Study and Demonstration of Energy Reduction in Cold Storage Trucks with Vacuum Insulation Panels

Assadawut Issaro

A Thesis Submitted in Fulfillment of the Requirements for the

Degree of Master of Engineering in Energy Technology

Prince of Songkla University

2022

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I hereby certify that this work has not been accepted in substance for any other degree, and is not being current submitted in candidature for any degree.

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ชื่อวิทยานิพนธ์ การศึกษาและสาธิตลดการใช้พลังงานในรถขนส่งห้องเย็น ด้วยแผ่นฉนวนสุญญากาศ

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ปีการศึกษา 2564

บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อลดการใช้เชื้อเพลิงในระบบขนส่งโดยใช้แผงฉนวนสุญญากาศ (VIPs) สำหรับรถบรรทุกห้องเย็น วัสดุเป็นแผงฉนวนสุญญากาศ (VIPs) เป็นฉนวนสั่งทำพิเศษโดยใช้เส้นใยแก้วที่สภาวะการนำความร้อนของวัสดุที่เลือกอยู่ระหว่าง 0.0028 ถึง 0.007 W/mK วิธีทดลองรถบรรทุกห้องเย็นที่มีทั้งแบบมีแผงฉนวนสุญญากาศ (VIPs) และแบบไม่มีแผงฉนวนสุญญากาศ (VIPs) ของรถขนส่งห้องเย็น 4 รุ่น ดังรูปที่ 4 ซึ่งมีรุ่น 1 (รถบรรทุก 4 ล้อ) รุ่น 2 (รถบรรทุกขนาดใหญ่ 4 ล้อ) รุ่น 3 (รถบรรทุก 6 ล้อ) และรุ่น 4 (รถบรรทุก 10 ล้อ) การติดตั้งเซ็นเซอร์ในห้องเย็นถูกกระจายในทุกผนังเพื่อให้เกิดความแตกต่างและการกระจายของอุณหภูมิเย็น ผลลัพธ์ที่ได้จะคำนวณจากผลการประหยัดพลังงาน พบว่า รุ่น 1 (รถบรรทุก 4 ล้อ) ประหยัดน้ำมันได้ดีที่สุด คิดเป็น 20.24% สำหรับรถแช่เย็น ส่วนรถแช่แข็งพบว่า รุ่น 1 (รถบรรทุก 4 ล้อ) ประหยัดน้ำมันได้ดีที่สุด คิดเป็น 16.99% งานวิจัยนี้สามารถประยุกต์ใช้รถบรรทุกห้องเย็นประเภทอื่นๆ หรือการวิจัยในลักษณะเดียวกับผนังอากาศ โดยการใส่แผงฉนวนสุญญากาศ (VIPs) ภายในฉนวนภายนอกเพื่อลดการถ่ายเทความร้อน

Thesis Title Study and Demonstration of Energy Reduction in Cold Storage Trucks with Vacuum Insulation Panels

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Major Program Energy Technology

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ABSTRACT

This research aims to reduce fuel consumption in transportation systems using vacuum insulation panels (VIPs) for cold storage trucks. The material was vacuum insulation panels (VIPs) is a custom-made insulator using glass wool board and the thermal conductivity conditions of the selected materials ranged between 0.0028 and 0.007 W/mK. Comparative experiment method of cold storage trucks equipped with VIPs and without VIPs of 4 model frozen cars, as shown in Figure 4. Which has Model 1 (4 Wheels Truck), Model 2 (4 Wheels large Truck), Model 3 (6 Wheels Truck), and Model 4 (10 Wheels Truck). The sensor installation in the cold room is distributed in every wall to achieve differentiation and distribution of cold temperatures. The results are calculated as the energy saving result, it was found Model 1 (4 Wheels Truck) have best fuel savings was 11.25% for chiller trucks. As for frozen trucks, it was found Model 1 (4 Wheels Truck) have best fuel savings was 16.99%. This research can apply other types of cold storage trucks or research in the same way as the air wall by inserting VIPs insulation inside the external insulation to reduce heat transfer.

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Assadawut Issaro

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LIST OF ABBREVIATIONS AND SYMBOLS

VIPs	= Vacuum Insulated Panels
Covid-19	= Coronavirus disease starting in 2019
DW	= Developing World
B	= Baht
VAS	= Vapour Absorption System
VCS	= Vapour Compression System
GPS	= Global Positioning System
W	= Watt
°C	= Degree Celsius
K	= Kelvin
kcal	= Kilocalories
hr	= Hour
mm	= Milli Meter
m	= Meter
m^2	= Square Meter
hp	= Horsepower
XPS	= Extruded Polystyrene
CFC	= Chlorofluorocarbon
HCFC	= Hydrochlorofluorocarbon
PIR	= Polyisocyanurate
PU	= Polyurethane
EPS	= Expanded polystyrene

CHAPTER 1

Introduction

1.1 Background

Coronavirus impacted the whole e-commerce industry, altering the business's features. According to Andrienko (2020), 52 percent of consumers avoid purchasing at a conventional street-side company or a business that serves clients face-to-face in an office or store with crowded surroundings [1]. Furthermore, 36 percent said they won't go shopping unless they have a coronavirus vaccine. Covid showed shifting levels of effect on various things, inferring that the infection generally affects a few and a low effect on others. Individuals decide to remain at home rather than go out due of Covid-19, thus individuals are telecommuting and shopping from home utilizing the web stage [2]. The production network affects worldwide exchange firms, from exchanging to the board. Organizations, all things considered, from large companies to minuscule traders, expected to refresh their techniques. To build up purchaser dependability and assurance that customers get their stuff in a great condition, all organizations use internet shopping and door to door delivery administration. Maintaining a web business might support clients who cannot visit the store and, in this way, acquire pay. Notwithstanding the way that web shopping has expanded generously as of late, Covid-19 has profoundly changed the way individuals live and shop [3].

While e-commerce is significantly expanding, logistic business or domestic transport is also expanding accordingly [4]. Most of the people lived in Bangkok, Perimeter, and Phitsanulok, representing 14.1 percent of the populace. Most of them bought things through online, which the example size had recently bought on the web. Preceding the Covid-19 flare-up in Thailand, most of things were garments, attire, and style, with 218 people web based shopping before the plague, and 204 individuals internet shopping during the pestilence, representing 51.0 percent of the aggregate. Food and refreshments/conveyance, which represented 188 people and 14.4 percent of the aggregate, got the most votes [5]. Thus, web shopping has become more famous in Thailand during the last year. Accordingly, the homegrown cargo sending industry has extended; there are at present more than ten cargo forwarders and new dealers joining the market consistently [6].

Cold-chain logistics refers to a supply chain system in which perishable and fresh food logistics are produced, stored, transported, sold, and all other aspects of the perishable and fresh food logistics are kept at a constant temperature to ensure food quality and safety, reduce losses, and prevent pollution. Fresh food is generally transferred from production cold storage to cold storage distribution center, then to sales cold storage, as part of the cold chain logistics process, to ensure that the food can be given at a low temperature along the supply chain. The cold chain is critical for maintaining product quality, increasing shelf life, and ensuring product quality. Its methods help to prevent food spoilage and waste from the farms to the tables of customers.

1.2 Rationale

This results in the capacity to deliver products over longer distances to customers, as well as increased customer satisfaction. Furthermore, it provides an opportunity for chain participants to get additional benefits while reducing their damages and costs. Most products in the cold chain are temperature sensitive and perishable, such as agricultural products, livestock products, fishery products, processed food, chemical products, and other temperature-controlled products [7]. The global cold chain business, including some developing regions, has seen significant changes in the previous decade. In the recent decade, global total cold chain capacity has grown. In the developing world (DW), it more than doubled in India, climbed by 66 percent in Brazil, and 20 percent in China, but remained very low or non-existent in many countries. It is a severe concern in areas with a warm temperature or throughout the summer. In certain parts of the DW, the cold chain industry has a low return on investment when compared to other industries. In general, the cold chain in the DW is still underdeveloped and requires significant upgrades, posing obstacles [8]

Organizations in the internet business area can rapidly and helpfully exchange and pay utilizing a web-based stage. Nonetheless, the coordination methodology is needed for the conveyance of items from the merchant to the beneficiary. The conveyances will occur following the buy and arrive at shoppers in an opportune, right, and unquestionable way, making this a troublesome test to address attributable to the genuine dissemination of items, which includes a few natural conditions [4]. Thailand's food and refreshment industry, especially new dry and frozen natural product, developed at a normal of 24.1 percent somewhere in the range of 2016 and 2020, with the development pattern of pharmaceutical industry business foundations expanding by in excess of 100% from January to September 2020, because of the Covid 2019 outbreak. This has brought about an increment popular for food and medication transportation, just as for cold chain the executives. However, the cold chain logistic process of each product has different details. In logistics management, the cold chain is focused on storage and distribution. Cold chain management should be as short as possible and consistent with the shelf life of each product [9].

Thailand is the gateway to the fast-enlarging market, economy, human resource, world class infrastructure due to the geographical and location of Thailand and strong government support making it one of the most attractive investments and demand for cold chains is expected to develop in the future. Major frozen food producers in Thailand have started investing and expanding their production capacity to meet the growing demand for cold chain products. Import value in 2012, B251,152.31 million, increased to B331,261.48 million in 2018. The export value in 2012, B444,904.96 million, increased to B509,779.07 million in 2018. Furthermore, Thailand had 338 refrigerated vehicle operators in 2019 [7]

1.3 Objective of the Study

1. Investigate a cooling system using vacuum insulation panels (VIPs) in order to study the transformation of transport to transportation. Energy-saving and environmentally friendly (Green Logistics)

2. To study the potential to reduce energy consumption by vacuum insulation panels (VIPs).

1.4 Scope of the Study

This research study aims to study, research and demonstrate the use of energy in transportation system. And design a cooling system by reducing energy consumption in the logistics of 4 model frozen cars (temperatures of -23 to -25 ^{o}C) Which has Model 1 (4 Wheels Truck), Model 2 (4 Wheels large Truck), Model 3 (6 Wheels Truck), and Model 4 (10 Wheels Truck). by installing vacuum insulation panels (VIPs). And test driving under the real environment.

1.5 Organization of the Report

The thesis consists of five chapters that are described in detail below.

Chapter 2 presents a literature review on the importance of cold chain logistics and cold room that playing an important role in maintaining temperature to maintain quality and reduce the risk of product loss, including insulation is a material that resists or prevents heat energy to kept optimize temperatures in cool room.

Chapter 3 describes the methodology used in this study. material and Designing vacuum insulation panels (VIPs) for cold storage trucks.

Results and discussion are present in chapter 4 and chapter 5 conclusion and additional ideas and organizational recommendations for future research and development.

CHAPTER 2

Literature Review

2.1 Cold Chain Logistics

A cold chain logistics is a continuous process to strictly maintain the temperature and plays a significant role to ensure the effectiveness of the storage and handling process to ensure the quality of special goods that need special requirements for the product. By maintaining the temperature to preserve quality and reduce the risk of product loss. And sharing the data to tracking of cold chains to ensure the health and safety of people. Genovese et al., (2017) has mentioned that cold chains should be processed, packaged and shipped at the appropriate temperature as expeditiously to provide customers with fresh and quality products and to enhance cold transportation [10].

Since there is the temperature control of the product to be continually cooled and maintain a suitable temperature of approximately +1°C of the desired temperature. According to the type of products of Thailand, such as tropical fruits and vegetables, the temperature should be above 5°C. To decelerate the biochemical processes that will occur with products, decelerate the continuous growth of some products, reduce water loss, reduce the response to ethylene which will lead to faster ripening or shorter shelf life [11].

The cold chain logistics process includes of 5 main activities:

First activity is the production process for industrial products, food, medicine, and pharmaceuticals. The temperature is controlled from the production process, raw material storage, production process and preparing the temperature-control shipping for longer shelf life. Second activity is storage (either long-term or short-term) is storage with temperature-control warehouse or cold storage. Storage will depend on the type, size and location of the warehouse. Third activity is old storage packing and processing, the packing or processing of the goods is controlled at the appropriate temperature in the cold storage and the product packaging is conducive to shelf life. Fourth activity is distribution of temperature control in all modes of transportation. And the last activity is marketing (sales to consumers) is the temperature control at placement or storage, as well as the external environment that may affect the refrigerator, freezer, or storage location [9].

2.1.1 Key factors in the cold chain

Cold chains are generally technological processes that maintain the integrity of products and merchandise that are vulnerable to temperature changes throughout the supply chain. It generally involves strategic logistics planning to carry out Efficiently operate the cold chain and requires in-depth knowledge of the chemical and biological processes involved in the degree of perishability. There are four key factors in the cold chain [12], including:

1. Cooling systems. Making the environment suitable for storage and transportation which need to pay attention to how to reduce the temperature or cooling, such as using ice or cold water freezing using a vacuum system. The operator must have an understanding of the nature of the product. in order to be able to choose the appropriate cooling method for the type of product.

2. Cold storage. It is an area for storing products with internal temperature control to be suitable for maintaining the quality according to the type of products and not causing temperature changes according to external conditions. For storing goods for a certain period of time before distributing them to the market at further distances. The temperature control of cold storage is generally from less than 25 °C to minus temperature. There are two main types of refrigeration systems used in cold storage warehouses: Vapour absorption system (VAS) and Vapour compression system (VCS)

3.Cold transport. The use of vehicles for moving goods in a mode of transport with constant temperature and humidity. as well as maintaining the integrity of the product in temperature-controlled transport, most of the time, containers are required that perform well under various transportation conditions and can control the temperature inside the container to be suitable for the goods and to withstand the Global Positioning System (GPS) to be used to track temperature-controlled transport vehicles in real time.

4. Cold processing and distribution is the supply of things facilitating for product packaging and processing as well as certification Hygiene. Consolidation and disassembly of components for distribution. This activity also includes the use of packaging that complies with standards and proper packing processes that will help maintain condition of goods and reduce losses during movement and transport.

2.1.2 Optimization Cold Chain Logistics

Cold chain development is an important factor in ensuring the sustainability of logistics and supply chains. Because it is a process that reduces the loss of goods. A follow-up system is needed to know the reasons for this. This will cause the operators to manage resources more efficiently. Tracking and Tracing System is an important factor in tracking products in the cold chain process. can be divided into two systems:

1. Tracking is a tracking system to let the manufacturer know where the products are sent to be sold in the event that raw materials are found to be defective in one lot of production, all problematic lots will be recalled correctly.

2. Traceability is the ability to ascertain from where the goods are sourced from the raw materials, packaging or related parts or there is a production problem when and from which production line. This will let you know where the problem is and how much of the product has been produced and have detailed information in the production process. Traceability is carried out throughout the supply chain from production, delivery and distribution to the final consumer.

2.2 Cold Room [13]

Cold storage is a place where the kept food at low temperatures. However, it must not be lower than the freezing point of that food. It is generally around -18 °C, but it also depends on the type of food be preserved. The temperature of the cold room used will vary. Which can be divided into five types of cold storage as follows.

2.2.1 Air Blast Freezer Room [14]

Air Blast Freezer Room used for the freezing product to cool quickly without causing damage to cells. The freezing of each product is different. For example, freezing vegetables or fruits must be frozen quickly not to break the cell wall. Which is caused by the water inside the cell changing from liquid to solid state (Flake ice) or frozen seafood exports must try not to cause ice crystals inside the meat cells because it will cause the cells to bruise in general. Go to the freezing room; the wind is freezing. It Will have a capacity of 2.5 Tons of product, which takes time to freeze (Freeze) about 4 to 5 hours, with the requirements to pull the temperature should not exceed 6 hours. About -35 °C or depends on the product.

2.2.2 Freezer Room [15]

The freezer Room use to cool down and store products for long periods. For example, the temperatures below the freezing point are frozen fish stored at about -17.8 to -23.3 °C, which can take a store for 8 to 10 months. Therefore, most of the required operating temperature is about -5 to -25 °C, depending on the product.

2.2.3 Air Blast Chill Room [16]

Air Blast Chill Room is used to reduce the temperature of the product for use in the following process. Alternatively, to control bacteria, most acute refrigeration chambers also have time requirements. Most of the required operating temperature is about 2 to -10 °C or depending on the product.

2.2.4 Cold Storage Room [17]

Cold Storage Room is used to store goods. The product will be frozen where the temperature of goods to be stored is "lower" or "equal to" the temperature of the storage room. In calculating the cooling load, it is not necessary to charge the heat from the product. Most of the required operating temperatures are about -25 °C or depending on the product.

2.2.5 Anti-Room [18]

Anti-Room is used to reduce the outside air temperature, which has high temperatures flowing into the freezer room, cold air, freezer room, or low-temperature storage room. This room intends for storing products. or distribution depending on the user. Most of the required operating temperatures are about -5 to +10 °C or depending on the type of operation.

2.3 Type of insulation

An insulator is a material that resists or prevents heat energy from being quickly passed from one side to the other. Good insulation will be a lightweight material, which consists of many tiny bubbles. It has the property of resisting heat conduction. The blocking the heat in this area of many tiny bubbles, there is no convection. Each type of insulator will have different heat resistance. A good insulator must resist heat passing from one side to the other to a minimum.

However, the lower the coefficient of thermal conductivity (K value), the better the insulator can resist heat. Therefore, it can be classified according to the following types.

2.3.1 Vacuum Insulated Panels (VIPs) [19], [20]

A vacuum Insulated Panels (VIPs) is insulation consisting of a gas cabinet around a rigid core from which air has been evacuated—used in refrigeration unit buildings. Moreover, insulated shipping containers make insulation performance better than conventional insulating materials. The VIPs core material has similar thermal characteristics to conventional insulator materials; VIPs has a much lower thermal conductivity (k-value) than conventional insulators. It has a higher heat resistance per unit thickness. Commercially available VIPs typically have a thermal conductivity of 0.004 W/(m K) at the center of the panel. VIPs with thermal conductivity of 0.005-0.008 W/(m K) after cooling is allowed. (Thermal conduction through the edge of the panel) and the inevitable loss of vacuum over time.

VIPs heat resistance per unit thickness compares favorably with conventional insulators. For example, standard mineral wool has a thermal conductivity of 0.044 W/ (m K), and a rigid polyurethane foam sheet is approximately 0.024 W/ (m K). Therefore, five of the common insulators Have a heat resistance (R-value) about five times per unit thickness. Based on a typical k-value of 0.007 W/ (m K), the R-value of a VIPs with a thickness of 25 mm (1 in) is typical of 3.5 m^2K/W (20 h ft 2 °C Fahrenheit/BT. u). Rockwool 154 mm (6 in.) or 84 mm (3 in.) of rigid polyurethane foam panels are required to achieve the same R-value.

However, the heat resistance per unit price is much less than that of conventional materials. VIPs is more complicated to produce than polyurethane foam or mineral wool. Furthermore, strict quality control of membrane fabrication and sealing is essential. If the panel maintains a vacuum for an extended period, air will gradually enter the panel, and as the panel pressure normalizes to the ambient air, the R-value decreases. Cooling, Therefore, is not susceptible to this form of deterioration. Polyurethane foam is also susceptible to water absorption and performance degradation.

2.3.2 Extruded Polystyrene Foam (XPS) [21], [22]

Extruded polystyrene insulation (XPS) is a rigid, relatively high density, extruded polystyrene insulation board. It has a 100% closed-cell structure produced in a fully automated continuous extrusion following international specifications and standards. The closed-cell structure of extruded polystyrene (XPS) prevents water penetration to the structure of the insulation board and provides long-term strength and durability. It is produced using NON-CFC / NON-HCFC, Environmentally Friendly Products.

XPS foam board is possible to provide a wide range of exceptional properties to the product, such as:

- High resistance to heat flow, i.e., low thermal conductivity
- Resistance to water vapor diffusion and water absorption
- Uniform density distribution
- Relatively high compressive strength
- Resistant to weathering
- Resistance to bacteria and micro-organism growth.

2.3.3 Polyisocyanurate (PIR) [23], [24]

Polyisocyanurate or PIR is another type of insulation that has been developed. However, before we get into PIR, let us get acquainted with other types of insulation (Polyisocyanurate) (PIR) developed from polyurethane. It has the same properties as PU Foam but has good flame retardant properties. Then and lower smoke values in other countries, PIR insulation is more popular because it provides more safety and faster extinguishing. Moreover, the smoke content is lower, and It is CFC-free insulation that does not affect the destruction of the ozone layer that will cause global warming.

