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GREEN LOGISTICS: AN ENERGY AND EMISSION MODELING FOR TEMPERATURE CONTROLLED OUTBOUND TRANSPORT

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ABBVERIATIONS

A_t	The total area of trailers surface (m^2)
A_d	The area of the trailers doorway (m^2)
c_i	The inside surface conductance of (W/m^2K)
c_o	The outside surface conductance of (W/m^2K)
C_p	The specific heat of air inside the trailer (kJ/kgK)
CO_2	Carbon dioxide
d	The case study route distance (km)
D_f	The doorway flow factor
D_t	The door opening time factor
E	the effectiveness factor of the doorway protective device
E_{CO2}	The factor for eCO_2 emissions in kilograms produced by one liter of diesel fuel (eCO_2/kg/dm^3)
eCO_2	Equivalent carbon dioxide
E_d	The energy density for the diesel fuel (43.1 MJ/kg)
E_{DA}	The average diesel consumption per 100 kilometers (dm^3/100km)
E_f	The fuel efficiency factor of a diesel motor
F_m	Density factor in infiltration equation
GDP	Gross Domestic Product
GHG	Green House Gasses
GL	Green Logistics
GSCM	Green Supply Chain Management
HGV	Heavy goods vehicle
h_i	The enthalpy of infiltration air (kJ/kg)

h_r	The enthalpy of refrigerated air (kJ/kg)
k_i	The thermal conductivity of insulation material (W/mK)
P	The number of door way passages
$P_{CO2\ trailer}$	The produced eCO_2 emissions (kg)
$P_{CO2\ trailer}$	The produced eCO_2 emissions (kg)
Q	The energy heat load (MJ*)*
Q_2	Heating energy for transmission load
Q_3	Heating energy for product load
Q_4	Heating energy from Infiltration load when trailer door are open.
SCM	Supply Chain Management
Ton-km	A unit of freight carriage equal to the transportation of one metric ton of freight one kilometer.
T_o	The Ambient temperature (K)
T_i	The inside Temperature in the trailer (K)
U	The overall heat transfer coefficient (W/m²K)
V	Trailers volume (m³)
x_i	The thickness of the insulated body in meters (m)
ρ	The density of air in the trailer (m³/kg)
$ρ_d$	The diesel density (g/dm³)
$ρ_i$	The density of infiltration air (m³/kg)
$ρ_r$	The density of a refrigerated air (m³/kg)
θ_p	The door open and closing time (s)
θ_o	The time when the door is fully open (s)
θ_d	The total time of the delivery (s)

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ABSTRACT:

The research problem in this study is an energy consumption and carbon dioxide emission production modeling by temperature measurements. The temperature data was collected by GreenLC project from a temperature controlled outbound transport. The selected research questions was related on the modeling, if it is possible to calculate the energy consumption based on the temperature measurement data. What are the affective heat loads when modeling an outbound transport? Furthermore, what are the carbon dioxide emissions produced by outbound transport model? The research was based on the principles of the Green logistics and the characteristic of supply chain and outbound transport. Moreover, Modeling was based earlier studies that considered modeling temperature controlled transport and thermal features of a trailer. In addition, the energy calculations was based on thermodynamic principles and earlier energy calculation studies made on temperature controlled transport. The research problem was answered with two different energy models made from the GreenLC project outbound transport. The both models illustrated the case study closely and the cumulative energy load correlation had high values in both models. However, important finding was that, if models is wanted to reflect even more the case study more specific starting values should have been available. The research questions was also answered. The energy consumption can be calculated from the temperature measurement, if the trailer specifications are available. The most important heat loads in both energy models was the infiltration air from door-openings, the conduction heat through trailers body and the product heat load from replaced air in the trailer. Lastly, the carbon dioxide emissions was successfully calculated and found quite small. However, the infiltrations heat load produced 60 percent of the total emissions and it was found very interesting.

