigeration life cycle climate performance, *Sustainable Energy Technologies and Assessments*, Vol. 21, Pages 33-49.

Spence,S,W,T., Doran, W,J., Artt, D,W., Mc Cullough, G., (2005). Performance analysis of a feasible air-cycle refrigeration system for road transport, *International Journal of Refrigeration*, Vol. 28, Issue 3, Pages 381-388.

Gao, P., Wang,L,W., Zhu, F,Q., (2021). Vapor-compression refrigeration system coupled with a thermochemical resorption energy storage unit for a refrigerated truck PV, *Applied Energy* , Vol. 290, no. 116756.

Mousazade, A., Rafee, R., Valipour, M,S., (2020). Thermal performance of cold panels with phase change materials in a refrigerated truck , *International Journal of Refrigeration*, Vol. 120, Pages 119-126.

Rai, A., Sun, J., Tassou, S,A., (2019). Numerical investigation of the protective mechanisms of air curtain in a refrigerated truck during door openings, *Energy Procedia*, Volume 161, Pages 216-223.

Artuso,P., Rossetti,A., Minetto, S., Marinetti, S., Moro, L., Del Col, D., (2019). Dynamic modeling and thermal performance analysis of a refrigerated truck body during operation, *International Journal of Refrigeration*, Vol. 99, Pages 288-299.

Micheaux,T,L., Ducoulombier,M., Moureh,J., Sartre,V., Bonjour,J., (2015). Experimental and numerical investigation of the infiltration heat load during the opening of a refrigerated truck body, *International Journal of Refrigeration*, Vol. 54, Pages 170-189.

ASHRAE, (2016). Chapter 25 Cargo Containers, Rail Cars, Trailers, And Trucks, *ASHRAE Handbook, Washington DC.*

Osieczko,K., Zimon, D., Płaczek,E., Prokopiuk,I., (2021). Factors that influence the expansion of electric delivery vehicles and trucks in EU countries, *Journal of Environmental Management*, Volume 296, 113177.

Nykvist, B., Olsson, O., (2021). The feasibility of heavy battery electric trucks, *Joule*, Vol. 5, Issue 4, Pages 901-913.

Li,J., Yang, B., (2020). Quantifying the effects of vehicle technical performance and electricity carbon intensity on greenhouse gas emissions from electric light truck: A case study of China, *Atmospheric Pollution Research*, Vol. 11, Issue 8, Pages 1290-1302.

Liimatainen, H., Vliet, O., Aplyn, D., (2019). The potential of electric trucks – An international commodity-level analysis , *Applied Energy*, Vol. 236, Pages 804-814.

Sanjay, S., Joshua, D., Pearce, M., (2021). Electric vehicle charging potential from retail parking lot solar photovoltaic awnings , *Renewable Energy*, Vol. 16, Pages 608-617.

Yan,Y,A., Tseng,C,Y., Leong,J,C., (2012). Feasibility of Solar Powered Cooling Device for Electric Car, *Energy Procedia* ,Volume 14, Pages 887-892.

Tiano,F,A., Rizzo, G., Feo,G,D., Landolfi, S., (2018). Converting a Conventional Car into a Hybrid Solar Vehicle: LCA Approach , *IFAC-Papers On Line* , Vol. 51, Issue 31, Pages 188-194.

Sathre, R., Gustavsson, L., (2021). A lifecycle comparison of natural resource use and climate impact of biofuel and electric cars , *Energy*, Vol. 237, 121546.

Boström,T., Babar, B., Hansen, J,B., Good, G., (2021). The pure PV-EV energy system – A conceptual study of a nationwide energy system based solely on photovoltaics and electric vehicles , *Smart Energy* ,Vol. 1, no. 100001.