Unique properties of PIR insulation (PIR)

1) PIR reaction occurs at a higher temperature than the reaction of PUR, so it has a solid molecular structure, making PIR stronger than polyurethane. (Reports show that temperatures above 200 ^{o}C are required to break the chemical bonds of PIR, whereas PUR uses only 100-110 ^{o}C).[25]

2) PIR (PIR) is suitable for use with residences. Because it has less smoke value than polyurethane foam (PUR), PIR has a fire-retardant value of less than 25 but a smoke value lower than 50, while polyurethane poured Polyurethane foam has a flame retardant rating of less than 25 and a smoke rating of 150-350. In addition, polyurethane foam (PU) is less flexible and powdery than a PIR sheet.[26]

2.3.4 Expanded polystyrene foams (EPS) [27], [28]

EPS stands for Expanded Polystyrene Foam. When used to produce EPS foam, the raw material will expand when heated from steam (Steam) to become white foam beads, and then be molded (Molding), which has two types: – Extrusion into various shapes according to the shape of the mold (Shape Molding), such as an icebox. Moreover, various packages are extruded into blocks (Block Molding) and then cut to the desired size and shape. In general, EPS foam expands approximately 50 times, and when expanded, 98% of the air will be replaced by air. Only 2% of the volume is PS plastic, so the foam is so big but so lightweight. It is this feature that allows the EPS foam to absorb shocks well. Suitable for use in packing products, it also supports vertical weight transfer without deformation. Therefore, it can be used as a material for making roads. Please solve the problem of road collapse; It is also used as a heat and cold insulator. Because 98% of the air contained within it acts as a good insulator. Foam is commonly known. In terms of features, it is light but can support the weight well. In addition to that, it also has thermal insulation properties and prevents the passage of sound. Therefore, it is suitable for the construction of want to save energy Load-bearing work or shockproof work, including work that requires lightness. Foam is used for many different types of applications, such as building construction. Energy-saving home construction Roads, bridges, construction of floating houses insulation work Packaging work and lost foam work, many other tasks depending on the type of properties that need to be used. Nowadays, foam properties play a more significant role in reducing energy consumption and stopping global warming.[28]

2.3.5 Polyurethane Foams (PU Foam) [29]

Polyurethane foam insulation or Rigid Polyurethane Foam is material to prevent heat - cold, leakage, and noise reduction with a closed-cell structure (Closed Cell) with a hollow air cavity called Air Gap. Installed using Spraying method to materials such as metal, wood, brick, concrete, glass, plastic, gypsum tiles, etc. Polyurethane foam insulation. Solidly bonded together with the material. No insulating joints, the thickness of the foam can be set as needed. Therefore, it can entirely reduce heat. It does not absorb water and does not absorb water, reduces noise, is suitable for installation under the roof, on the roof of a residential house, industrial plant, cold storage industry, Air conditioners and industries that require temperature control, etc.

The most efficient insulating against heat and cold energy. It does not cause heat and cold energy transmission is durable to use in temperatures at –70 °C to 100 °C and has a service life of more than ten years without any maintenance. PU foam is not acid-alkali. Or other toxic solvents, flammable insulators but not flame retardant because of the flame retardant. Therefore, it is not fuel when it is burned.[30] It is lightweight, foam size 1 m^2 x 1 $m^2$1 inch thick, it weighs less than 1 kg, so it does not add weight to the foundation structure. Can bear pressure up to 2.20 kg. Easy to install. Spraying PU foam insulation takes only 3 seconds to set. Moreover, it will solidify in only 20 seconds and can also be sprayed Can be attached to all kinds of materials. Its density is 35-50 kg/m^3, complex and does not deteriorate, and can be molded according to the injected material. It can be sprayed or dripped in every corner and does not absorb water, is durable, does not collapse, and causes the temperature in the room to drop more than 8-20 °C, will prevent more than 90% heat radiation from the outside, but if using internal air conditioners together with It will take time for air conditioning to cool quickly. Just a noticeably short time.

2.3.6 Foam glass [31], [32]

Foam glass is a lightweight insulating material. Hardening material is made up of millions of glass cells that are entirely sealed to each other. Foam glass insulation is an excellent insulator for cold protection commonly used in petroleum applications with encapsulated spaces in each cell. Moreover, it can use foam glass to cover pipes and tanks in various petrochemical processes-both on the ground or underground. Whether indoor or outdoor in the temperature range of interest (600–900 °C), foam glass is a porous glass foam material. Its advantages as Building materials include lightweight, high strength, and thermal and acoustic insulation properties. It is made by heating a mixture of crushed glass or granules and a blowing agent (foaming chemicals) such as carbon or limestone. Near the melting point of the glass, the blowing agent emits gas, causing bubbles in the glass. After cooling, the mixture solidifies into a solid material with gas-filled closed cell pores comprising most of its volume. Foam glass occupies an increasingly important position in low heat insulation, moisture-proof engineering, and sound absorption due to its high durability, safety, and reliability. In addition, production is the recycling of waste materials, an example of environmental protection and significant economic benefits.

By Cold storage, insulators have been continuously developed from the past to the present. The progressing of cold room insulators, as shown in Figure 2.1 [33]. Found that, the best heat transfer coefficient (U value) value is vacuum insulated panels (VIPs) [34] and smallest size [35]. Therefore, VIPs is appropriate to be used in this research to reduce the heat load, reduce energy consumption, and maintain the quality of the product[36].

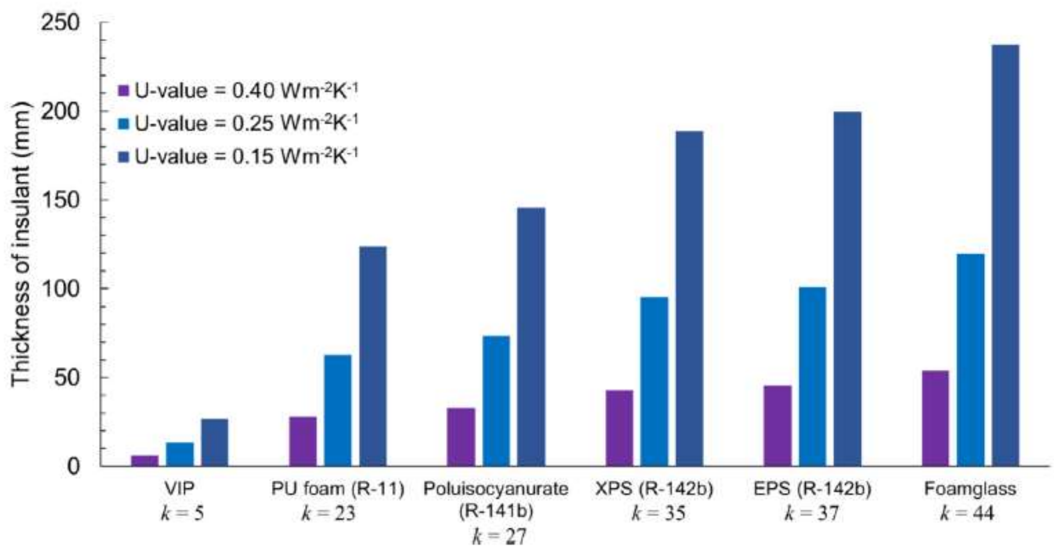

Fig. 2.1 The progressing of cold room insulator [36]

2.4 Dielectric Properties

When it comes to the dielectric properties of materials considered to have good insulators, the degree of insulation must be determined based on three main theoretical properties.

- Resistivity
- Conductivity
- Thermal Capacity

2.4.1 Resistivity [37]

The thermal resistance or "R-Value" is a value that indicates the ratio between the thickness of material along with the heat flow and its thermal conductivity. When objects are nested in multiple layers, The total thermal resistance is equal to the sum of the thermal resistance of each class of the given material combined. Furthermore, the thermal resistance is related to the reciprocal thermal conductivity; if the thermal resistance is high, the material will also have a low thermal conductivity.

The thermal resistance or "R-Value" value can be calculated from

$$R = 1 / C = \Delta X / K$$

where R = Resistivity - m^2-K / Watt

C = Thermal Capacity - W / m^2-K or J / kg-K

ΔX = the thickness of the material to be considered

K = thermal conductivity - W / m-K

2.4.2 Conductivity [37]

Thermal conductivity, or "K–Value", can describe the thermal conductivity of a single material. It is measured in terms of the amount of heat flow per unit time from one distance point to another point with different temperatures per unit of cross-sectional area flowing and the temperature measurement is Wm/m^2-K = W/m-K (or W/m-^{o}C) where the coefficient of thermal conductivity (K – Value) of each material varies greatly, e.g., glass fiber insulation is 0.03 W/m-K copper is 384 W/m-K. The total thermal conductivity coefficient can be calculated backward from the k value as follows [25].

$$U = \frac{1}{\frac{1}{h_0} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \ldots + \frac{x_n}{k_n} + \frac{1}{h_i}}$$

where U = total thermal conductivity coefficient, unit is Btu/h-ft^2-^{o}F (W/m^2K)

h_o = coefficient of thermal conductivity of outdoor air, unit is Btu/h-ft^2-^{o}F or (W/m^2-K)

h_I = coefficient of thermal conductivity of indoor air, unit is Btu/h-ft^2-^{o}F or (W/m^2-K)

x_n = the thickness of the material in the nth layer, in inches or (m.).

k_n = oefficient of thermal conductivity of the nth layer of material, expressed as Btu-in/h-ft-^oF (W/m-K)

2.4.3 Thermal Capacity [38]

The heat capacity of the matter is equal to the product of the mass of the substance and the specific heat capacity. The specific heat capacity of matter (Specific Heat Capacity) is a value that tells the relationship between heat and temperature. It is because the specific heat capacity of the matter is the amount of heat energy that causes a substance of one mass to rise by 1 degree and is measured in Cal/g-^oC or J/kg-K or some cases are Wh/kg-K. For example, the heat capacity of brick and concrete is 800 – 1000 J/kg-K, water is 4176 J/kg-K, and dry air is 1005 J/kg-K etc.

The material's heat capacity will not be able to tell if it should be directly, so it is good because if the heat capacity is low, the heat transfer into the interior will be significant. It will pass faster. which is suitable for the part that is used only at night but on the other hand, being able to store much heat, the heat that is transmitted to the building will be less or will pass more slowly (Time-Lag), which is suitable for areas that are used only during the day. The heat transfer due to the material's heat capacity is related to the time interval that must be selected accordingly.

2.4.3.1 Total heat transfer value [39]

It is a value used to show the total heat that enters the building. It may also be called the "Q" value. It can calculate from the relationship between the Heat transfer coefficient, the total area exposed to sunlight, and equivalent temperature difference between indoor and outdoor.

$$Q = U \cdot A \cdot \Delta T$$

Where Q = total heat transfer value W (J/s)

U = heat transfer coefficient (W/m^2-^oC)

A = total area exposed to sunlight (m^2)

ΔT = equivalent temperature difference between indoor and outdoor (^oC)

2.6 Research reviews

Table 2.1 Shown related articles and research.

Related research	Gap conditional	Reference
In this paper, the conductivity of VIPs was well predicted using a theoretical and experimental model developed in this work. To investigate the influence of durability, researchers created three generic barrier envelopes and measured property characteristics. In a theoretical prediction model, VIPs were able to keep their insulating qualities efficiently for a long period. In addition, various optimization approaches to increase VIPs life have been presented. Finally, the findings are critical in forecasting VIPs lifetime and real building utilization.	VIPs is applied and tested on buildings to simulate VIPs service life, but VIPs is not simulated in cold storage.	[40]
In this paper, to evaluate the performance of VIPs, this research focused on thermal conductivity of the porous core material, thermal conductivity of gases, and thermal radiation. The performance of VIPs was investigated using a validated heat transfer model. The findings showed that the model was capable of accurately predicting thermal conductivity. Thermal conductivity would be reduced with a smaller mean diameter and internal pressure.	The research-based on heat transfer model validated VIPs performance of porous core materials. However, this research has not brought VIPs to simulate in a cold room.	[41]

Related research	Gap conditional	Reference
In this paper, VIPs had the lowest payback period among the insulating materials tested in this article, ranging from 2.5 years to 17 years, depending on the rental revenue of the property. VIPs were shown to be economically viable for installation on non-domestic buildings in high-rental-value areas, assuming a 60-year lifetime. VIPs for any installation, regardless of use, including residential and non-residential buildings, refrigerators, freezers, and refrigerated vehicles, to name a few.	Research shows the worthiness of investing in VIPs insulation for residential and non-residential buildings, refrigerators, freezers, and cold storage vehicles, for example. To the application in cold storage and demonstrated the ability to save fuel in transport vehicles as well.	[42]
In this paper, the design approach, construction details, equipment, and thermal performance monitoring observations of a VIPs retrofitting wall system in Yukon, Canada, are presented in this article. The ability to construct VIPs in Canadian subarctic conditions and accessible thermal performance data over three years give positive signs for constructability and long-term thermal performance. Vacuum insulation panels (VIPs) have thermal resistance ratings up to 10 times more than traditional thermal insulation materials in the middle of the panel.	This research will present a design approach to Construction details, equipment, and thermal performance verification of VIPs insulation is wall systems, but VIPs insulation in refrigerated trucks have not yet.	[43]

Related research	Gap conditional	Reference
This paper studies the thermal losses on the edges of vacuum insulation panels (VIPs) by the thickness of the panels, the type of edge design (single- or multi-layered foils), the inorganic barrier material, and the thickness of the barrier layers. Via numerical simulations for VIPs of varying thickness, the thermal bridging effects a determined for different influencing factors.	This paper examines the edge heat loss of VIPs insulation by panel thickness. Type of edge design (single-layer or multi-layer foil), but the VIPs insulation does not test going for actual use in refrigerated trucks.	[44]

CHAPTER 3

Methodology

The aims of this research are performed energy-saving and environmentally friendly (Green Logistics) by designs the vacuum insulated panels (VIPs) that custom-made insulator using wool board as a cooling system. In methodology part performs by comparative energy consumption between the cold storage trucks installed with VIPs and without VIPs.Test by driving cold storage trucks under the real environment from Bangkok to Prince of Songkla University, Hatyai Campus. The researcher has defined the following Materials and Methods

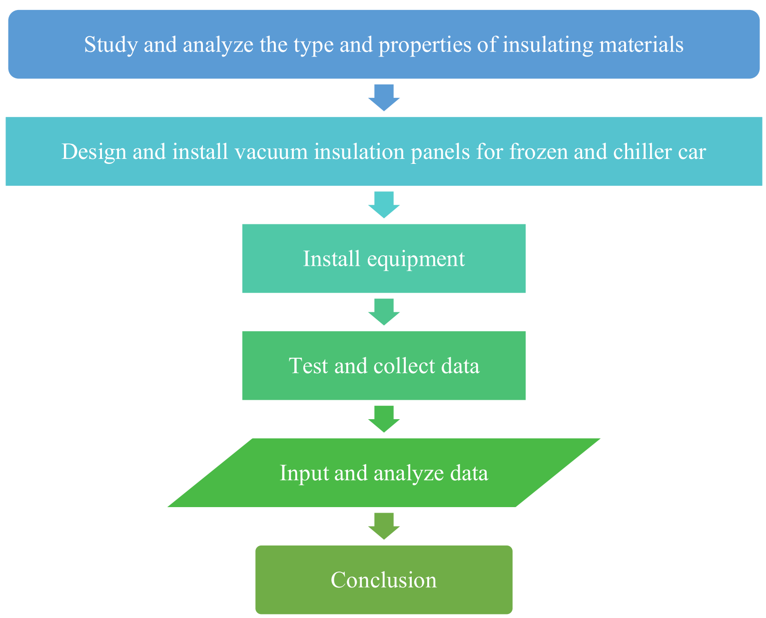

Fig. 3.1 Show research flow process

3.1 Materials

The material, VIPs is a custom-made insulator using glass wool board pressed at 10 tons per square meter, then vacuumed and foil wrapped, as shown in Figure 3.2. The limitations of VIPs are currently not available in a wide variety of applications [45], as they must be prevented from impacting or kinking resulting in loss of insulation due to vacuum loss [46]. The vacuum insulated panels (VIPs), as shown in Figure 3.4 [47]. The thermal conductivity conditions of the selected materials ranged between 0.0028 and 0.007 W/mK and has a size of 12 mm [48].

Heat transfer occurs by three mechanisms as follows convection, conduction and radiation. Creating a vacuum in VIPs will actually reduce convection because it is the elimination of gas molecules that can transfer heat energy. Shown that VIPs higher insulation performance than compared with conventional material. as shown in Figure 3.3.

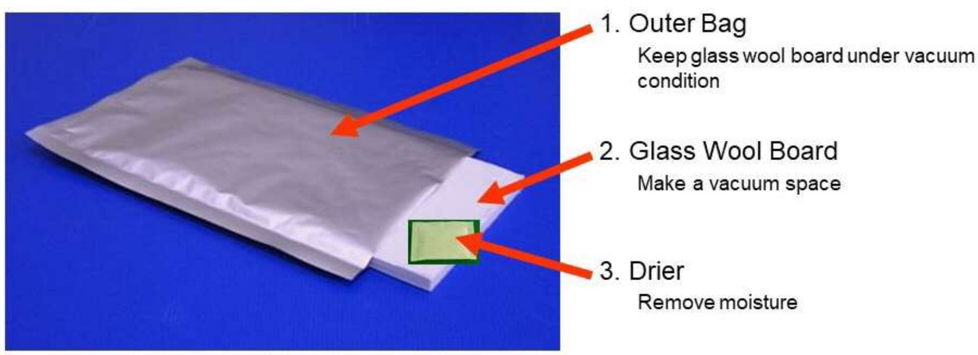

Fig. 3.2 Basic structure of VIPs

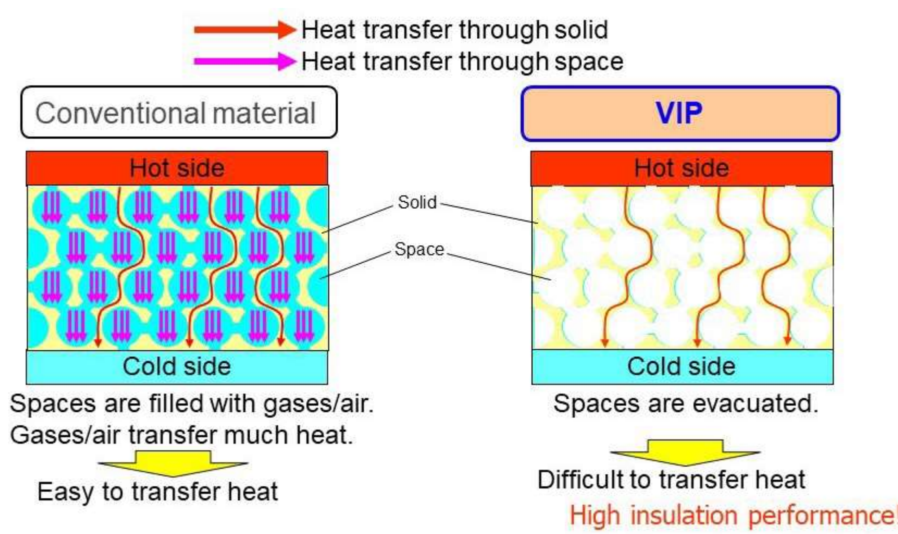

Fig. 3.3 Heat transfer model of insulation

3.2 Methods

3.2.1 Study and analyze the type and properties of insulating materials.

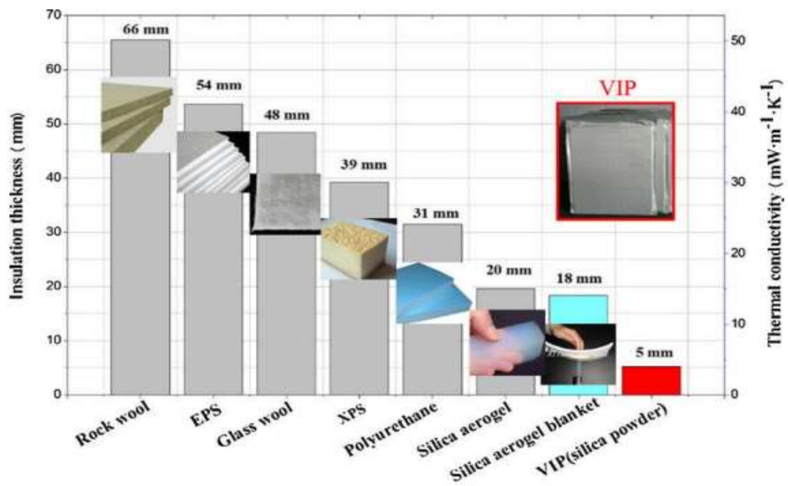

Fig. 3.4 Insulation thickness for U-value = 0.6 W/m^2K and thermal conductivity for different types of insulation materials

As a type of superfine thermal insulations, vacuum insulation panels (VIPs) have already been extensively applied in insulating refrigerators, cold storages and building envelopes. However, their thermal insulation performance becomes poor with the increase of internal pressure, which results in a short service life of 5–25 years for commonly used VIPs. To enhance their thermal performance and prolong their service life, VIPs with fiber felt/silica aerogel composite cores were prepared. The microstructure and thermal conductivity of the as-prepared core material were experimentally investigated. Based on the experimental results, theoretical models for predicting the thermal performance and service life of VIPs were firstly developed. By using the models, the effects of aerogel density (50–200 kg m^{-3}) and fiber content (0–20 vol.%) on the thermal performance and the service life of VIPs with aerogel composite cores were studied. The results indicated that a minimum insulation thickness with 5.6 mm was obtained by optimizing the fiber content for a maximum U-value of 0.6 W m^{-2} K^{-1} in accordance with the building efficiency standard of the cold area in China of the energy efficiency of public buildings (GB 50189-2015). Finally, the simultaneous effects of the aerogel density and fiber content on service life were further explored by using the service life contour. A long service life with over 50 years was achieved for

VIPs with aerogel composite cores, which could promote their applications in building thermal insulation for energy efficiency [49].

3.2.2 Design vacuum insulation panels (VIPs) for cold storage trucks to be tested

3.2.2.1 The main structure of cold storage trucks wall

The main structure of cold storage trucks wall is Sandwich panel, The fiberglass reinforced with polyurethane foam (PU foam). That makes it a lightweight and high-strength structural material with the properties of PU. that can withstand pressure and high performance of insulation. The thickness of the cold storage is 120 mm.