KEYWORDS: Green Logistics, Supply Chain, Energy modeling, Carbon dioxide emissions

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TIIVISTELMÄ:

Tässä työssä tutkittiin vihreä logistiikan kannalta jakeluketjun kylmäkuljetuksen energia kuulutusta ja hiilidioksidi päästöjä energiamallinnuksen kautta. Tutkimukseen käytetiin GreenLC projektin suorittamia lämpötilamittaustuloksia jakelukuljetuksesta ja tavoitteena oli lämpötila-aineiston kautta mallintaa kylmäkuljetuksen energian kulutusta. Olennaisia tutkimuskysymyksinä pidetiin energian kulutuksen määrän laskemista lämpötila-aineistosta, traileriin kohdistuvien lämpökuormien valitsemista ja hiilidioksidi päästöjen määrä, sekä jakautumista energiakulutuslähteiden kautta. Tutkimusmenetelmien tausta pohjautui vihreän logistiikan perusteisiin, sekä jakeluketjun ominaispiirteisiin toimittajaketjussa. Lisäksi mallinnusta varten tarkasteltiin aikaisempia kylmäketjujen mallinnuksia ja energiapäästöjen mallinnuksia kylmäkuljetuksessa. Suoritetut energia kulutuksien laskut perustuivat termodynamiikan perusteisiin, sekä aikaisempiin tutkimusmenetelmiin kylmäkuljetuksessa. Tutkimusongelmaan tavoitteisiin päästiin ja kaksi energiamallinnusta tehtiin tutkimusaineiston pohjalta. Molemmat mallinnukset vastasivat hyvin tutkimusaineiston case-tapausta ja kumulatiivisen energiankulutuksen korrelaatiot olivat case-tapaukseen liittyen korkeat. Tämä kuvaa mallinnuksen onnistumista. Tosin tutkimuksen tuloksista ilmeni, että vielä tarkemman mallintamiseen olisi tarvittu myös tarkemmat lähtötiedot. Tutkimuskysymyksien osalta vastaus saatiin kaikkiin kohtiin. lämpötila-aineiston perusteella voitiin laskea energiakulutus, joskin itse trailerin ominaisuuksista vaadittiin lisätietoa. Tärkeimmät lämpökuormat kyseisen mallinnuksen kannalta olivat ovien avauksesta johtuva traileriin sisään virtaava ilma, vähenevän lastin tilalle tullut ulkoilma ja trailerin eristeen läpi johtuva lämpö. Mallinnuksesta saadut hiilidioksidi päästöt olivat suhteellisen pienet, mutta huomattavaa oli että 60 prosenttia kylmäkuljetuksen aikana johtuvista päästöistä tuli ovien avauksien takia.

AVAINSANAT: Vihreä logistiikka, jakeluketju, energiamallinnus, hiilidioksidipäästöt.

1 INTRODUCTION

The global economic growth of the past century has increased the consumption of goods. The transportation of goods follows closely the global economic shifts. (Baier & Bergstrand 2001: 1; Dekker, Bloemhof & Mallidis 2012: 2.) When more goods are sold, more are produced and the risen quantity of goods are requiring more transportation. Although, the economic growth and transportation growth has been buoyant throughout 21st century, the sudden economic crisis affected also on the logistic business with decrease in the end of the first decade of twenty first century. In spite of the economic crisis and its effects on logistics, transportation volumes (ton-km) in longer time period are increasing to achieve new records. (International transport forum 2012: 11–13.) This is due multiple reasons and one of the biggest is the ongoing population growth. Another, and maybe more interesting, is the spreading of the markets to wider areas that increases the distance between the producers and consumer and consequently increases the length of transports. Third reason for increased need of transportation is the centralized production and the dominance role of global organizations in the markets that has risen over the past decades. The goods are produced in few places with large quantities and relatively low costs and shipped worldwide to the consumers. This increases the number of transported products and the length of transport itself. The efficiency of logistics has an important role in this to provide a reliable and cheap ways of transport. Although, equally important is the availability of cheap energy for transport vehicles that enables the long distance transports. (Baier & Bergstrand 2001.)