- Insulation wall: The sandwich panel uses polyurethane foam combined with fiberglass reinforced plastic (FRP) 2 sides that maintain a constant temperature inside the cold room, as shown in Figure 3.5
- Ground sheet: Sandwich panel, the bottom layer sheet is a Fiberglass Reinforced Plastic (FRP) to protect the layer of polyurethane foam (PU foam) from damage. On the top, the PU foam is protected with waterproof plywood (Marine Plywood) and 2 layers of aluminum sheets glued together. The assembly method is the same as the side wall. and above the truck, as shown in Figure 3.6

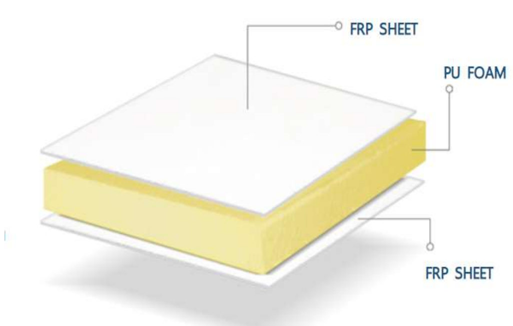

Fig. 3.5 Structure of cold storage trucks wall

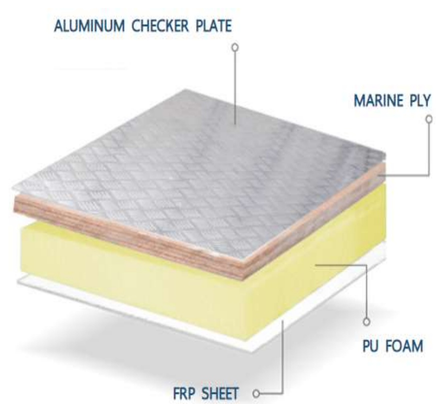

Fig. 3.6 Structure of ground sheet

(http://www.carryboycargobox.com/cool-box/th/)

3.2.2.2 The methods

The methods, Comparative experiment method of cold storage trucks equipped with VIPs and without VIPs [50] of 4 model cold storage trucks, as shown in Figure 3.7, 3.8, 3.9, 3.10. Which has Model 1 (4 Wheels Truck), Model 2 (4 Wheels large Truck), Model 3 (6 Wheels Truck) and Model 4 (10 Wheels Truck). All 4 models of the cold storage trucks will have the machine specification as shown in Table 3.1 [51]. There are 7 temperature measurement points, consisting of 6 temperature points inside the cold room and 1 outside temperature in model 1,4. There are 6 temperature measurement points, consisting of 5 temperature points inside the cold room and 1 outside temperature in model 3. There are 5 temperature measurement points, consisting of 4 temperature points inside the cold room and 1 outside temperature in model 2. The sensor installation in the cold room is distributed in every wall to achieve differentiation and distribution of cold temperatures. The installation of the sensor outside the cold storage is installed behind the cold storage trucks to prevent wind and pressure coming into contact with the sensor, resulting in inaccurate measurements. The Temperature measurement location, as shown in Figure 3.11, 3.12, 3.13, 3.14 [52] and how to install an additional VIPs in a cold room, as shown in Figure 3.15 [53].

The model 2 frozen car has been tested first. By using 5 temperature sensors, it was found that the temperature data of the cooling distribution in the cold room may not be comprehensive for analysis. Further testing was to increase the temperature sensor to 6 in the model 3 frozen car and increase the temperature sensor to 7 in the model 1 and 4 frozen cars respectively. Therefore, the number of temperature sensors are installed in each model frozen car has a different number.

Fig. 3.7 Cold storage trucks (Model 1)

Fig. 3.8 Cold storage trucks (Model 2)

Fig. 3.9 Cold storage trucks (Model 3)

Fig. 3.10 Cold storage trucks (Model 4)

Table 3.1 Spec cars 4 model

Item / Model	Model 1	Model 2	Model 3	Model 4
1. Compressor				
1.1 Model	SD5H14	SD-709/TM-16	DKS-32	DKS-32
1.2 CC	138	163	313	313
2. Motor 380V	-	-	-	7.5 hp
3. Refrigerant Types				
- Frozen	R 404A	R 404A	R 404A	R 404A
- Chiller	R 134a	R 134a	R 134a	R 134a
4. Application Range				
4.1 Truck Type (Wheels)	4	4	6	10
4.2 Cabinet Dimension (m)				
- W	1.66	1.72	2.16	2.30
- L	2.41	3.38	6.50	7.10
- H	1.60	1.60	2.15	2.30
4.3 Room Temp. (°C)	0 or -25 °C	0 or -25 °C	0 or -25 °C	0 or -25 °C
- Frozen	– 25 °C	– 25 °C	– 25 °C	– 25 °C
- Chiller	2 °C	2 °C	2 °C	2 °C
5. Truck detail (Isuzu Truck)				
- CC	1900 CC	3000 CC	5200 CC	7790 CC
- hp	150 hp	130 hp	150 hp	300 hp
6. Fuel	Diesel	Diesel	Diesel	Diesel

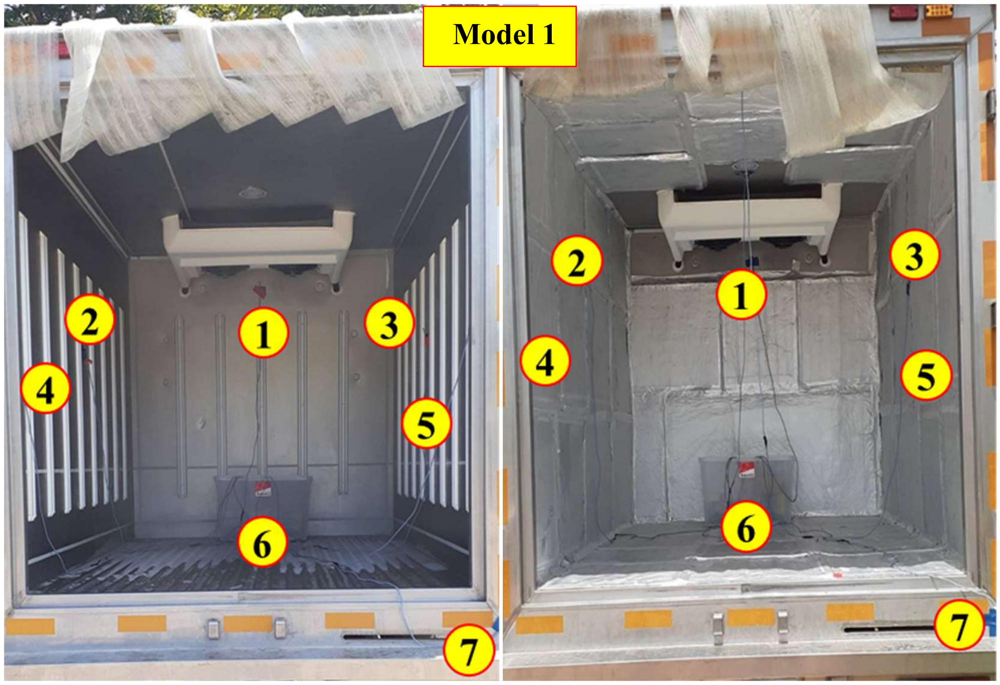

Fig. 3.11 The Temperature measurement location. (Model 1)

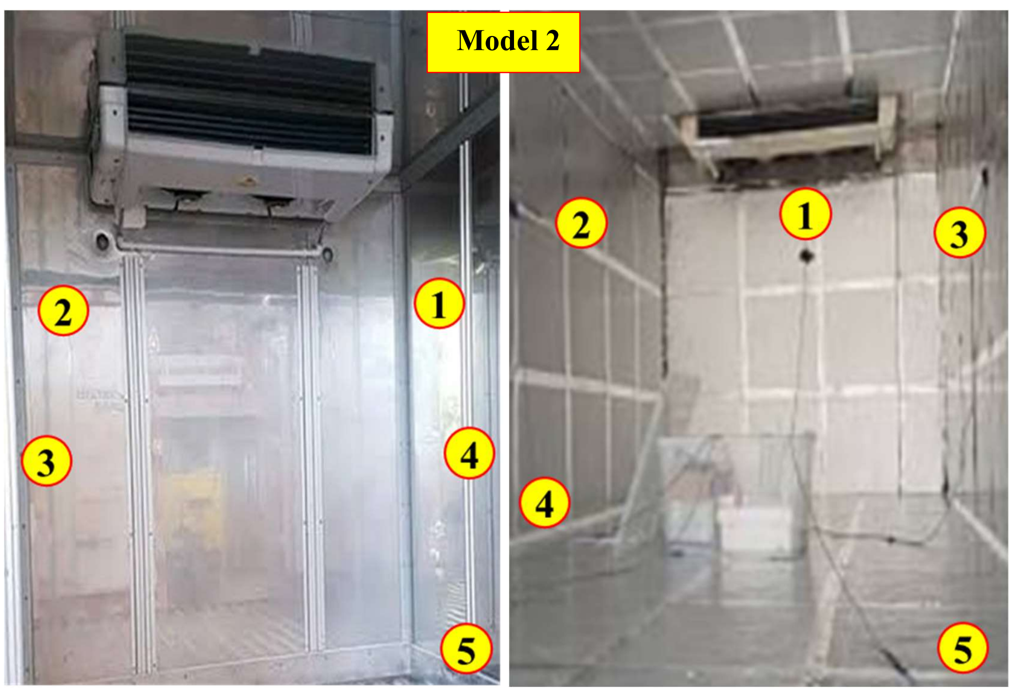

Fig. 3.12 The Temperature measurement location. (Model 2)

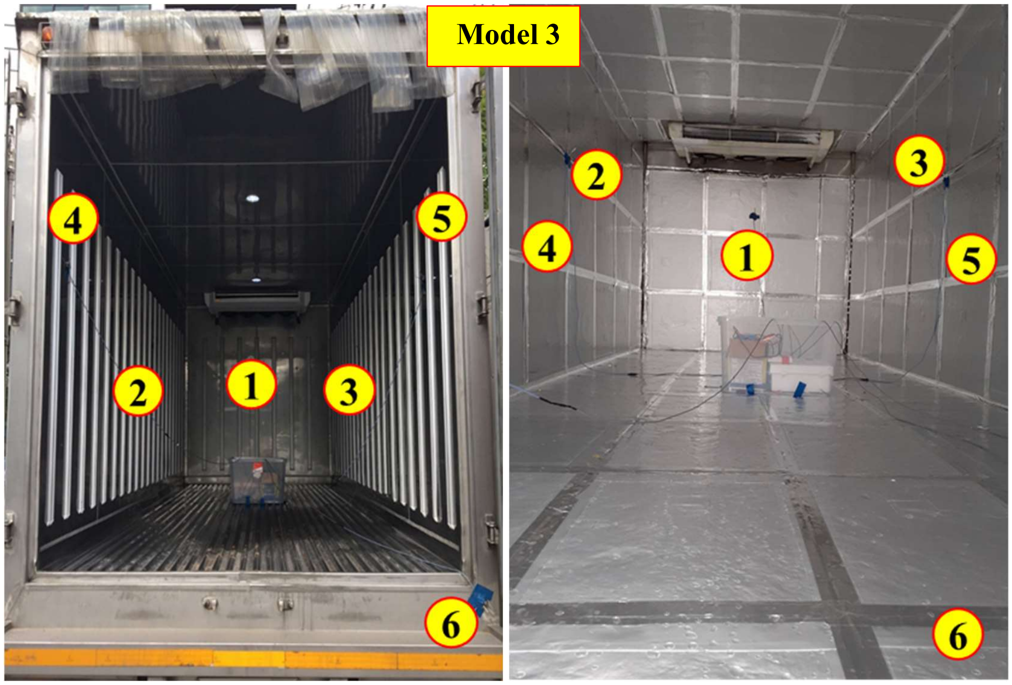

Fig. 3.13 The Temperature measurement location. (Model 3)

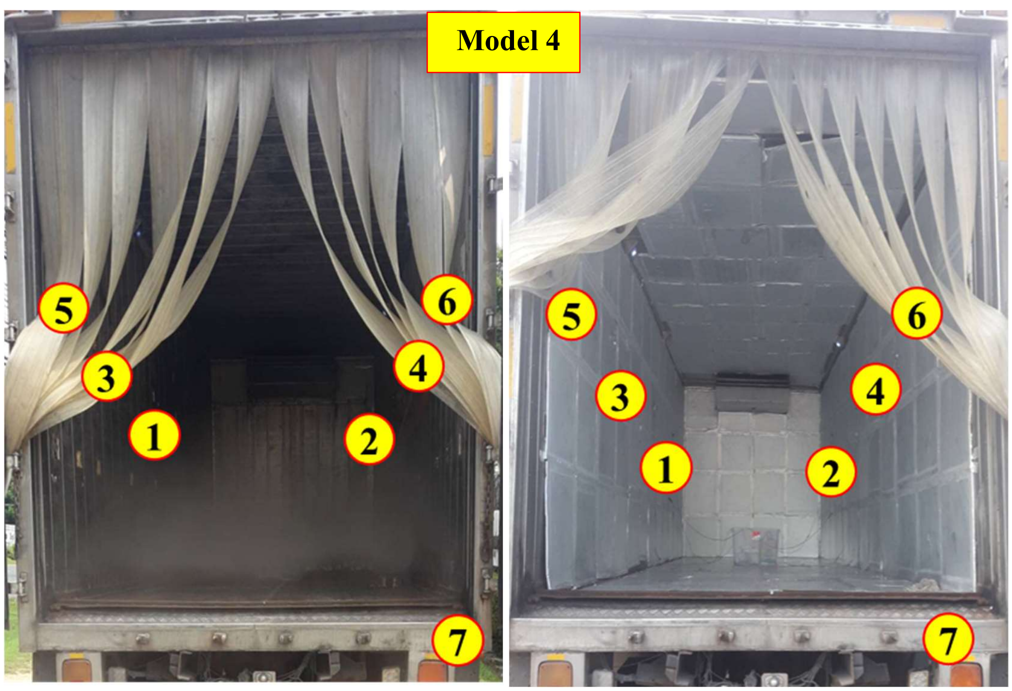

Fig. 3.14 The Temperature measurement location. (Model 4)

Fig. 3.15 How to install an additional VIPs in a cold room [36].

3.2.3 Test and data collection

After that, test the cold storage trucks. From Bangkok to Prince of Songkla University, Hatyai Campus and test driving under the real environment.

Data collection is performed by measuring the temperature every 5 minutes, as shown in Figure 3.16. Then the temperature data will record with XWEB500D EVO. 12Vdc car battery electricity will be converted to 220 Vac by an inverter before being used to power the devices as follows:

1) XJA50D probe acquisition modules: converts data from a probe temperature sensor that measures temperature every 5 minutes into the XWEB500D EVO
2) XWEB500D EVO: data collection device
3) Router WiFi: transmits the data through the monitoring system.

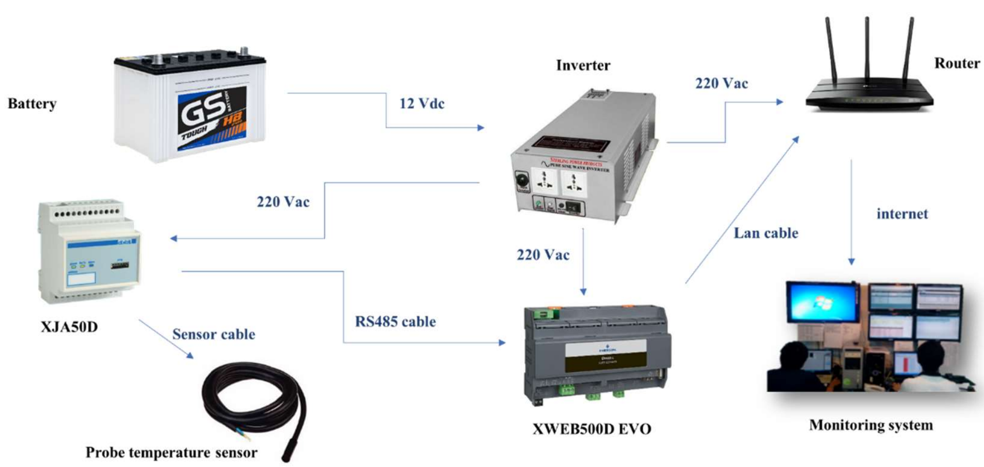

Fig. 3.16 The principle of operation of the device

CHAPTER 4

Result

Chapter 3 describes the methodology used in this study. The temperature is measured by the sensor every 5 minutes to see how the temperature is maintained in the cold room. This information will be used to analyze compressor operating. The fuel consumption rate of cold storage trucks is calculated based on the test distance per fuel consumption. The comparison test will be conducted before and after installation of the VIPs, where the fuel consumption rate is consistent with the compressor operating. as shown in chapter 4**.**

4.1 Model 1 - 4 Wheels Truck

4.1.1 Chiller 4 Wheels Truck without VIPs

As a result of the temperature results prior to installation of VIPs, as shown in Figure 4.1, it was found that the refrigerated cars were controlled an average of 5 °C and defrosted 6 times a day due to the compressor operating at 2 °C for evaporator temperature in low temperature condition. During the defrosting time, the temperature of the freezer room will rise to a maximum of 10 °C due to the defrosting with heater. The ambient average temperature is 30 °C along the route was 942 km. The compressor takes 10 minutes to reach the set temperature, and it rises when the compressor stops running to the point where it starts up again in 5 minutes. The compressor cut in - cut off time before install VIPs, as shown in Figure 4.2.

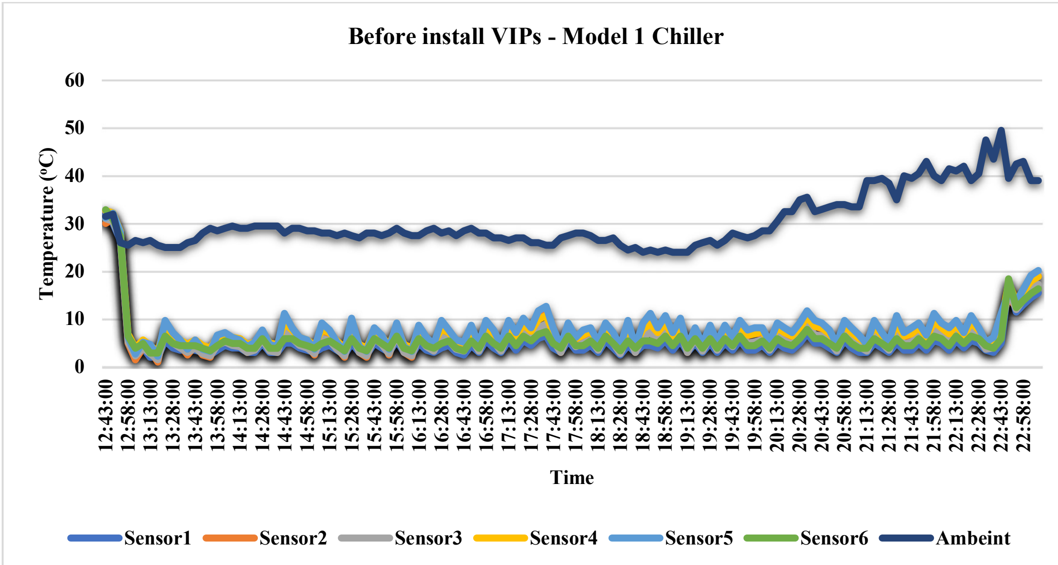

Fig. 4.1 Temperature results before installation of VIPs. (Model 1 Chiller)

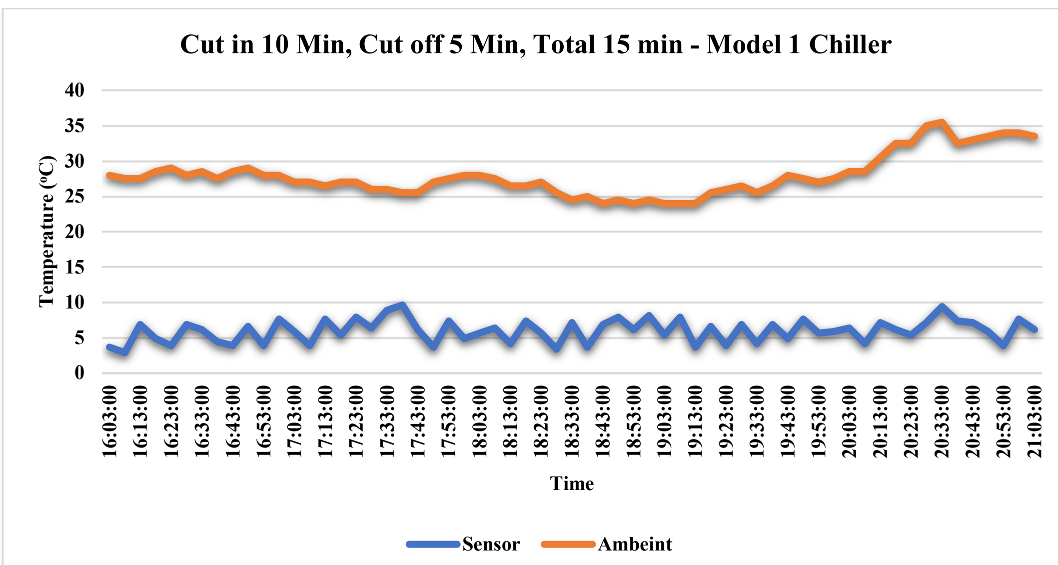

Fig. 4.2 The compressor cut in – cut off time before installation of VIPs. (Model 1 Chiller)

Thermal conductivity (K) of PU Foam 0.0224 kcal/m.hr.°C

W1 wall (Front wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 1.66 m. = 2.656 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W1 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 2.656 x 0.187 x 38 = 19 kcal / hr.