Climate change debate has been under a public discussion increasingly in the last decades. Although, the concepts such as green logistics has been first published already in 1950s. (McKinnon, Browne & Whiteing 2012: 4-5.) Organizations, governments and consumers have increased their attention towards actions which reduces the climate change. New legislation is made to decrease emissions and especially production of carbon dioxides, Organizations are developing new technologies and products to reduce environmental impact and consumers are selecting more environmentally friendly products to support the cause. In addition, several third party effects has influence on the choices that are made to reduce environmental impact. For example, the increased oil price has pushed the organizations to develop more energy efficiency solutions and increase the use of alternative energy sources. (McKinnon et al. 2012: 31-36.) Although, it is interesting to see what influence the resent changes in oil prices will have, especially if the oil price reduction prolong itself.

The food production and its supply chain has overcome an industrial change as well. After the middle of twentieth-century century the overall food supply chain is modified with the same principles as other mass produced products. The origin of raw materials can be far away from the production plant where the raw materials are more efficient to produce which rises the need of transport. Morever, the retailers and consumers can be far away from the production plant which increases the need and length of distribution. A great deal of the food supply chains material flows are perishable products. The perishable products need a climate controlled transport, such as temperature and humidly controlled transport, to avoid damaging the goods. This increases the vehicles energy load and consequently the emissions and the costs produced by the vehicle. (Tassou, De-Lille & Lewis 2004; Eurostat European Commission 2009.)

This Papers is focusing on the green supply chain and more closely to the outbound logistics of temperature controlled transport. The study problem is to design an energy load model for outbound delivery. The model is based on a case study that was conducted by GreenLC project. By modeling the delivery route from the case study, calculations is made to detect the energy consumption and emissions production of a temperature controlled trailer. The risen study questions are: what are the heat loads and energy forces that has influence on the temperature controlled trailer? Is it possible to calculate energy consumption from the case study's temperature measurements? How much emissions is produced during the modelled route? Is the model the designed model comparable to the case study's routing? In the trailer heat and energy calculations the principles of thermodynamics are applied and studies from Tassau et all (2009) and from ASHREA handbook (2006) are used to apply the relevant thermodynamic principle that are influencing on the temperature controlled trailer.

The paper starts with an overview of the situation of logistics. How it is changed with the changes of global economic situation and how logistic is changing in the contents of the risen of the environmental awareness. After this, the green supply chain is presented from the organizational point of view and how the green logistics has different characteristic in different parts of the supply chain. Furthermore, the temperature controlled supply chain, with its special requirements, is explained more closely in the green supply chain chapter. Green logistics is an important part of green supply chain, however, the means of transportations varies throughout the supply chain. It is important to present the characteristics of road transport, what is the main way to execute outbound logistics, and how green logistics is applied in temperature controlled transport. In the methodology section, the case study is presented and basing on the specification of the case study two outbound routing models are designed. In addition, based on the case study the relevant heat and energy calculations are presented and conducted in the methodology section. After this, the case study and model calculation results are presented and an example calculations shown to illustrate the actual calculation procedure. In the discussion section the design models are compared to the case study calculations and the study questions are answered. Lastly, in the conclusions some of the occurred problems in the model designing are presented and interesting study problems risen for future researches.

2 LOGISTICS IN NUMBERS

> *"Logistics is the detailed organization and implementation of a complex operation." (Oxford Dictionary 2014).*

The term logistics is widely used to describe transport, storage and handling of goods as well as moving people. The moving of goods, from raw material suppliers to production and further to retailers and finally to end consumers, is also considered under logistics, although, they requires many different ways of transportation. This is also known for a as a supply chain. (McKinnon et al. 2012: 3.) Logistics can be also considered as a flow of abstract things such as information or energy. Often physical and abstract flow is combined in logistics and then goods are usually delivered with some additional information such as packing and handling information. (Tandem Logistics Inc. 2014.)

2.1 The economic size of logistic industry

Transportation is convenient to divide based on the characteristics of the transported product. The figure one shows the growth of goods and passengers in Europe between years 1995 and 2006. In addition, the growth is compared to the Gross Domestic Product (GDP) to illustrate the change of economic growth to transport growth. (Eurostat European Commission 2009: 5.) From the Eurostat report can be concluded that transport of goods has been growing annually 2.8 percent while GDP had grown 2.4 percent and transport of passengers 1.7 percent. The transport of goods was measured in ton-km, which means 1000 kilogram of goods transported in kilometers (McKinnon et al. 2012: 39).