W2 wall (Back wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 1.66 m. = 2.656 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W2 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 2.656 x 0.187 x 38 = 19 kcal / hr.

W3 wall (Right wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 2.41 m. = 3.856 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W3 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 3.856 x 0.187 x 38 = 27 kcal/hr.

W4 wall (Left wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 2.41 m. = 3.856 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W4 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 3.856 x 0.187 x 38 = 27 kcal/hr.

Ceiling wall

1. Wall area (A) = wall width x wall length = 1.66 m. x 2.41 m. = 4.001 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

Ceiling wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 4.001 x 0.187 x 38 = 28 kcal/hr.

Floor wall

1. Wall area (A) = wall width x wall length = 1.66 m. x 2.41 m. = 4.001 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

Floor wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 4.001 x 0.187 x 38 = 28 kcal/hr.

Total heat transfer rate (Q)

= wall W1 + wall W2 + wall W3 + wall W4 + wall floor + wall ceiling

= 19 + 19 + 27 + 27 + 28 + 28 = 148 kcal/hr.

Safety Factor multiplier in case of external temperature change

= 256 x 1.15 = 170 kcal/hr.

Total heat transfer rate (Q) of chiller 4 wheels truck without VIPs = 170 kcal/hr.

4.1.2 Chiller 4 Wheels Truck with VIPs

As a result of the temperature results rear to installation of VIPs, as shown in Figure 4.3, it was found that the refrigerated cars were controlled an average of 4 °C and defrosted 7 times a day due to the compressor operating at 2 °C for evaporator temperature in low temperature condition. During the defrosting time, the temperature of the freezer room will rise to a maximum of 10 °C due to the defrosting with heater. The average temperature along the route was 942 km., averaging 31 °C. The compressor takes 10 minutes to reach the set temperature, and it rises when the compressor stops running to the point where it starts up again in 10 minutes. The compressor cut in – cut off time after install VIPs, as shown in Figure 4.4.

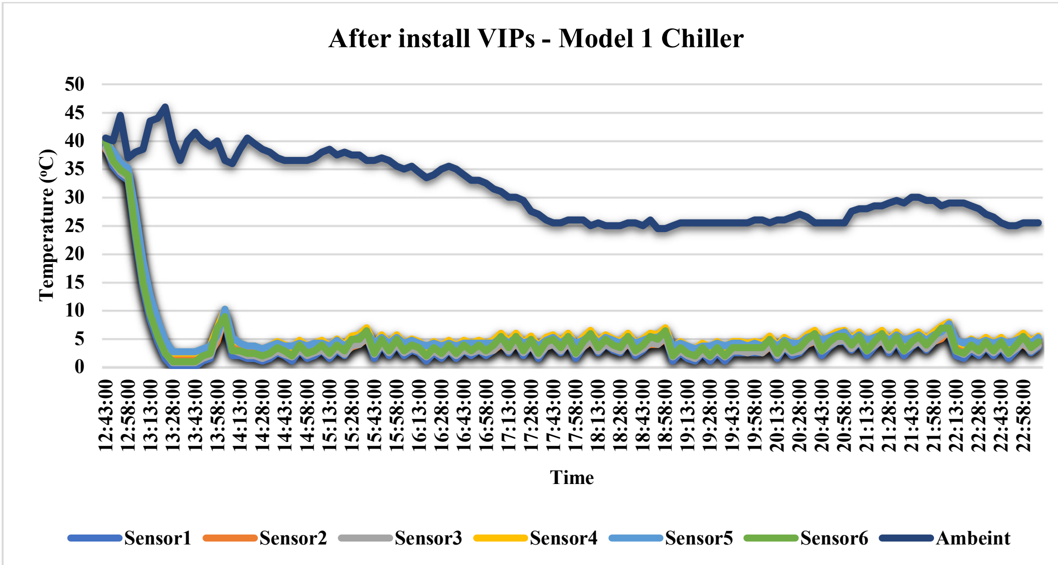

Fig. 4.3 Temperature results after installation of VIPs. (Model 1 Chiller)

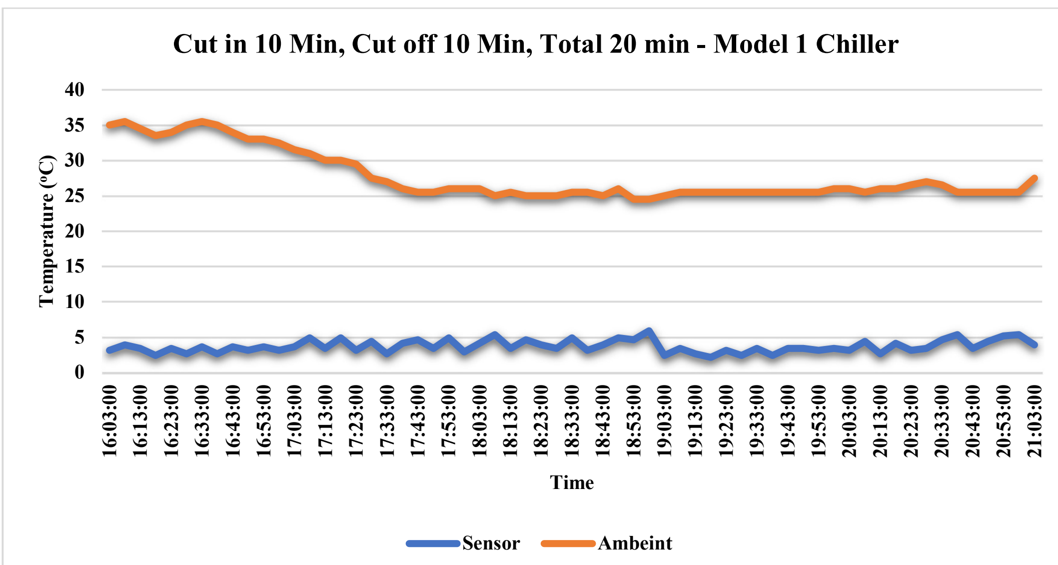

Fig. 4.4 The compressor cut in – cut off time after installation of VIPs. (Model 1 Chiller)

Thermal conductivity (K) of VIPs 0.0062 kcal/m.hr.°C

W1 wall (Front wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 1.66 m. = 2.656 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W1 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 2.656 x 0.052 x 38 = 5 kcal / hr.

W2 wall (Back wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 1.66 m. = 2.656 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W2 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 2.656 x 0.052 x 38 = 5 kcal / hr.

W3 wall (Right wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 2.41 m. = 3.856 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W3 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 3.856 x 0.052 x 38 = 8 kcal/hr.

W4 wall (Left wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 2.41 m. = 3.856 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W4 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 3.856 x 0.052 x 38 = 8 kcal/hr.

Ceiling wall

1. Wall area (A) = wall width x wall length = 1.66 m. x 2.41 m. = 4.001 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

Ceiling wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 4.001 x 0.052 x 38 = 8 kcal/hr.

Floor wall

1. Wall area (A) = wall width x wall length = 1.66 m. x 2.41 m. = 4.001 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

Floor wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 4.001 x 0.052 x 38 = 8 kcal/hr.

Total heat transfer rate (Q)

= wall W1 + wall W2 + wall W3 + wall W4 + wall floor + wall ceiling

= 5 + 5 + 8 + 8 + 8 + 8 = 42 kcal/hr.

Safety Factor multiplier in case of external temperature change

= 42 x 1.15 = 48 kcal/hr.

Total heat transfer rate (Q) of chiller 4 wheels truck with VIPs = 48 kcal/hr.

Test results show that VIPs insulation can maintain the same temperature as without VIPs insulation but the time required for cut in cut off is better to install VIPs insulation. The energy saving effect comes from the moment when the compressor is stopped, which means saving fuel to be used in cooling as a result of VIPs insulation. When all the results are calculated as the energy saving result, it is obtained that over a distance of 942 km., the fuel price is 26.29 baht / liter. It was found that the fuel consumption rate before VIPs installation was 9.98 km / liter, and compared with the after VIPs installation at 12.00 km / liter, the fuel savings was 20.24%.

4.1.3 Frozen 4 Wheels Truck without VIPs

As a result of the temperature results prior to installation of VIPs, as shown in Figure 4.5, it was found that the refrigerated cars were controlled an average of -12 °C and defrosted 6 times a day due to the compressor operating at -25 °C for evaporator temperature in low temperature condition. During the defrosting time, the temperature of the freezer room will rise to a maximum of -8 °C due to the defrosting with heater. The ambient average temperature is 26 °C along the route was 944 km. The compressor takes 5 minutes to reach the set temperature, and it rises when the compressor stops running to the point where it starts up again in 5 minutes. The compressor cut in - cut off time before install VIPs, as shown in Figure 4.6.

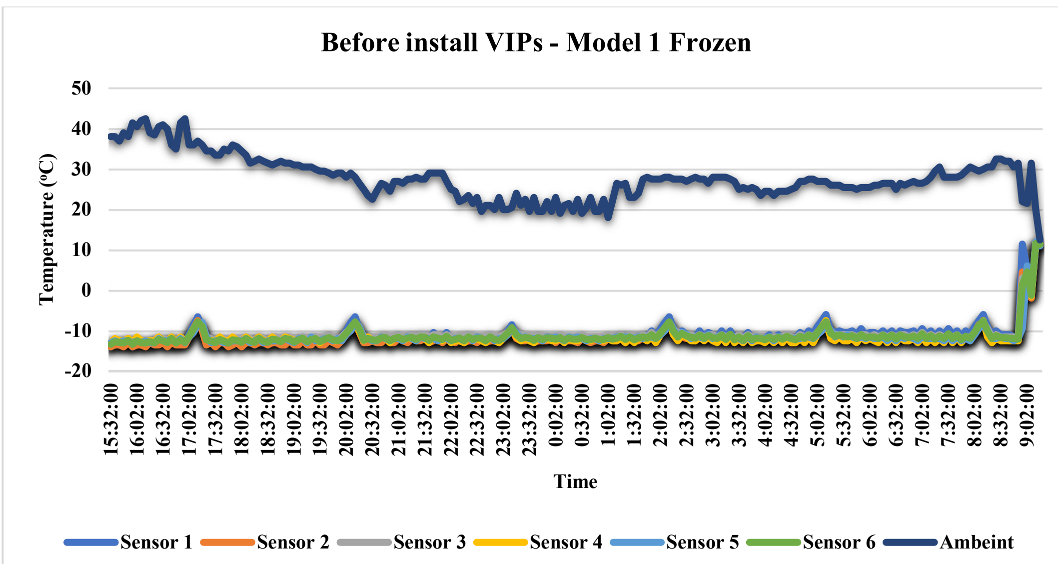

Fig. 4.5 Temperature results before installation of VIPs. (Model 1 Frozen)

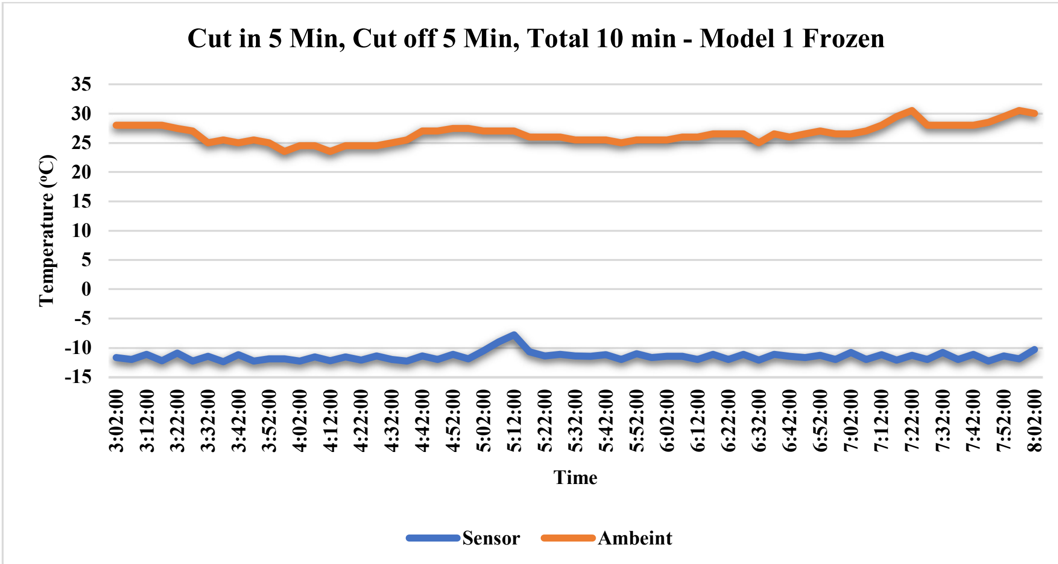

Fig. 4.6 The compressor cut in – cut off time before installation of VIPs. (Model 1 Frozen)

Thermal conductivity (K) of PU Foam 0.0224 kcal/m.hr.°C

W1 wall (Front wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 1.66 m. = 2.656 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W1 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 2.656 x 0.187 x 65 = 32 kcal / hr.

W2 wall (Back wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 1.66 m. = 2.656 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W2 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 2.656 x 0.187 x 65 = 32 kcal / hr.

W3 wall (Right wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 2.41 m. = 3.856 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W3 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 3.856 x 0.187 x 65 = 47 kcal/hr.

W4 wall (Left wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 2.41 m. = 3.856 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W4 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 3.856 x 0.187 x 65 = 47 kcal/hr.

Ceiling wall

1. Wall area (A) = wall width x wall length = 1.66 m. x 2.41 m. = 4.001 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

Ceiling wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 4.001 x 0.187 x 65 = 49 kcal/hr.

Floor wall

1. Wall area (A) = wall width x wall length = 1.66 m. x 2.41 m. = 4.001 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

Floor wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 4.001 x 0.187 x 65 = 49 kcal/hr.

Total heat transfer rate (Q)

= wall W1 + wall W2 + wall W3 + wall W4 + wall floor + wall ceiling

= 32 + 32 + 47 + 47 + 49 + 49 = 256 kcal/hr.

Safety Factor multiplier in case of external temperature change

= 256 x 1.15 = 294 kcal/hr.

Total heat transfer rate (Q) of frozen 4 wheels truck without VIPs = 294 kcal/hr.

4.1.4 Frozen 4 Wheels Truck with VIPs

As a result of the temperature results rear to installation of VIPs, as shown in Figure 4.7, it was found that the refrigerated cars were controlled an average of -12 °C and defrosted 6 times a day due to the compressor operating at -25 °C for evaporator temperature in low temperature condition. During the defrosting time, the temperature of the freezer room will rise to a maximum of -8 °C due to the defrosting with heater. The ambient average temperature is 26 °C along the route was 944 km. The compressor takes 10 minutes to reach the set temperature, and it rises when the compressor stops running to the point where it starts up again in 10 minutes. The compressor cut in – cut off time after install VIPs, as shown in Figure 4.8.

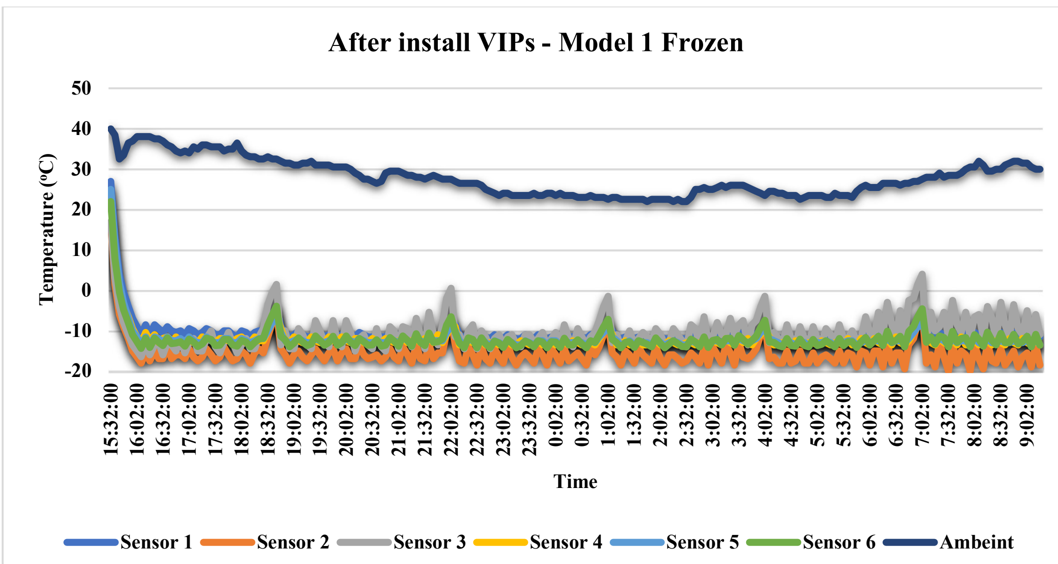

Fig. 4.7 Temperature results after installation of VIPs. (Model 1 Frozen)

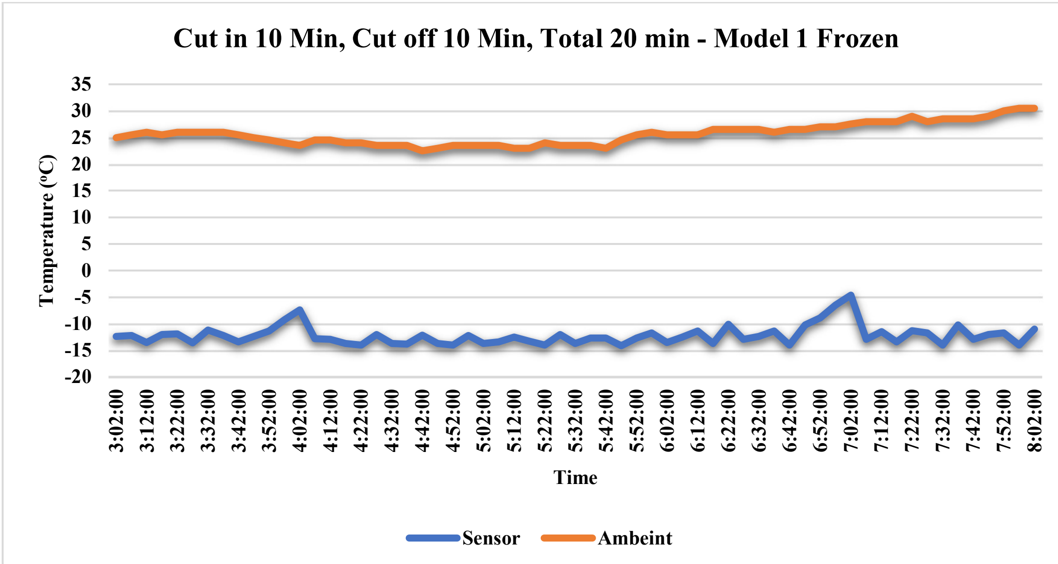

Fig. 4.8 The compressor cut in – cut off time after installation of VIPs. (Model 1 Frozen)

Thermal conductivity (K) of VIPs 0.0062 kcal/m.hr.°C

W1 wall (Front wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 1.66 m. = 2.656 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W1 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 2.656 x 0.052 x 65 = 9 kcal / hr.

W2 wall (Back wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 1.66 m. = 2.656 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W2 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 2.656 x 0.052 x 65 = 9 kcal / hr.

W3 wall (Right wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 2.41 m. = 3.856 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W3 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 3.856 x 0.052 x 65 = 13 kcal/hr.

W4 wall (Left wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 2.41 m. = 3.856 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W4 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 3.856 x 0.052 x 65 = 13 kcal/hr.

Ceiling wall

1. Wall area (A) = wall width x wall length = 1.66 m. x 2.41 m. = 4.001 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

Ceiling wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 4.001 x 0.052 x 65 = 14 kcal/hr.

Floor wall

1. Wall area (A) = wall width x wall length = 1.66 m. x 2.41 m. = 4.001 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

Floor wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 4.001 x 0.052 x 65 = 14 kcal/hr.

Total heat transfer rate (Q)

= wall W1 + wall W2 + wall W3 + wall W4 + wall floor + wall ceiling

= 9 + 9 + 13 + 13 + 14 +14 = 72 kcal/hr.

Safety Factor multiplier in case of external temperature change

= 72 x 1.15 = 83 kcal/hr.

Total heat transfer rate (Q) of frozen 4 wheels truck with VIPs = 83 kcal/hr.

Test results show that VIPs insulation can maintain the same temperature as without VIPs insulation but the time required for cut in cut off is better to install VIPs insulation. The energy saving effect comes from the moment when the compressor is stopped, which means saving fuel to be used in cooling as a result of VIPs insulation. When all the results are calculated as the energy saving result, it is obtained that over a distance of 944 km., the fuel price is 26.39 baht / liter. It was found that the fuel consumption rate before VIPs installation was 7.12 km / liter, and compared with the after VIPs installation at 8.33 km / liter, the fuel savings was 16.99%.

4.2 Model 2 - 4 Wheels large Truck

4.2.1 Chiller 4 Wheels large Truck without VIPs

As a result of the temperature results prior to installation of VIPs, as shown in Figure 4.9, it was found that the refrigerated cars were controlled an average of 3 °C and defrosted 6 times a day due to the compressor operating at 2 °C for evaporator temperature in low temperature condition. During the defrosting time, the temperature of the freezer room will rise to a maximum of 10 °C due to the defrosting with heater. The ambient average temperature is 30 °C along the route was 973 km. The compressor takes 5 minutes to reach the set temperature, and it rises when the compressor stops running to the point where it starts up again in 5 minutes. The compressor cut in - cut off time before install VIPs, as shown in Figure 4.10.

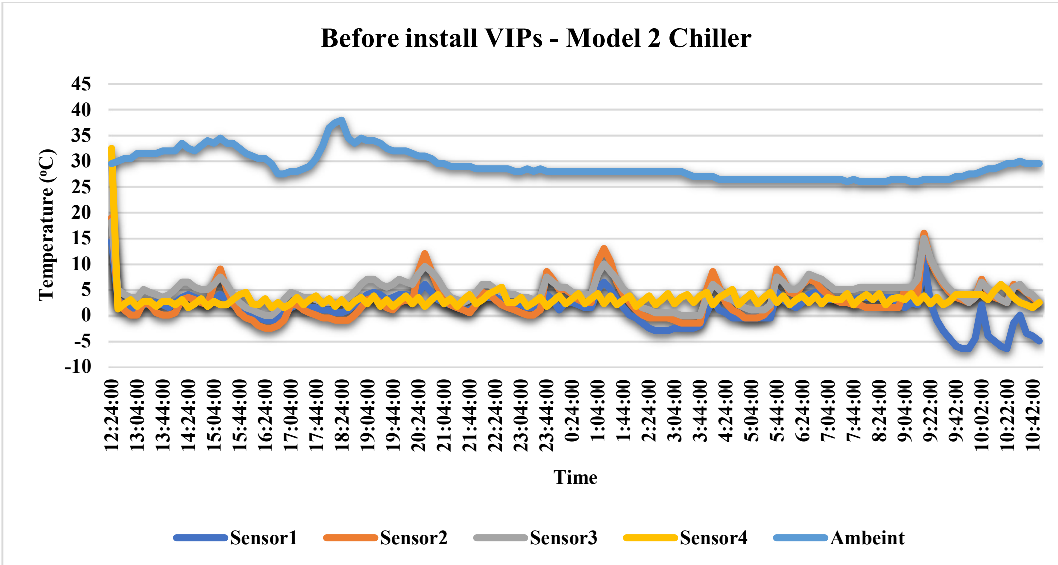

Fig. 4.9 Temperature results before installation of VIPs. (Model 2 Chiller)

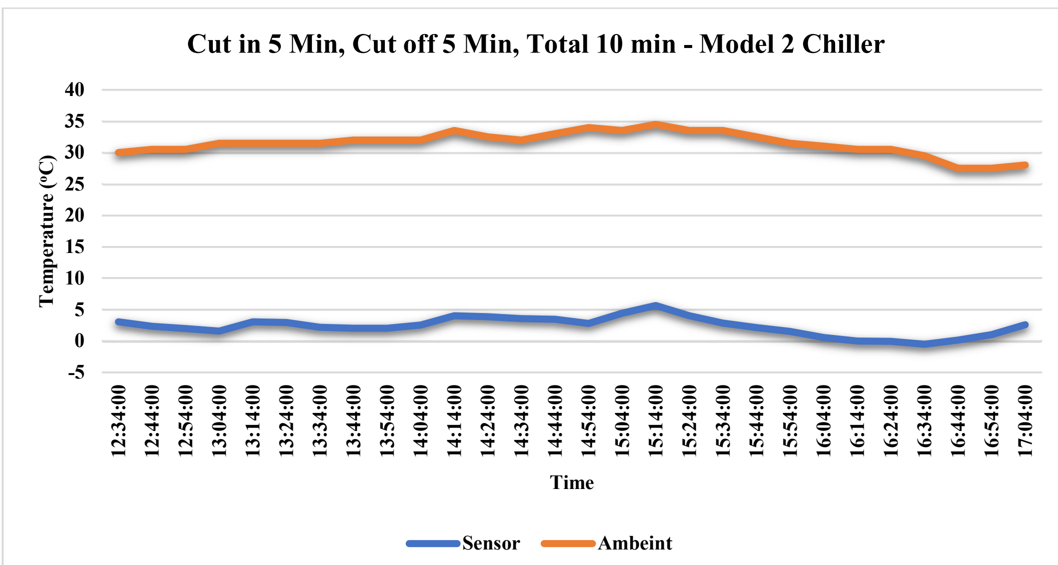

Fig. 4.10 The compressor cut in – cut off time before installation of VIPs. (Model 2 Chiller)

Thermal conductivity (K) of PU Foam 0.0224 kcal/m.hr.°C

W1 wall (Front wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 1.72 m. = 2.752 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W1 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 2.752 x 0.187 x 38 = 20 kcal / hr.

W2 wall (Back wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 1.72 m. = 2.752 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W2 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 2.752 x 0.187 x 38 = 20 kcal / hr.

W3 wall (Right wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 3.38 m. = 5.408 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W3 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.408 x 0.187 x 38 = 38 kcal/hr.

W4 wall (Left wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 3.38 m. = 5.408 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W4 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.408 x 0.187 x 38 = 38 kcal/hr.

Ceiling wall

1. Wall area (A) = wall width x wall length = 1.72 m. x 3.38 m. = 5.814 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

Ceiling wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.814 x 0.187 x 38 = 41 kcal/hr.

Floor wall

1. Wall area (A) = wall width x wall length = 1.72 m. x 3.38 m. = 5.814 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

Floor wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.814 x 0.187 x 38 = 41 kcal/hr.

Total heat transfer rate (Q)

= wall W1 + wall W2 + wall W3 + wall W4 + wall floor + wall ceiling

= 20 + 20 + 38 + 38 + 41 + 41 = 198 kcal/hr.

Safety Factor multiplier in case of external temperature change

= 198 x 1.15 = 228 kcal/hr.

Total heat transfer rate (Q) of chiller 4 wheels large truck without VIPs = 228 kcal/hr.

4.2.2 Chiller 4 Wheels large Truck with VIPs

As a result of the temperature results rear to installation of VIPs, as shown in Figure 4.11, it was found that the refrigerated cars were controlled an average of 5 °C and defrosted 5 times a day due to the compressor operating at 2 °C for evaporator temperature in low temperature condition. During the defrosting time, the temperature of the freezer room will rise to a maximum of 8 °C due to the defrosting with heater. The average temperature along the route was 973 km., averaging 30 °C. The compressor takes 5 minutes to reach the set temperature, and it rises when the compressor stops running to the point where it starts up again in 10 minutes. The compressor cut in – cut off time after install VIPs, as shown in Figure 4.12.

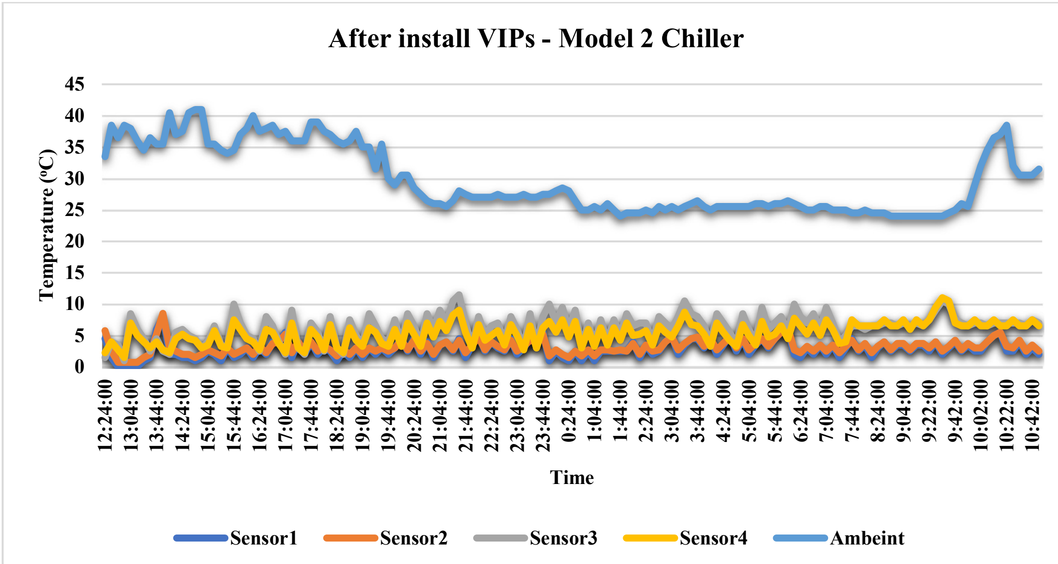

Fig. 4.11 Temperature results after installation of VIPs. (Model 2 Chiller)

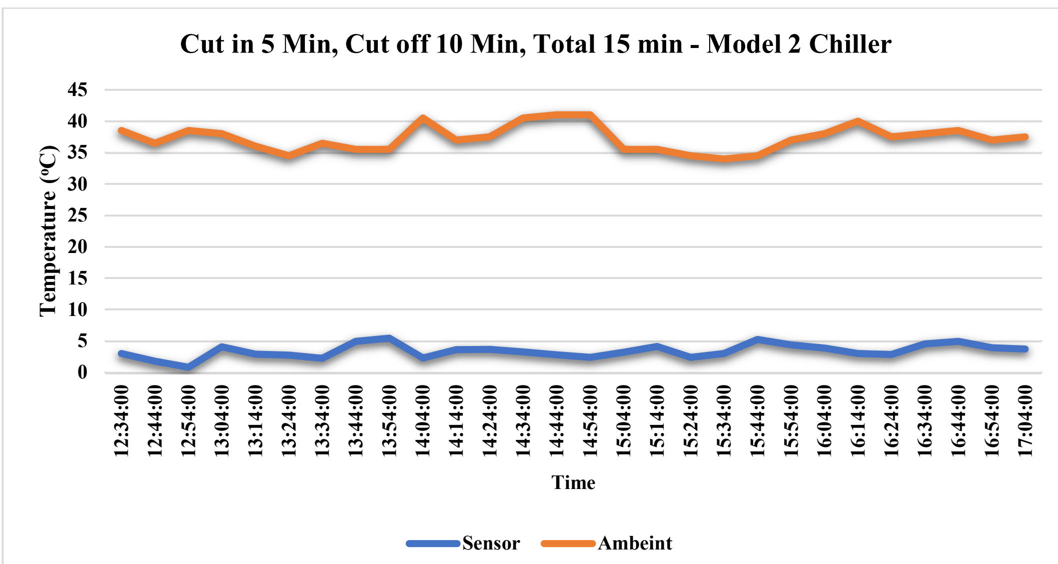

Fig. 4.12 The compressor cut in – cut off time after installation of VIPs. (Model 2 Chiller)

Thermal conductivity (K) of VIPs 0.0062 kcal/m.hr.°C

W1 wall (Front wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 1.72 m. = 2.752 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W1 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 2.752 x 0.052 x 38 = 5 kcal / hr.

W2 wall (Back wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 1.72 m. = 2.752 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W2 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 2.752 x 0.052 x 38 = 5 kcal / hr.

W3 wall (Right wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 3.38 m. = 5.408 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W3 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.408 x 0.052 x 38 = 11 kcal/hr.

W4 wall (Left wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 3.38 m. = 5.408 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W4 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.408 x 0.052 x 38 = 11 kcal/hr.

Ceiling wall

1. Wall area (A) = wall width x wall length = 1.72 m. x 3.38 m. = 5.814 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

Ceiling wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.814 x 0.052 x 38 = 11 kcal/hr.

Floor wall

1. Wall area (A) = wall width x wall length = 1.72 m. x 3.38 m. = 5.814 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

Floor wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.814 x 0.052 x 38 = 11 kcal/hr.

Total heat transfer rate (Q)

= wall W1 + wall W2 + wall W3 + wall W4 + wall floor + wall ceiling

= 5 + 5 + 11 + 11 + 11 + 11 = 54 kcal/hr.

Safety Factor multiplier in case of external temperature change

= 54 x 1.15 = 62 kcal/hr.

Total heat transfer rate (Q) of chiller 4 wheels large truck with VIPs = 62 kcal/hr.

Test results show that VIPs insulation can maintain the same temperature as without VIPs insulation but the time required for cut in cut off is better to install VIPs insulation. The energy saving effect comes from the moment when the compressor is stopped, which means saving fuel to be used in cooling as a result of VIPs insulation. When all the results are calculated as the energy saving result, it is obtained that over a distance of 973 km., the fuel price is 25.79 baht / liter. It was found that the fuel consumption rate before VIPs installation was 15.12 km / liter, and compared with the after VIPs installation at 16.30 km / liter, the fuel savings was 7.80%.

4.2.3 Frozen 4 Wheels large Truck without VIPs

As a result of the temperature results prior to installation of VIPs, as shown in Figure 4.13, it was found that the refrigerated cars were controlled an average of -14 °C and defrosted 5 times a day due to the compressor operating at -25 °C for evaporator temperature in low temperature condition. During the defrosting time, the temperature of the freezer room will rise to a maximum of -12 °C due to the defrosting with heater. The average temperature along the route was 976 km., averaging 34 °C. The compressor takes 5 minutes to reach the set temperature, and it rises when the compressor stops running to the point where it starts up again in 5 minutes. The compressor cut in - cut off time before install VIPs, as shown in Figure 4.14.

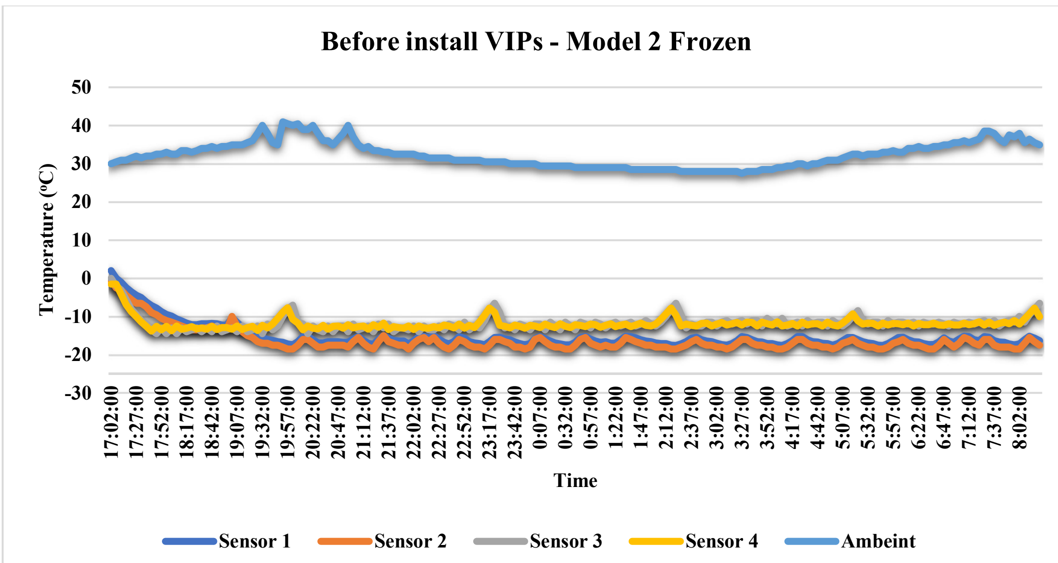

Fig. 4.13 Temperature results before installation of VIPs. (Model 2 Frozen)

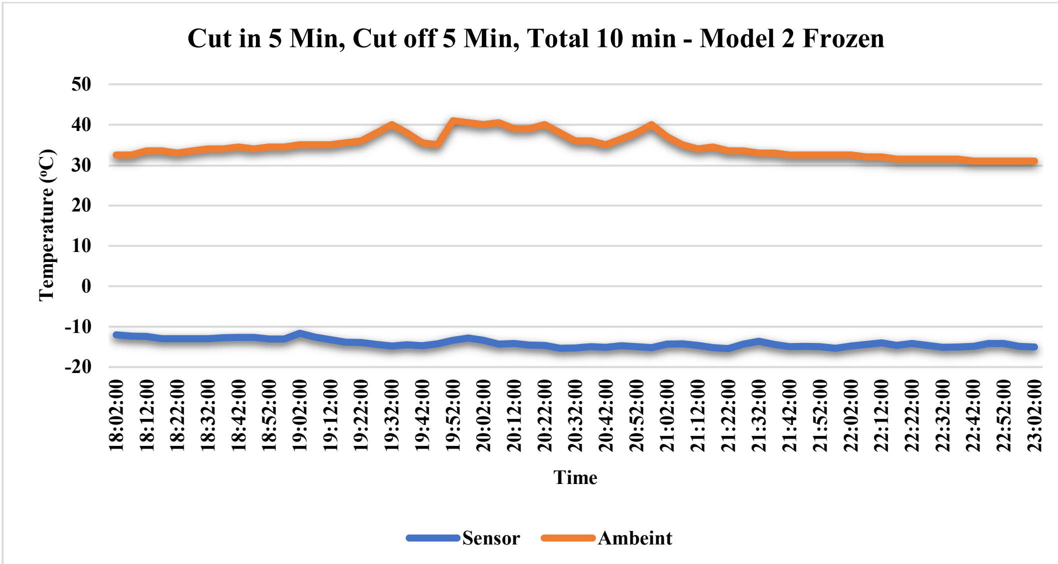

Fig. 4.14 The compressor cut in – cut off time before installation of VIPs. (Model 2 Frozen)

Thermal conductivity (K) of PU Foam 0.0224 kcal/m.hr.°C

W1 wall (Front wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 1.72 m. = 2.752 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W1 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 2.752 x 0.187 x 65 = 33 kcal / hr.

W2 wall (Back wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 1.72 m. = 2.752 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W2 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 2.752 x 0.187 x 65 = 33 kcal / hr.

W3 wall (Right wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 3.38 m. = 5.408 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W3 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.408 x 0.187 x 65 = 66 kcal/hr.

W4 wall (Left wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 3.38 m. = 5.408 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W4 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.408 x 0.187 x 65 = 66 kcal/hr.

Ceiling wall

1. Wall area (A) = wall width x wall length = 1.72 m. x 3.38 m. = 5.814 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

Ceiling wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.814 x 0.187 x 65 = 71 kcal/hr.

Floor wall

1. Wall area (A) = wall width x wall length = 1.72 m. x 3.38 m. = 5.814 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

Floor wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.814 x 0.187 x 65 = 71 kcal/hr.

Total heat transfer rate (Q)

= wall W1 + wall W2 + wall W3 + wall W4 + wall floor + wall ceiling

= 33 + 33 + 66 + 66 + 71 + 71 = 340 kcal/hr.

Safety Factor multiplier in case of external temperature change

= 340 x 1.15 = 391 kcal/hr.

Total heat transfer rate (Q) of frozen 4 wheels large truck without VIPs = 391 kcal/hr

4.2.4 Frozen 4 Wheels large Truck with VIPs

As a result of the temperature results rear to installation of VIPs, as shown in Figure 4.15, it was found that the refrigerated cars were controlled an average of -14 °C and defrosted 5 times a day due to the compressor operating at -25 °C for evaporator temperature in low temperature condition. During the defrosting time, the temperature of the freezer room will rise to a maximum of -8 °C due to the defrosting with heater. The average temperature along the route was 976 km., averaging 33 °C. The compressor takes 5 minutes to reach the set temperature, and it rises when the compressor stops running to the point where it starts up again in 10 minutes. The compressor cut in – cut off time after install VIPs, as shown in Figure 4.16.

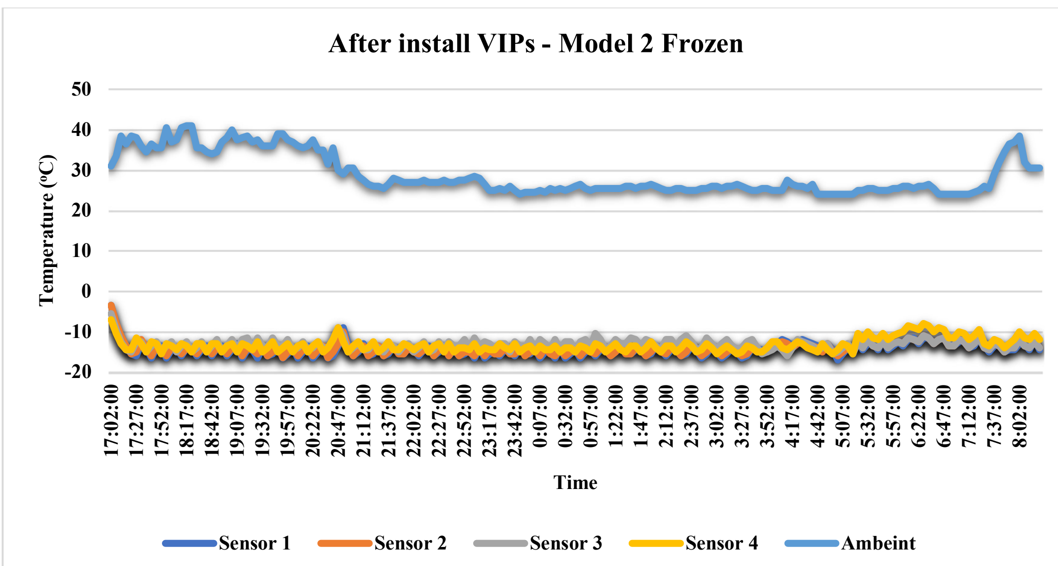

Fig. 4.15 Temperature results after install VIPs. (Model 2 Frozen)

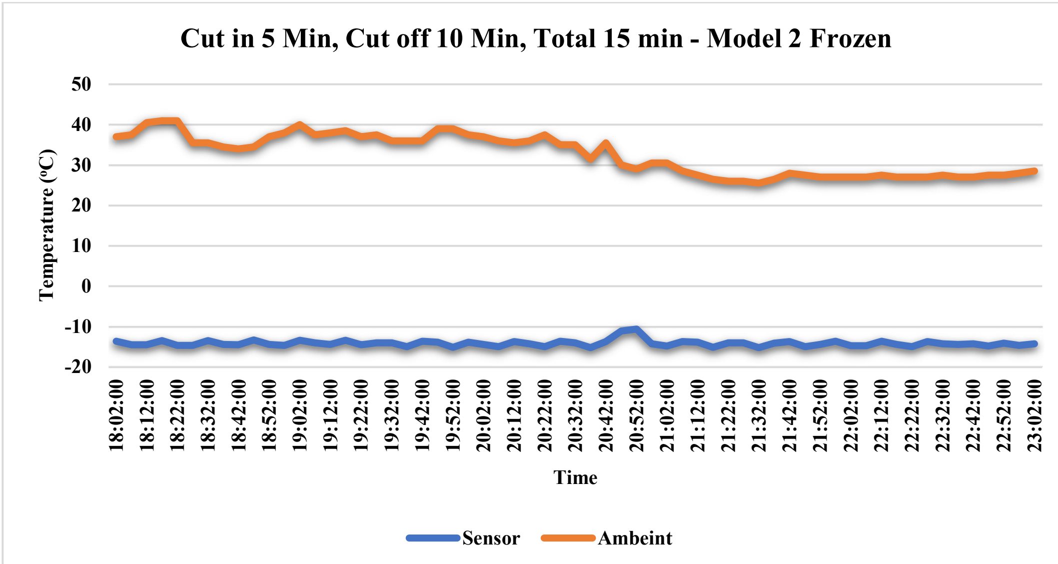

Fig. 4.16 The compressor cut in – cut off time after install VIPs. (Model 2 Frozen)

Thermal conductivity (K) of VIPs 0.0062 kcal/m.hr.°C

W1 wall (Front wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 1.72 m. = 2.752 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W1 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 2.752 x 0.052 x 65 = 9 kcal / hr.