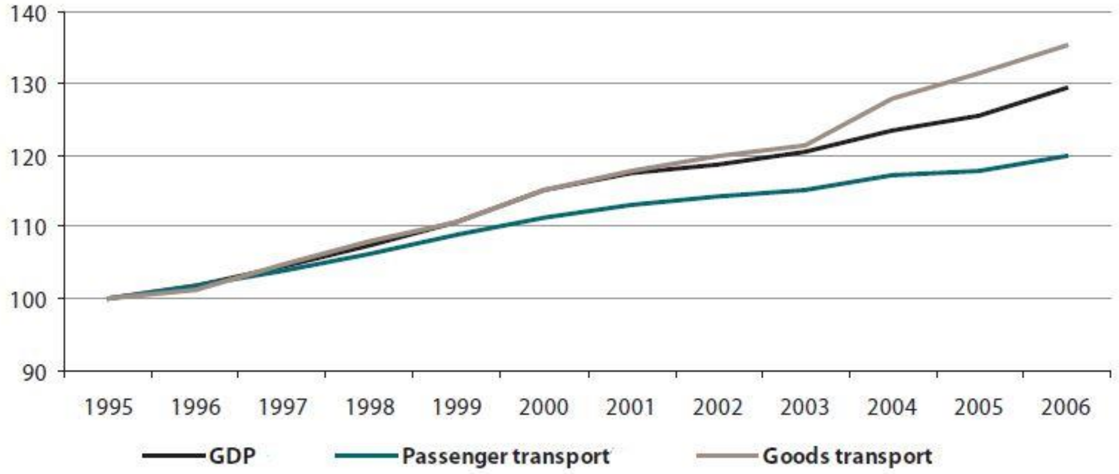


Figure 1. Transportation of goods and passengers compared to GDP. (Index 1995 = 100). (Directorate-General Energy and Transport 2009: 4.)

The transportation is divided in four subcategories in based on the used vehicle. The categories are road, rail, marine and air transports. (Eurostat European Commission, 2009: 4.) In this study concentration is on road transport. However, to give a better idea of the total transportation the all four categories will be presented. In the figure two can be seen that close to 46 percent of goods are transported by roads. Marine freight is the second largest with the total percentiles of 40.6. Goods transported by rail covers only 10.5 percent and transport by air only one tenth of percent.

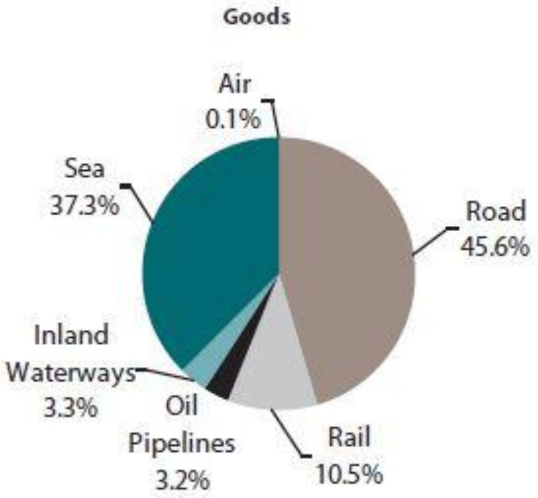


Figure 2. Transportation of goods between vehicles. (Directorate-General Energy and Transport 2009: 5.)