W2 wall (Back wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 1.72 m. = 2.752 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W2 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 2.752 x 0.052 x 65 = 9 kcal / hr.

W3 wall (Right wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 3.38 m. = 5.408 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W3 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.408 x 0.052 x 65 = 18 kcal/hr.

W4 wall (Left wall)

1. Wall area (A) = wall width x wall length = 1.60 m. x 3.38 m. = 5.408 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W4 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.408 x 0.052 x 65 = 18 kcal/hr.

Ceiling wall

1. Wall area (A) = wall width x wall length = 1.72 m. x 3.38 m. = 5.814 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

Ceiling wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.814 x 0.052 x 65 = 20 kcal/hr.

Floor wall

1. Wall area (A) = wall width x wall length = 1.72 m. x 3.38 m. = 5.814 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

Floor wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.814 x 0.052 x 65 = 20 kcal/hr.

Total heat transfer rate (Q)

= wall W1 + wall W2 + wall W3 + wall W4 + wall floor + wall ceiling

= 9 + 9 + 18 + 18 + 20 + 20 = 94 kcal/hr.

Safety Factor multiplier in case of external temperature change

= 94 x 1.15 = 108 kcal/hr.

Total heat transfer rate (Q) of chiller 4 wheels large truck with VIPs = 108 kcal/hr.

Test results show that VIPs insulation can maintain the same temperature as without VIPs insulation but the time required for cut in cut off is better to install VIPs insulation. The energy saving effect comes from the moment when the compressor is stopped, which means saving fuel to be used in cooling as a result of VIPs insulation. When all the results are calculated as the energy saving result, it is obtained that over a distance of 976 km, the fuel price is 25.79 baht / liter. It was found that the fuel consumption rate before VIPs installation was 12.91 km / liter, and compared with the after VIPs installation at 13.32 km / liter, the fuel savings was 3.18%.

4.3 Model 3 - 6 Wheels Truck

4.3.1 Chiller 6 Wheels Truck without VIPs

As a result of the temperature results prior to installation of VIPs, as shown in Figure 4.17, it was found that the refrigerated cars were controlled an average of 3 °C and defrosted 7 times a day due to the compressor operating at 2 °C for evaporator temperature in low temperature condition. During the defrosting time, the temperature of the freezer room will rise to a maximum of 5 °C due to the defrosting with heater. The ambient average temperature is 30 °C along the route was 1,025 km. The compressor takes 5 minutes to reach the set temperature, and it rises when the compressor stops running to the point where it starts up again in 5 minutes. The compressor cut in - cut off time before install VIPs, as shown in Figure 4.18.

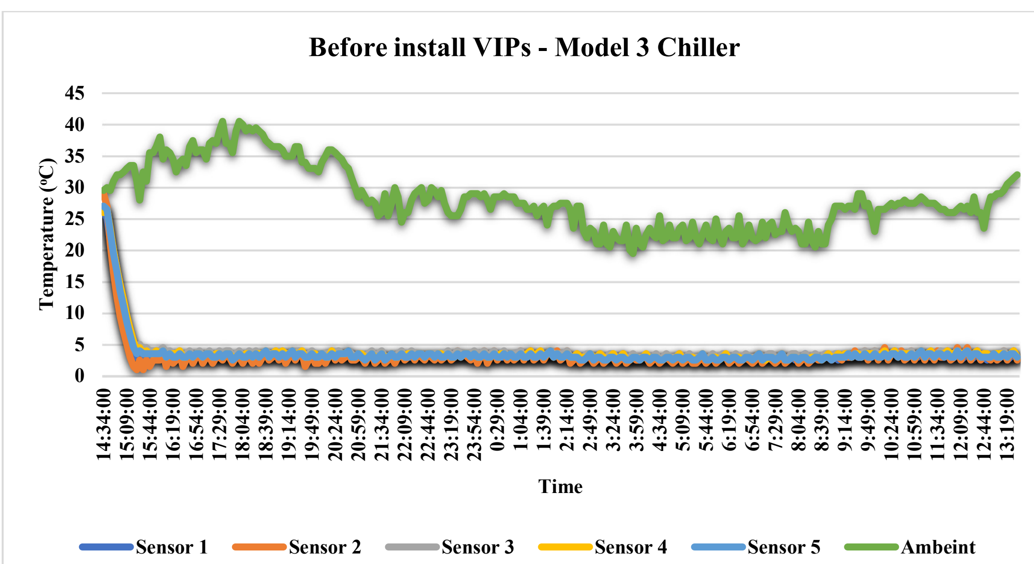

Fig. 4.17 Temperature results before installation of VIPs. (Model 3 Chiller)

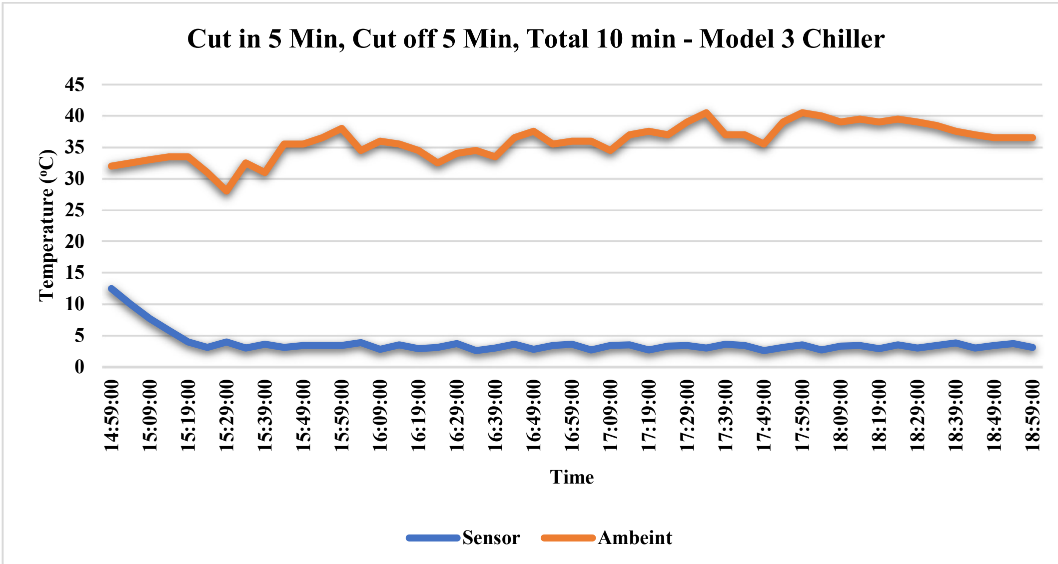

Fig. 4.18 The compressor cut in – cut off time before installation of VIPs. (Model 3 Chiller)

Thermal conductivity (K) of PU Foam 0.0224 kcal/m.hr.°C

W1 wall (Front wall)

1. Wall area (A) = wall width x wall length = 2.15 m. x 2.16 m. = 4.644 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W1 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 4.644 x 0.187 x 38 = 33 kcal / hr.

W2 wall (Back wall)

1. Wall area (A) = wall width x wall length = 2.15 m. x 2.16 m. = 4.644 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W2 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 4.644 x 0.187 x 38 = 33 kcal / hr.

W3 wall (Right wall)

1. Wall area (A) = wall width x wall length = 2.15 m. x 6.50 m. = 13.975 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W3 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 13.975 x 0.187 x 38 = 99 kcal/hr.

W4 wall (Left wall)

1. Wall area (A) = wall width x wall length = 2.15 m. x 6.50 m. = 13.975 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W4 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 13.975 x 0.187 x 38 = 99 kcal/hr.

Ceiling wall

1. Wall area (A) = wall width x wall length = 2.16 m. x 6.50 m. = 14.040 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

Ceiling wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 14.040 x 0.187 x 38 = 100 kcal/hr.

Floor wall

1. Wall area (A) = wall width x wall length = 2.16 m. x 6.50 m. = 14.040 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

Floor wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 14.040 x 0.187 x 38 = 100 kcal/hr.

Total heat transfer rate (Q)

= wall W1 + wall W2 + wall W3 + wall W4 + wall floor + wall ceiling

= 33 + 33 + 99 + 99 + 100 + 100 = 464 kcal/hr.

Safety Factor multiplier in case of external temperature change

= 464 x 1.15 = 534 kcal/hr.

Total heat transfer rate (Q) of chiller 6 wheels truck without VIPs = 534 kcal/hr.

4.1.2 Chiller 6 Wheels Truck with VIPs

As a result of the temperature results rear to installation of VIPs, as shown in Figure 4.19, it was found that the refrigerated cars were controlled an average of 4 °C and defrosted 10 times a day due to the compressor operating at 2 °C for evaporator temperature in low temperature condition. During the defrosting time, the temperature of the freezer room will rise to a maximum of 8 °C due to the defrosting with heater. The average temperature along the route was 1,025 km., averaging 30 °C. The compressor takes 5 minutes to reach the set temperature, and it rises when the compressor stops running to the point where it starts up again in 10 minutes. The compressor cut in – cut off time after install VIPs, as shown in Figure 4.20.

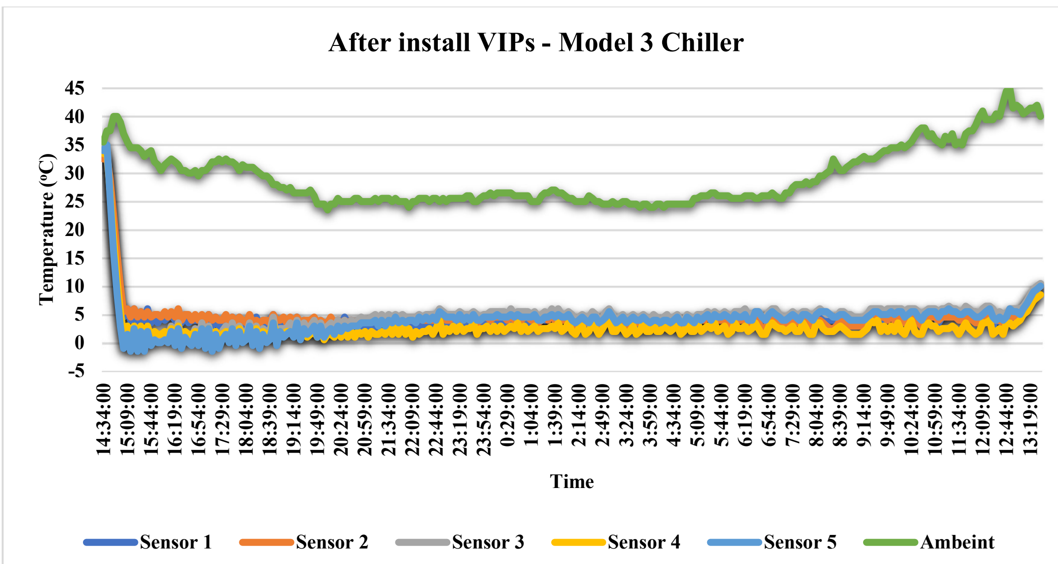

Fig. 4.19 Temperature results after installation of VIPs. (Model 3 Chiller)

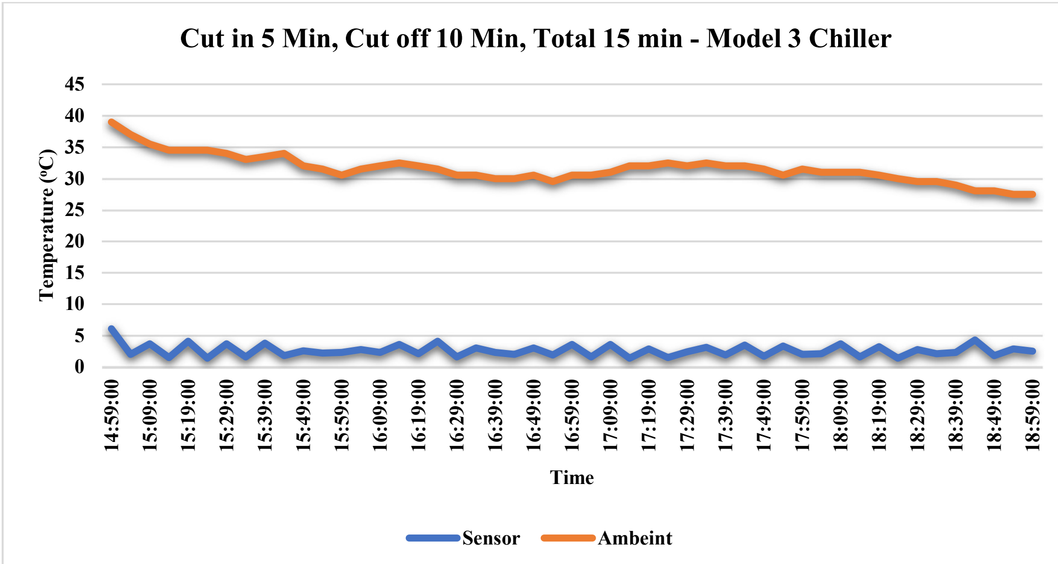

Fig. 4.20 The compressor cut in – cut off time after installation of VIPs. (Model 3 Chiller)

Thermal conductivity (K) of VIPs 0.0062 kcal/m.hr.°C

W1 wall (Front wall)

1. Wall area (A) = wall width x wall length = 2.15 m. x 2.16 m. = 4.644 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W1 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 4.644 x 0.052 x 38 = 9 kcal / hr.

W2 wall (Back wall)

1. Wall area (A) = wall width x wall length = 2.15 m. x 2.16 m. = 4.644 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W2 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 4.644 x 0.052 x 38 = 9 kcal / hr.

W3 wall (Right wall)

1. Wall area (A) = wall width x wall length = 2.15 m. x 6.50 m. = 13.975 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W3 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 13.975 x 0.052 x 38 = 28 kcal/hr.

W4 wall (Left wall)

1. Wall area (A) = wall width x wall length = 2.15 m. x 6.50 m. = 13.975 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W4 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 13.975 x 0.052 x 38 = 28 kcal/hr.

Ceiling wall

1. Wall area (A) = wall width x wall length = 2.16 m. x 6.50 m. = 14.040 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

Ceiling wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 14.040 x 0.052 x 38 = 28 kcal/hr.

Floor wall

1. Wall area (A) = wall width x wall length = 2.16 m. x 6.50 m. = 14.040 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

Floor wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 14.040 x 0.052 x 38 = 28 kcal/hr.

Total heat transfer rate (Q)

= wall W1 + wall W2 + wall W3 + wall W4 + wall floor + wall ceiling

= 9 + 9 + 28 + 28 + 28 + 28 = 130 kcal/hr.

Safety Factor multiplier in case of external temperature change

= 130 x 1.15 = 150 kcal/hr.

Total heat transfer rate (Q) of chiller 6 wheels truck with VIPs = 150 kcal/hr.

Test results show that VIPs insulation can maintain the same temperature as without VIPs insulation but the time required for cut in cut off is better to install VIPs insulation. The energy saving effect comes from the moment when the compressor is stopped, which means saving fuel to be used in cooling as a result of VIPs insulation. When all the results are calculated as the energy saving result, it is obtained that over a distance of 1,025 km., the fuel price is 26.39 baht / liter. It was found that the fuel consumption rate before VIPs installation was 5.36 km / liter, and compared with the after VIPs installation at 5.58 km / liter, the fuel savings was 4.10%.

4.3.3 Frozen 6 Wheels Truck without VIPs

As a result of the temperature results prior to installation of VIPs, as shown in Figure 4.21, it was found that the refrigerated cars were controlled an average of -16 °C and defrosted 22 times a day due to the compressor operating at -25 °C for evaporator temperature in low temperature condition. During the defrosting time, the temperature of the freezer room will rise to a maximum of -15 °C due to the defrosting with heater. The average temperature along the route was 1,025 km., averaging 25 °C. The compressor takes 5 minutes to reach the set temperature, and it rises when the compressor stops running to the point where it starts up again in 5 minutes. The compressor cut in - cut off time before install VIPs, as shown in Figure 4.22.

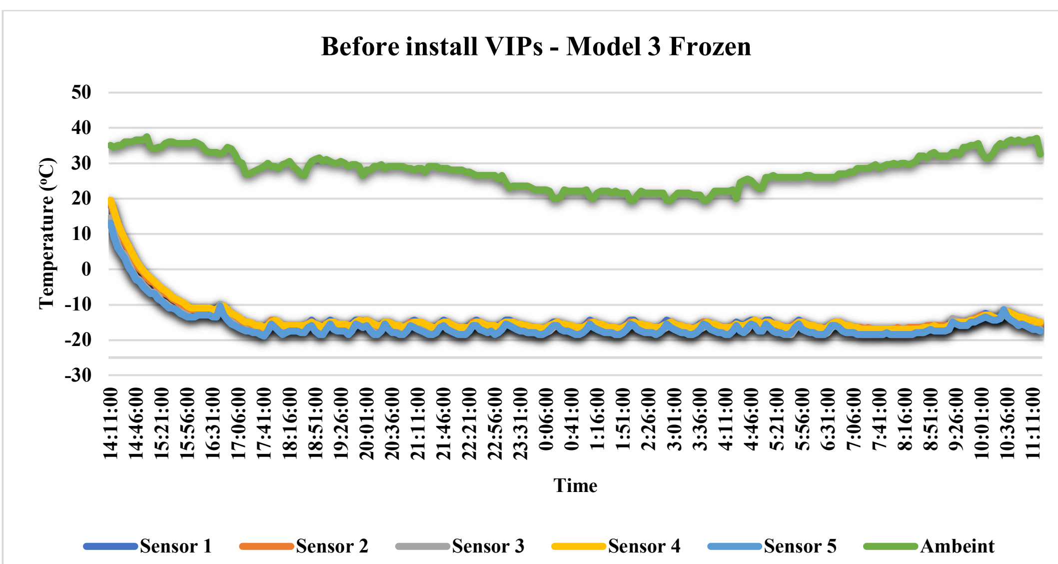

Fig. 4.21 Temperature results before installation of VIPs. (Model 3 Frozen)

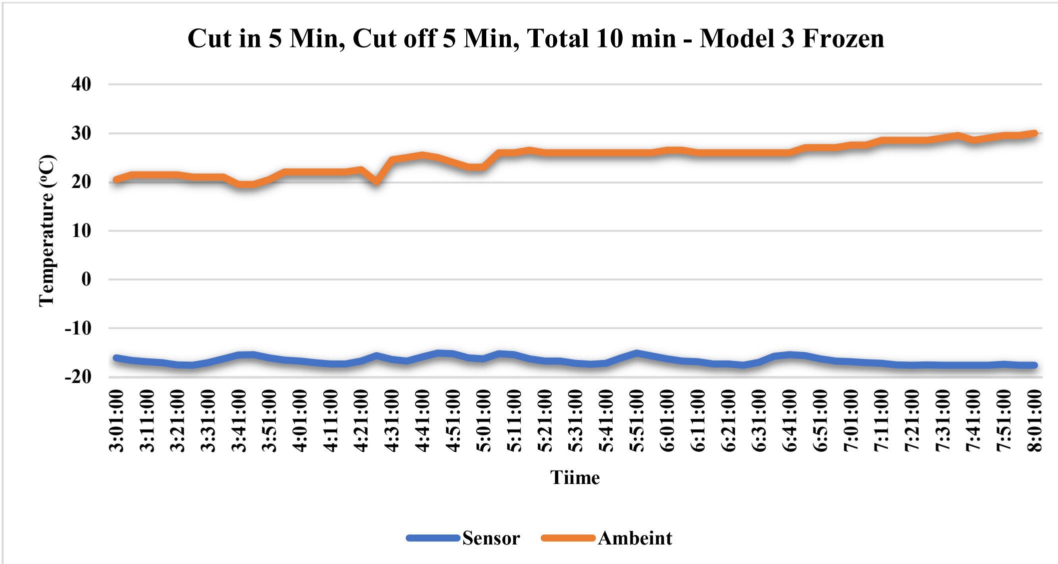

Fig. 4.22 The compressor cut in – cut off time before installation of VIPs. (Model 3 Frozen)

Thermal conductivity (K) of PU Foam 0.0224 kcal/m.hr.°C

W1 wall (Front wall)

1. Wall area (A) = wall width x wall length = 2.15 m. x 2.16 m. = 4.644 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W1 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 4.644 x 0.187 x 65 = 56 kcal / hr.