Logistics costs have also been examined at the company level and the cost of logistics has been measured propositionally to the turnover. A survey was conducted in 2008 in Europe by European Logistics Association and A.T Kearney consultants 2009. (Solakivi, Ojala, Lorentz, Laari & Töyli 2012: 50.) In the Figure three can be seen that logistics costs in the 1980, to the 2000 has decreased significantly, however, after 2003 the cost has started to rise again. According to the study, the main reason of the rise of the logistics costs are the transport costs. Furthermore, the fluctuation of logistics costs in European companies has been varied from 6 percent to 12 percent during 1987 and 2008. The percentages are reasonable low to compared Finnish companies where the average logistics costs from turnover was in year 2011 12.1 percent. (solakivi, et al. 2012: 82.) In addition, In a study of Klaus, Kille and Schwemmer (2011) the size of European logistic market was defined to be 930 billion euros and 42 percent of this was calculated to be transport costs, 26 percent warehouse costs, 22 percent inventory holding costs and 10 percent administration costs. Furthermore, according to the study 73.4 percent of the transport costs was accumulated from road transport. (European Logistics Association & AT Kearney 2009.)

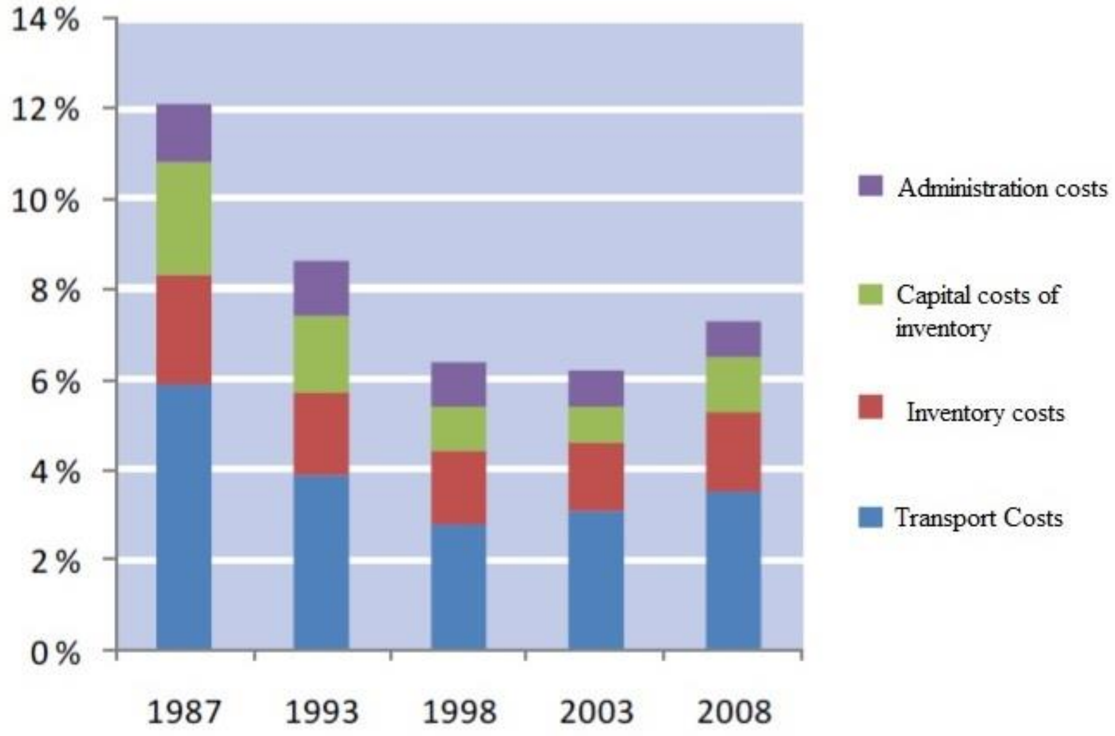


Figure 3. Logistics costs from Turnover in percetice. (European Logistics Association & AT Kearney 2009.)

To conclude it can be said that logistics reflects on the ongoing economic situation. When the economic situation is growing it also increases the need of logistics. (McKinnon et al. 2012: 8–11.) Also the changes in industry has had influence on the logistics. Centralized production has increased and the length of the transports by roads and favors the road transport that is more convenient and is easily convertible to the needs of logistics. (McKinnon et al. 2012: 12–15.) Furthermore, transports consumes the major part of logistics costs and road transports is the largest of transports for European companies. The logistics costs for a company can be more than one tenth of a company's turnover and this drives companies to reduce the economic impact with sustainable and green logistics. (McKinnon et al. 2012: 13–22; Solakivi et al. 2012: 82–88.)

2.2 Energy efficiency and emissions

The biggest cost in logistics is transportation. The fuel consumed in transportation is closely related to the energy efficiency and environmental impact in logistics (McKinnon et al. 2012: 229–230). The oil price and ongoing climate change are driven organizations towards energy efficiency and emission cuts. The rising oil price throughout twenty first century and the increasing social awareness in environmental issues are pressuring organization to be more energy efficient and lower the environmental impact by reducing Green House Gas (GHG) emissions. (McKinnon et al. 2012: 266–271.)

Transport produce quarter of European Union's GHG emissions and is the second largest GHG producer in Europe, after energy production. Road transport covers over 70 percent of the total GHG's in transports and produces 17.9 percent of all GHG emissions in 2009. (Hill, Brannigan, Smokers, Schorten, Van Essen & Skinner 2012: 2-3.) The data shown in figure four is based on the European Environmental Agency's research and it shows 27 European countries total GHG emissions and focus on transport in more detailed. Furthermore, to same kind of result got the International Transport Forum (2010) where worldwide carbon dioxide (CO_2) emissions where calculated. In this research transport took 23 percent of worlds total CO_2 emissions. Energy production was responsible of 46 percent of total CO_2 emissions and manufacturing produced 20 percent. Out of the 23 percent of CO_2 emissions that transport was responsible, 73 percent was caused by road transport. Furthermore, between 1990 and 2008 the CO_2 emissions in transport has increased with 44 percent globally. (International Tranport Forum 2010.)

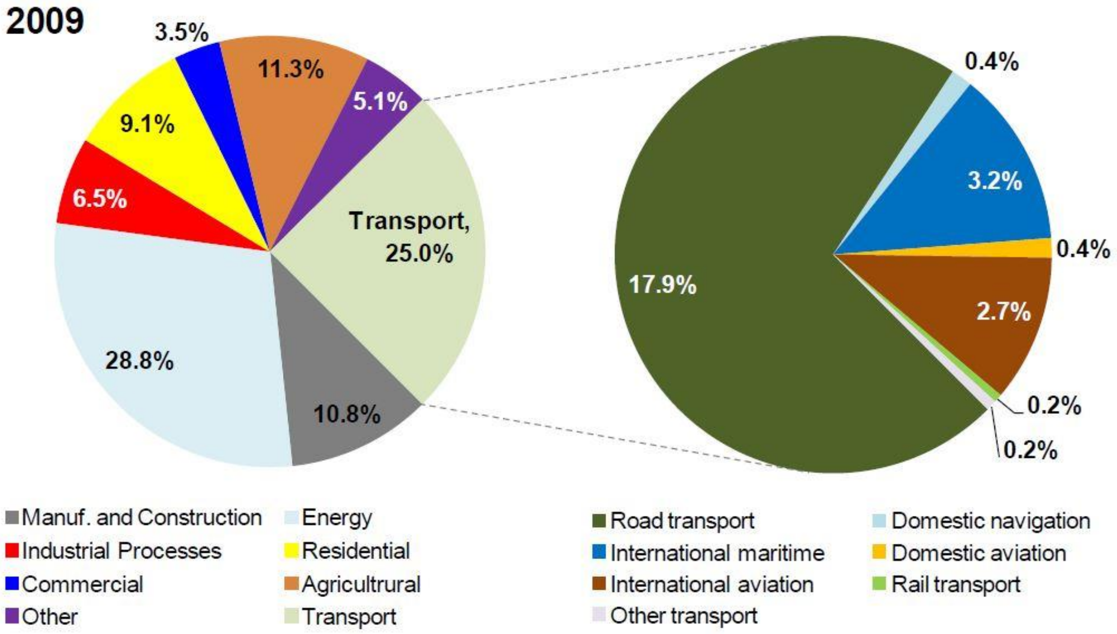


Figure 4. European GHG emissions by sector and by transport sector. (Hill et al. 2012: 2.)