W2 wall (Back wall)

1. Wall area (A) = wall width x wall length = 2.15 m. x 2.16 m. = 4.644 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W2 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 4.644 x 0.187 x 65 = 56 kcal / hr.

W3 wall (Right wall)

1. Wall area (A) = wall width x wall length = 2.15 m. x 6.50 m. = 13.975 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W3 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 13.975 x 0.187 x 65 = 170 kcal/hr.

W4 wall (Left wall)

1. Wall area (A) = wall width x wall length = 2.15 m. x 6.50 m. = 13.975 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W4 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 13.975 x 0.187 x 65 = 170 kcal/hr

Ceiling wall

1. Wall area (A) = wall width x wall length = 2.16 m. x 6.50 m. = 14.040 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

Ceiling wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 14.040 x 0.187 x 65 = 171 kcal/hr.

Floor wall

1. Wall area (A) = wall width x wall length = 2.16 m. x 6.50 m. = 14.040 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

Floor wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 14.040 x 0.187 x 65 = 171 kcal/hr.

Total heat transfer rate (Q)

= wall W1 + wall W2 + wall W3 + wall W4 + wall floor + wall ceiling

= 56 + 56 + 170 + 170 + 171 + 171 = 794 kcal/hr.

Safety Factor multiplier in case of external temperature change

= 794 x 1.15 = 913 kcal/hr.

Total heat transfer rate (Q) of frozen 6 wheels truck without VIPs = 913 kcal/hr.

4.3.4 Frozen 6 Wheels Truck VIPs with VIPs

As a result of the temperature results rear to installation of VIPs, as shown in Figure 4.23, it was found that the refrigerated cars were controlled an average of -16 °C and defrosted 27 times a day due to the compressor operating at -25 °C for evaporator temperature in low temperature condition. During the defrosting time, the temperature of the freezer room will rise to a maximum of -15 °C due to the defrosting with heater. The average temperature along the route was 1,025 km., averaging 24 °C. The compressor takes 10 minutes to reach the set temperature, and it rises when the compressor stops running to the point where it starts up again in 15 minutes. The compressor cut in – cut off time after install VIPs, as shown in Figure 4.24.

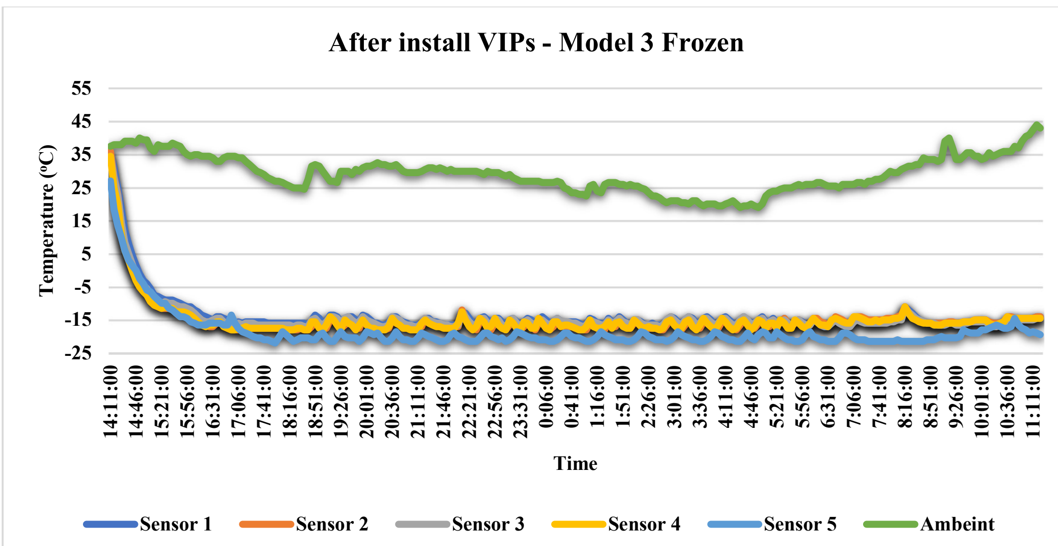

Fig. 4.23 Temperature results after installation of VIPs. (Model 3 Frozen)

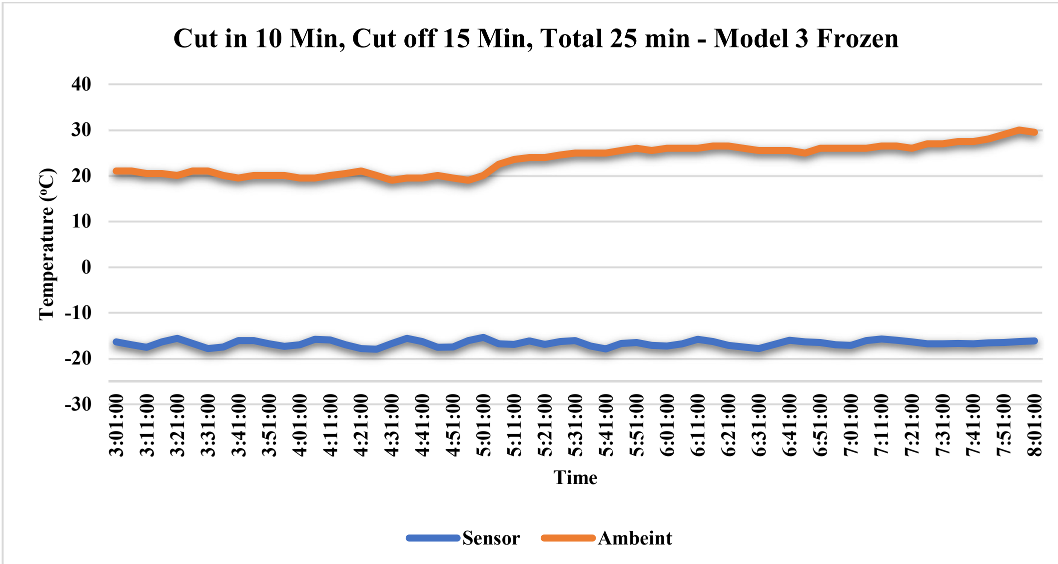

Fig. 4.24 The compressor cut in – cut off time after installation of VIPs. (Model 3 Frozen)

Thermal conductivity (K) of VIPs 0.0062 kcal/m.hr.°C

W1 wall (Front wall)

1. Wall area (A) = wall width x wall length = 2.15 m. x 2.16 m. = 4.644 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W1 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 4.644 x 0.052 x 65 = 16 kcal / hr.

W2 wall (Back wall)

1. Wall area (A) = wall width x wall length = 2.15 m. x 2.16 m. = 4.644 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W2 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 4.644 x 0.052 x 65 = 16 kcal / hr.

W3 wall (Right wall)

1. Wall area (A) = wall width x wall length = 2.15 m. x 6.50 m. = 13.975 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W3 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 13.975 x 0.052 x 65 = 47 kcal/hr.

W4 wall (Left wall)

1. Wall area (A) = wall width x wall length = 2.15 m. x 6.50 m. = 13.975 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W4 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 13.975 x 0.052 x 65 = 47 kcal/hr.

Ceiling wall

1. Wall area (A) = wall width x wall length = 2.16 m. x 6.50 m. = 14.040 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

Ceiling wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 14.040 x 0.052 x 65 = 47 kcal/hr.

Floor wall

1. Wall area (A) = wall width x wall length = 2.16 m. x 6.50 m. = 14.040 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

Floor wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 14.040 x 0.052 x 65 = 47 kcal/hr.

Total heat transfer rate (Q)

= wall W1 + wall W2 + wall W3 + wall W4 + wall floor + wall ceiling

= 16 + 16 + 47 + 47 + 47 + 47 = 220 kcal/hr.

Safety Factor multiplier in case of external temperature change

= 220 x 1.15 = 253 kcal/hr.

Total heat transfer rate (Q) of frozen 6 wheels truck with VIPs = 253 kcal/hr.

Test results show that VIPs insulation can maintain the same temperature as without VIPs insulation but the time required for cut in cut off is better to install VIPs insulation. The energy saving effect comes from the moment when the compressor is stopped, which means saving fuel to be used in cooling as a result of VIPs insulation. When all the results are calculated as the energy saving result, it is obtained that over a distance of 1,025 km, the fuel price is 26.09 baht / liter. It was found that the fuel consumption rate before VIPs installation was 4.88 km / liter, and compared with the after VIPs installation at 5.07 km / liter, the fuel savings was 3.89%.

4.4 Model 4 - 10 Wheels Truck

4.4.1 Chiller 10 Wheels Truck without VIPs

As a result of the temperature results prior to installation of VIPs, as shown in Figure 4.25, it was found that the refrigerated cars were controlled an average of -2 °C and defrosted 20 times a day due to the compressor operating at 2 °C for evaporator temperature in low temperature condition. During the defrosting time, the temperature of the freezer room will rise to a maximum of 4 °C due to the defrosting with heater. The ambient average temperature is 29 °C along the route was 1,023 km. The compressor takes 5 minutes to reach the set temperature, and it rises when the compressor stops running to the point where it starts up again in 5 minutes. The compressor cut in - cut off time before install VIPs, as shown in Figure 4.26.

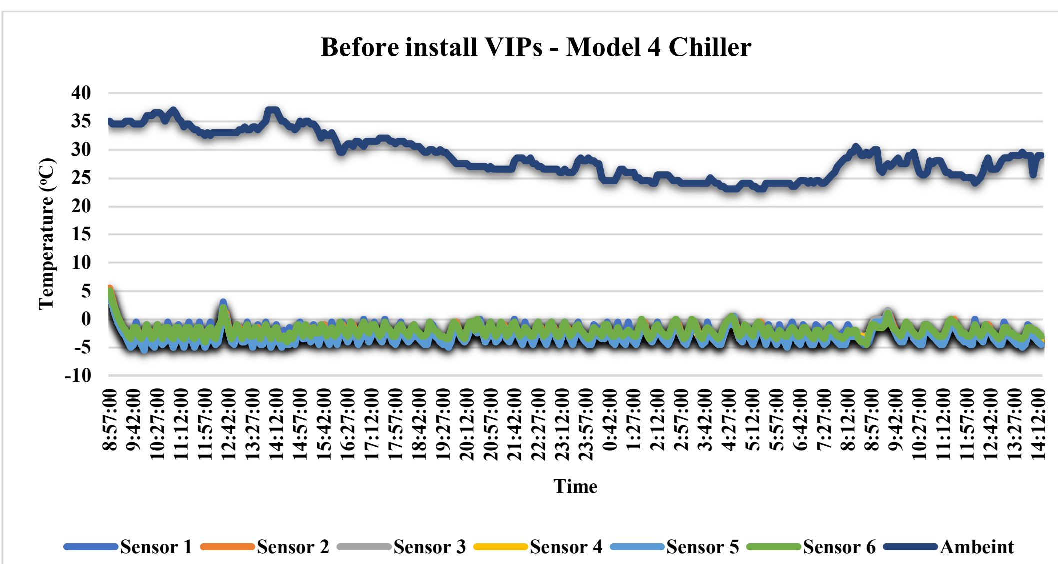

Fig. 4.25 Temperature results before installation of VIPs. (Model 4 Chiller)

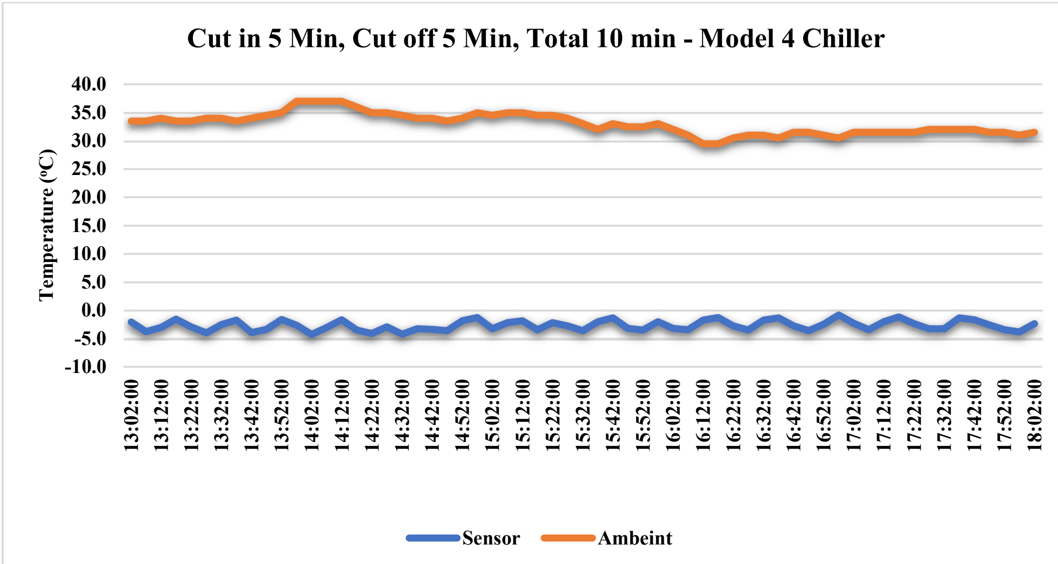

Fig. 4.26 The compressor cut in – cut off time before installation of VIPs. (Model 4 Chiller)

Thermal conductivity (K) of PU Foam 0.0224 kcal/m.hr.°C

W1 wall (Front wall)

1. Wall area (A) = wall width x wall length = 2.30 m. x 2.30 m. = 5.290 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W1 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.290 x 0.187 x 38 = 38 kcal / hr.

W2 wall (Back wall)

1. Wall area (A) = wall width x wall length = 2.30 m. x 2.30 m. = 5.290 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W2 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.290 x 0.187 x 38 = 38 kcal / hr.

W3 wall (Right wall)

1. Wall area (A) = wall width x wall length = 2.30 m. x 7.10 m. = 16.330 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W3 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 16.330 x 0.187 x 38 = 116 kcal/hr.

W4 wall (Left wall)

1. Wall area (A) = wall width x wall length = 2.30 m. x 7.10 m. = 16.330 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W4 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 16.330 x 0.187 x 38 = 116 kcal/hr.

Ceiling wall

1. Wall area (A) = wall width x wall length = 2.30 m. x 7.10 m. = 16.330 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

Ceiling wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 16.330 x 0.187 x 38 = 116 kcal/hr.

Floor wall

1. Wall area (A) = wall width x wall length = 2.30 m. x 7.10 m. = 16.330 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

Floor wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 16.330 x 0.187 x 38 = 116 kcal/hr.

Total heat transfer rate (Q)

= wall W1 + wall W2 + wall W3 + wall W4 + wall floor + wall ceiling

= 38 + 38 + 116 + 116 + 116 + 116 = 540 kcal/hr.

Safety Factor multiplier in case of external temperature change

= 540 x 1.15 = 621 kcal/hr.

Total heat transfer rate (Q) of chiller 10 wheels truck without VIPs = 621 kcal/hr.

4.4.2 Chiller 4 Wheels Truck with VIPs

As a result of the temperature results rear to installation of VIPs, as shown in Figure 4.27, it was found that the refrigerated cars were controlled an average of -2 °C and defrosted 21 times a day due to the compressor operating at 2 °C for evaporator temperature in low temperature condition. During the defrosting time, the temperature of the freezer room will rise to a maximum of 4 °C due to the defrosting with heater. The average temperature along the route was 1,023 km., averaging 29 °C. The compressor takes 5 minutes to reach the set temperature, and it rises when the compressor stops running to the point where it starts up again in 10 minutes. The compressor cut in – cut off time after install VIPs, as shown in Figure 4.28.

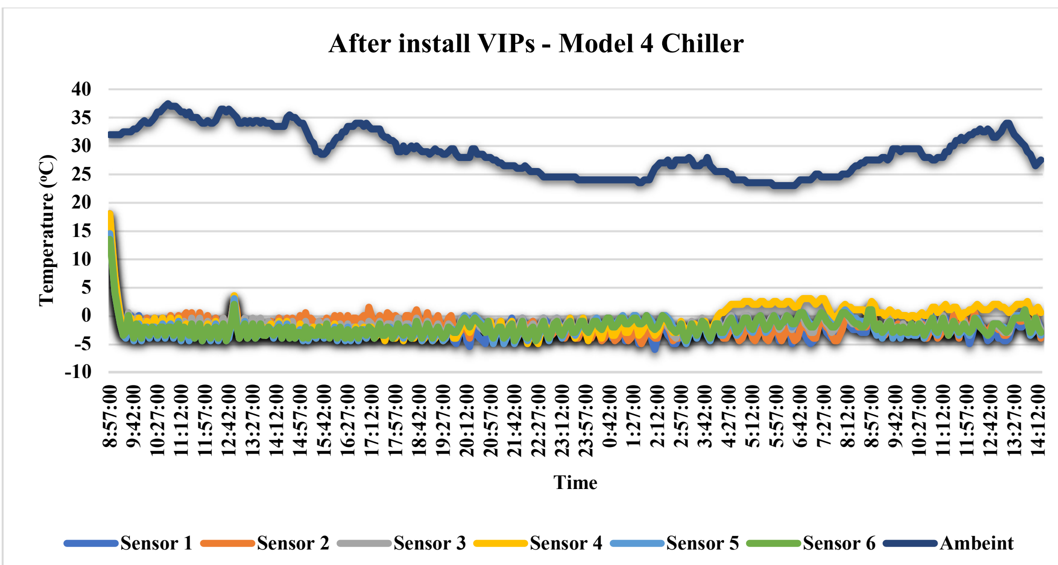

Fig. 4.27 Temperature results after installation of VIPs. (Model 4 Chiller)

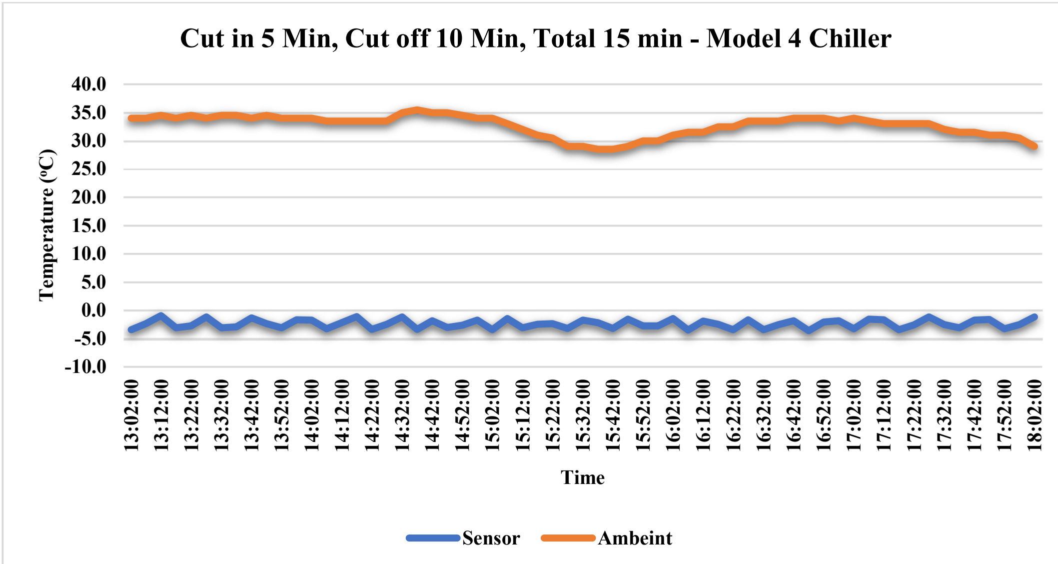

Fig. 4.28 The compressor cut in – cut off time after installation of VIPs. (Model 4 Chiller)

Thermal conductivity (K) of VIPs 0.0062 kcal/m.hr.°C

W1 wall (Front wall)

1. Wall area (A) = wall width x wall length = 2.30 m. x 2.30 m. = 5.290 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W1 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.290 x 0.052 x 38 = 10 kcal / hr.

W2 wall (Back wall)

1. Wall area (A) = wall width x wall length = 2.30 m. x 2.30 m. = 5.290 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W2 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.290 x 0.052 x 38 = 10 kcal / hr.

W3 wall (Right wall)

1. Wall area (A) = wall width x wall length = 2.30 m. x 7.10 m. = 16.330 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W3 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 16.330 x 0.052 x 38 = 32 kcal/hr.

W4 wall (Left wall)

1. Wall area (A) = wall width x wall length = 2.30 m. x 7.10 m. = 16.330 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

W4 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 16.330 x 0.052 x 38 = 32 kcal/hr.

Ceiling wall

1. Wall area (A) = wall width x wall length = 2.30 m. x 7.10 m. = 16.330 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

Ceiling wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 16.330 x 0.052 x 38 = 32 kcal/hr.

Floor wall

1. Wall area (A) = wall width x wall length = 2.30 m. x 7.10 m. = 16.330 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - 2 °C = 38 °C

Floor wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 16.330 x 0.052 x 38 = 32 kcal/hr.

Total heat transfer rate (Q)

= wall W1 + wall W2 + wall W3 + wall W4 + wall floor + wall ceiling

= 10 + 10 + 32 + 32 + 32 + 32 = 148 kcal/hr.

Safety Factor multiplier in case of external temperature change

= 148 x 1.15 = 170 kcal/hr.

Total heat transfer rate (Q) of chiller 10 wheels truck with VIPs = 170 kcal/hr.

Test results show that VIPs insulation can maintain the same temperature as without VIPs insulation but the time required for cut in cut off is better to install VIPs insulation. The energy saving effect comes from the moment when the compressor is stopped, which means saving fuel to be used in cooling as a result of VIPs insulation. When all the results are calculated as the energy saving result, it is obtained that over a distance of 1,023 km., the fuel price is 26.09 baht / liter. It was found that the fuel consumption rate before VIPs installation was 2.22 km / liter, and compared with the after VIPs installation at 2.36 km / liter, the fuel savings was 6.31%.

4.4.3 Frozen 10 Wheels Truck with VIPs installed

As a result of the temperature results prior to installation of VIPs, as shown in Figure 4.29, it was found that the refrigerated cars were controlled an average of -20 °C and defrosted 15 times a day due to the compressor operating at -25 °C for evaporator temperature in low temperature condition. During the defrosting time, the temperature of the freezer room will rise to a maximum of -18 °C due to the defrosting with heater. The average temperature along the route was 1,036 km., averaging 32 °C. The compressor takes 5 minutes to reach the set temperature, and it rises when the compressor stops running to the point where it starts up again in 5 minutes. The compressor cut in - cut off time before install VIPs, as shown in Figure 4.30.

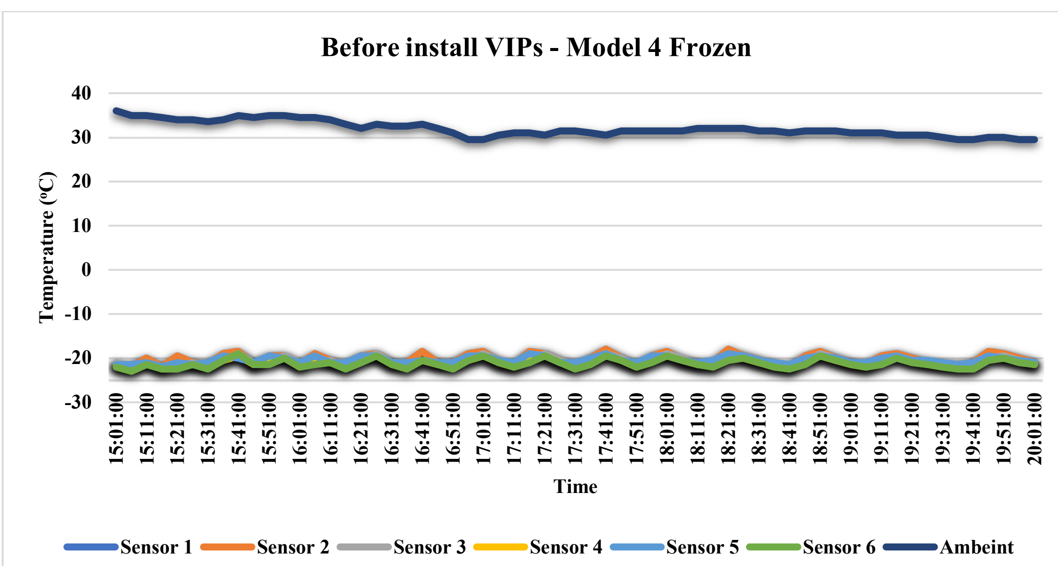

Fig. 4.29 Temperature results before installation of VIPs. (Model 4 Frozen)

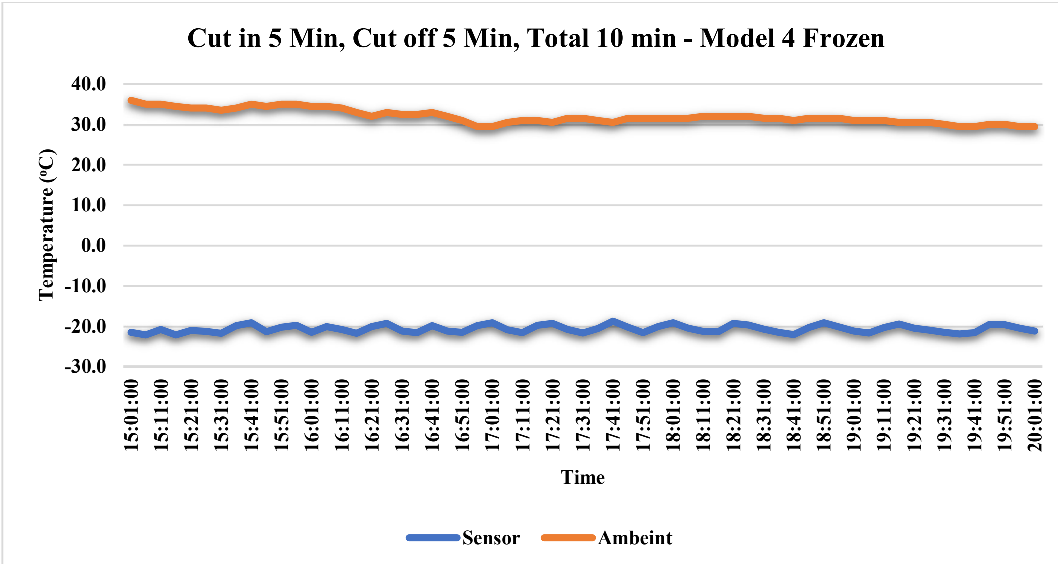

Fig. 4.30 The compressor cut in – cut off time before installation of VIPs. (Model 4 Frozen)

Thermal conductivity (K) of PU Foam 0.0224 kcal/m.hr.°C

W1 wall (Front wall)

1. Wall area (A) = wall width x wall length = 2.30 m. x 2.30 m. = 5.290 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W1 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.290 x 0.187 x 65 = 64 kcal / hr.

W2 wall (Back wall)

1. Wall area (A) = wall width x wall length = 2.30 m. x 2.30 m. = 5.290 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W2 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.290 x 0.187 x 65 = 64 kcal / hr.

W3 wall (Right wall)

1. Wall area (A) = wall width x wall length = 2.30 m. x 7.10 m. = 16.330 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W3 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 16.330 x 0.187 x 65 = 198 kcal/hr.

W4 wall (Left wall)

1. Wall area (A) = wall width x wall length = 2.30 m. x 7.10 m. = 16.330 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W4 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 16.330 x 0.187 x 65 = 198 kcal/hr.

Ceiling wall

1. Wall area (A) = wall width x wall length = 2.30 m. x 7.10 m. = 16.330 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

Ceiling wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 16.330 x 0.187 x 65 = 198 kcal/hr.

Floor wall

1. Wall area (A) = wall width x wall length = 2.30 m. x 7.10 m. = 16.330 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0224 kcal/m.hr.°C / 0.12 m.)) = 0.187 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

Floor wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 16.330 x 0.187 x 65 = 198 kcal/hr.

Total heat transfer rate (Q)

= wall W1 + wall W2 + wall W3 + wall W4 + wall floor + wall ceiling

= 64 + 64 + 198 + 198 + 198 + 198 = 920 kcal/hr.

Safety Factor multiplier in case of external temperature change

= 920 x 1.15 = 1,058 kcal/hr.

Total heat transfer rate (Q) of frozen 10 wheels truck without VIPs = 1,058 kcal/hr.

4.4.4 Frozen 10 Wheels Truck VIPs not installed

As a result of the temperature results rear to installation of VIPs, as shown in Figure 4.15, it was found that the refrigerated cars were controlled an average of -20 °C and defrosted 18 times a day due to the compressor operating at -25 °C for evaporator temperature in low temperature condition. During the defrosting time, the temperature of the freezer room will rise to a maximum of -18 °C due to the defrosting with heater. The average temperature along the route was 1,036 km., averaging 31 °C. The compressor takes 10 minutes to reach the set temperature, and it rises when the compressor stops running to the point where it starts up again in 15 minutes. The compressor cut in – cut off time after install VIPs, as shown in Figure 4.16.

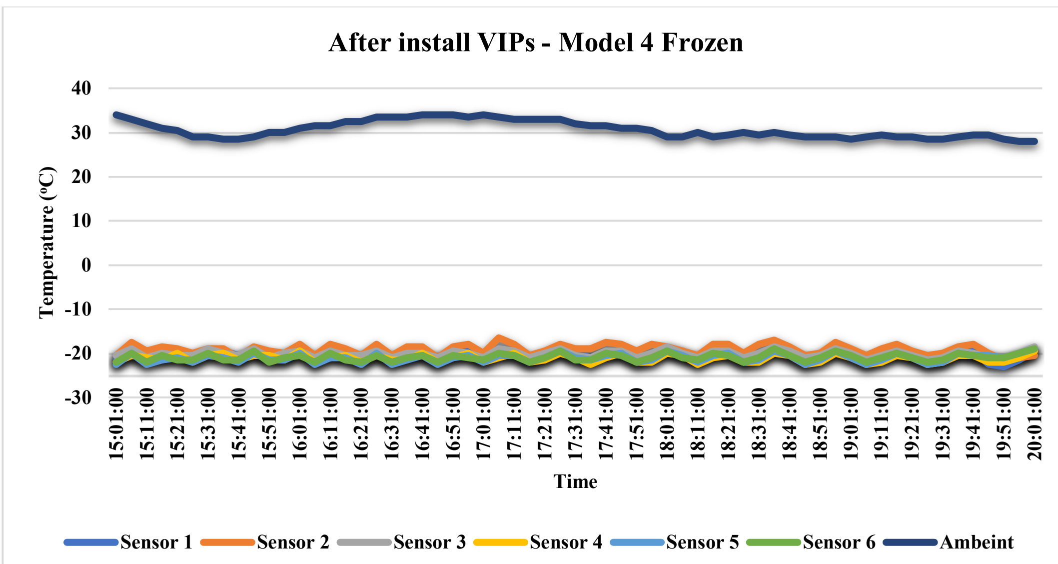

Fig. 4.31 Temperature results after installation of VIPs. (Model 4 Frozen)

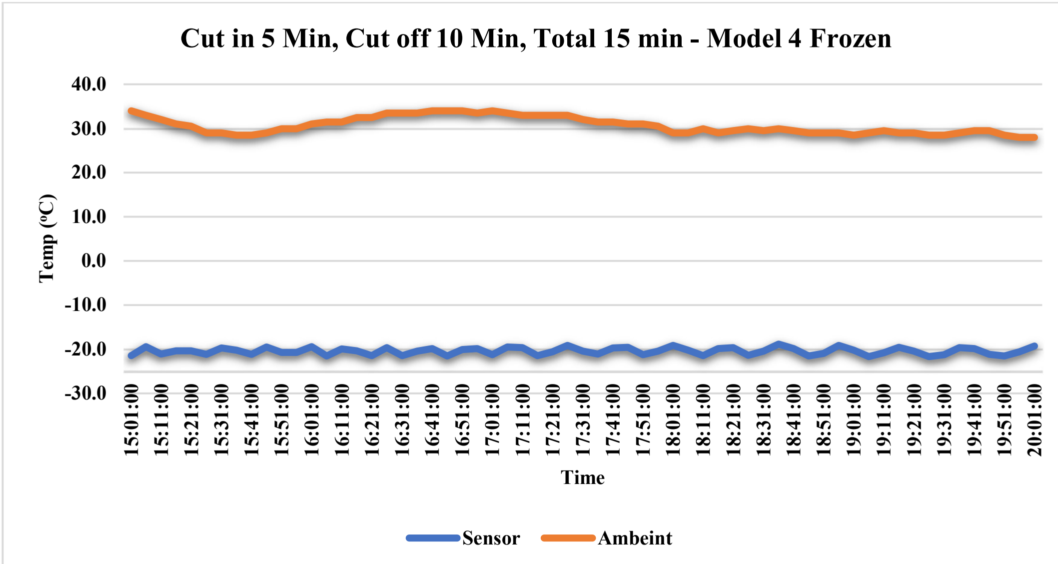

Fig. 4.32 The compressor cut in – cut off time after installation of VIPs. (Model 4 Frozen)

Thermal conductivity (K) of VIPs 0.0062 kcal/m.hr.°C

W1 wall (Front wall)

1. Wall area (A) = wall width x wall length = 2.30 m. x 2.30 m. = 5.290 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W1 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.290 x 0.052 x 65 = 18 kcal / hr.

W2 wall (Back wall)

1. Wall area (A) = wall width x wall length = 2.30 m. x 2.30 m. = 5.290 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W2 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 5.290 x 0.052 x 65 = 18 kcal / hr.

W3 wall (Right wall)

1. Wall area (A) = wall width x wall length = 2.30 m. x 7.10 m. = 16.330 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W3 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 16.330 x 0.052 x 65 = 55 kcal/hr.

W4 wall (Left wall)

1. Wall area (A) = wall width x wall length = 2.30 m. x 7.10 m. = 16.330 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

W4 Wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 16.330 x 0.052 x 65 = 55 kcal/hr.

Ceiling wall

1. Wall area (A) = wall width x wall length = 2.30 m. x 7.10 m. = 16.330 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

Ceiling wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 16.330 x 0.052 x 65 = 55 kcal/hr.

Floor wall

1. Wall area (A) = wall width x wall length = 2.30 m. x 7.10 m. = 16.330 m^2.

2. Thermal conductivity coefficient (U) = thermal conductivity (K) / insulation thickness = (0.0062 kcal/m.hr.°C / 0.12 m.)) = 0.052 kcal/m^2.hr.°C

3. Temperature difference between inside and outside (ΔT) = 40 °C - (-25 °C) = 65 °C

Floor wall heat transfer rate (Q) = $U \cdot A \cdot \Delta T$ = 16.330 x 0.052 x 65 = 55 kcal/hr.

Total heat transfer rate (Q)

= wall W1 + wall W2 + wall W3 + wall W4 + wall floor + wall ceiling

= 18 + 18 + 55 + 55 + 55 + 55 = 256 kcal/hr.

Safety Factor multiplier in case of external temperature change

= 256 x 1.15 = 294 kcal/hr.

Total heat transfer rate (Q) of frozen 10 wheels truck with VIPs = 294 kcal/hr.

Test results show that VIPs insulation can maintain the same temperature as without VIPs insulation but the time required for cut in cut off is better to install VIPs insulation. The energy saving effect comes from the moment when the compressor is stopped, which means saving fuel to be used in cooling as a result of VIPs insulation. When all the results are calculated as the energy saving result, it is obtained that over a distance of 1,036 km, the fuel price is 25.79 baht / liter. It was found that the fuel consumption rate before VIPs installation was 2.40 km / liter, and compared with the after VIPs installation at 2.67 km / liter, the fuel savings was 11.25%

The results of all 4 models, as shown in Table 4.1, Chiller cars was found Model 1 (4 Wheels Truck) have best fuel savings followed by the Model 2 (4 Wheels large Truck), Model 4 (10 Wheels Truck), and Model 3 (6 Wheels Truck) respectively and frozen cars was found Model 1 (4 Wheels Truck) have best fuel savings followed by the Model 4 (10 Wheels Truck), Model 3 (6 Wheels Truck), and Model 2 (4 Wheels large Truck) respectively.

Table 4.1 Summary fuel savings

Model	Type	Condition		Compressor Operating Time (Min)			fuel consumption rate
				Cut In	Cut Out	Total	(km / liter)
1	4 Wheels Truck	Chiller	With Out VIPs	10	5	15	9.98
			With VIPs	10	10	20	12.00
		Freezer	With Out VIPs	5	5	10	7.12
			With VIPs	10	10	20	8.33
2	4 Wheels large Truck	Chiller	With Out VIPs	5	5	10	15.12
			With VIPs	5	10	15	16.30
		Freezer	With Out VIPs	5	5	10	12.91
			With VIPs	5	10	15	13.32
3	6 Wheels Truck	Chiller	With Out VIPs	5	5	10	5.36
			With VIPs	5	10	15	5.58
		Freezer	With Out VIPs	5	5	10	4.88
			With VIPs	10	15	25	5.07
4	10 Wheels Truck	Chiller	With Out VIPs	5	5	10	2.22
			With VIPs	5	10	15	2.36
		Freezer	With Out VIPs	5	5	10	2.40
			With VIPs	5	10	15	2.67

CHAPTER 5

Conclusion and Recommendation

5.1 Conclusion

In many countries, land transportation is still used as the primary transportation and cold storage trucks are used to distribute products to different locations. VIPs insulation is an alternative way to reduce the cooling energy consumption of oil-driven compressors. Demonstrates the potential to reduce energy consumption that can still be achieved in the future, people should research other types of cold storage trucks or research in the same way as the air wall by inserting VIPs insulation inside the external insulation to reduce heat transfer. The results of the study can be summarized in each model as follows:

5.1.1 Summary of fuel savings

The results of all 4 models, Chiller cars was found Model 1 (4 Wheels Truck) have best fuel savings was 20.24% and frozen cars was found Model 1 (4 Wheels Truck) have best fuel savings 16.99%.

5.1.2 Break Even Point

Table 5.1 shown break-even point of chiller cars in model 1 chiller cars has a 6-sided wall area with a total size of 22 square meters. Installation cost of PU insulation total 48,400.00 baht, if changes to VIPs, the total value is 205,700.00 baht. That means the installation price of the two insulation types their difference equal to 157,300.00 baht.

Compared to the fuel consumption rate of the model 1 chiller car (PU insulation and VIPs) equal to 2.02 km / liter, and the fuel price is set to 30 Baht / liter. So, the break-even point of the model 1 chiller car is 31,148.51 km. In model 2, model 3 and model 4 break-even point equal to 92,182.49 km, 398,970.00 km and 305,339.05 km, respectively.

The break-even point of frozen cars installs with VIPs model 1, 2, 3 and 4 equals to 36,096.67 km, 216,801.95 km, 419,742.63 km, 179,120.74 km, respectively. as shown in table 5.2.

Table 5.1 Break Even Point (Chiller cars)

Model	Wall area (m^2)	installation equipment cost (Baht)	Chiller cars without VIPs		Chiller cars with VIPs	
			PU cost (Baht)	Total [1] (Baht)	VIPs cost (Baht)	Total [2] (Baht)
Model 1 (4 Wheels Truck)	22	18,700.00	29,700.00	48,400.00	187,000.00	205,700.00
Model 2 (4 Wheels large Truck)	28	23,800.00	37,800.00	61,600.00	238,000.00	261,800.00
Model 3 (6 Wheels Truck)	66	56,100.00	89,100.00	145,200.00	561,000.00	617,100.00
Model 4 (10 Wheels Truck)	76	64,600.00	102,600.00	167,200.00	646,000.00	710,600.00

Model	[2] - [1] (Baht)	Fuel Consumption Rate (km/liter)			Fuel cost (Baht/liter)	Break Even Point	
		Without VIPs	With VIPs	Save		(liter)	(km)
Model 1 (4 Wheels Truck)	157,300.00	9.98	12.00	2.02	30.00	2,595.71	31,148.51
Model 2 (4 Wheels large Truck)	200,200.00	15.12	16.30	1.18	30.00	5,655.37	92,182.49
Model 3 (6 Wheels Truck)	471,900.00	5.36	5.58	0.22	30.00	71,500.00	398,970.00
Model 4 (10 Wheels Truck)	543,400.00	2.22	2.36	0.14	30.00	129,380.95	305,339.05

Table 5.2 Break Even Point (Frozen cars)

Model	Wall area (m^2)	installation equipment cost (Baht)	Frozen cars without VIPs		Frozen cars with VIPs	
			PU cost (Baht)	Total [1] (Baht)	VIPs cost (Baht)	Total [2] (Baht)
Model 1 (4 Wheels Truck)	22	18,700.00	29,700.00	48,400.00	187,000.00	205,700.00
Model 2 (4 Wheels large Truck)	28	23,800.00	37,800.00	61,600.00	238,000.00	261,800.00
Model 3 (6 Wheels Truck)	66	56,100.00	89,100.00	145,200.00	561,000.00	617,100.00
Model 4 (10 Wheels Truck)	76	64,600.00	102,600.00	167,200.00	646,000.00	710,600.00

Model	[2] - [1] (Baht)	Fuel Consumption Rate (km/liter)			Fuel cost (Baht/liter)	Break Even Point	
		Without VIPs	With VIPs	Save		(liter)	(km)
Model 1 (4 Wheels Truck)	157,300.00	7.12	8.33	1.21	30.00	4,333.33	36,096.67
Model 2 (4 Wheels large Truck)	200,200.00	12.91	13.32	0.41	30.00	16,276.42	216,801.95
Model 3 (6 Wheels Truck)	471,900.00	4.88	5.07	0.19	30.00	82,789.47	419,742.63
Model 4 (10 Wheels Truck)	543,400.00	2.40	2.67	0.27	30.00	67,086.42	179,120.74

5.2 Recommendation

The results of this study can be used as a guideline for further development of energy saving in refrigerated trucks with vacuum insulated panels. Through the process of controlling and supervising road transport by truck by considering permission, determination and amendment of conditions in the transport operating license in accordance with the rules of the Central Land Transport Control Board.

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