The emissions produced by transportation contains several different GHG's. They vary in volume and in toxicity. However, in this research paper the studied GHG is CO_2 emissions. It is the second largest force after clouds and water vapor to have influence on climate change. Furthermore, from the fuels used in transports the CO_2 is the largest GHG by volume. Approximately 36 percent of CO_2 emissions is caused by energy sources such as gasoline and oil. (Kiehl & Trenberth 1997; Rapauch, Marland, Ciais, Le Quéré, Canadell, Klepper & Field 2007.)

3 SUPPLY CHAIN

> *“Sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development; and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations.” (WCED 1987).*

A traditional Supply Chain is determined as a system that connect the processes that are needed to produce and deliver a product from raw materials to the end customer. Supply Chain links together material suppliers, manufacturing facilities, distribution services and end customers. In other words, Supply Chain manages the material flow from raw material suppliers to the end customers and, in addition, manages the information flow both directions from a supplier to a customer and from a customer to a supplier. (Stevens 1989: 3–8.) However, efficiency problems has occurred throughout the Supply Chain that influence on the economic performance and, if the Supply Chain is not efficient from the economic point of view, it is likely to perform poorly from an environmental point of view as well. Some of these issues are addressed in the following chapters. (McKinnon et al. 2012: 119–120.)

The Traditional Supply Chain Management (SCM) has focused mainly on market and manufacturing issues. However, this has changed over the last decade and more focus is given to transportation. Green supply chain has emerged as an important approach for companies whom are developing their businesses towards environmentally sustainability. The notion of Green Supply Chain Management (GSCM) implies that environmental criteria’s are added to the Supply Chain Management and into the decision making context of the traditional supply chain management. (Emmett & Vivek 2010: 3)

The flow of materials and information in a supply chain is straight forward from the starting point to the supply chains ending point. However, there is a limited cooperation between the supply chain participants and restricted information flow that creates inefficiency and additional consumption of resources in a Supply chain. For example, every supply chain participant might have distorted or restricted information about the energy efficiency or greenhouse gas emission of the other supply chain participants, which leads to uncertainty of the total amount of energy and emissions that supply chain uses. Although, each participant may be concerned about their own emission production and may try to reduce them the ways of reducing cannot be as effective when supply chains upstream or downstream participants do not work together. In some cases there might be united focus on the total costs of the supply chain. However, even then the lack of information flow between supply chain participants does not reach the optimum and achieve the most efficient supply chain when discussion about environmental impact. (Emmett & Vivek 2010: 9; McKinnon et al. 2012: 102–119.)

3.1 Green Supply Chain

Green supply chain, on the other hand, strive to consider the environmental effects throughout the supply chain. This includes the production of raw materials, transportation, production, storage and the final disposal of goods. In the Green supply chain all participants from upstream and from downstream are presupposed to develop supply chain towards to be more environmentally sustainable. The open information flow is required to achieve the set environmental criteria's and to overcome the challenges that would be hard or even impossible to overcome by one participant of the supply chain. The support throughout suppliers, production and retailers increases the effectiveness of the environment performance and distributes the financial and operational costs. With this integration between upstream and downstream participants, the green supply chains supports individual companies to achieve individual goals that could not be otherwise possible and in the same time support other participants in their goals. Examples of these united goals, however an individual goal as well, could be for example to minimize waste, emission and costs in supply chain. (Emmett & Vivek 2010: 9; Isaksson & Huge-Brodin 2013: 217.)

Green supply chain can be divided in four subcategories: Green Supply Chain Planning, Green Procurement, Green Supply Chain Execution and Carbon Management. All subcategories are equally important to create a sustainable and efficient Green Supply Chain. However, in many cases management is concentrated on the Green Procurement and Green Supply Chain Execution which possible leads to the inefficient Green Supply Chain. (Emmett & Vivek 2010: 28–32.) In addition, especially in recent year's organizations has stress the problems of climate change with green logistics. This is due the global development related to the logistics. For example, oil price, climate change and consumer awareness of environmental issues drives organizations to focus on the development of green logistics. (Emmett & Vivek 2010: 17–25; McKinnon et al. 2012: 124-129.)

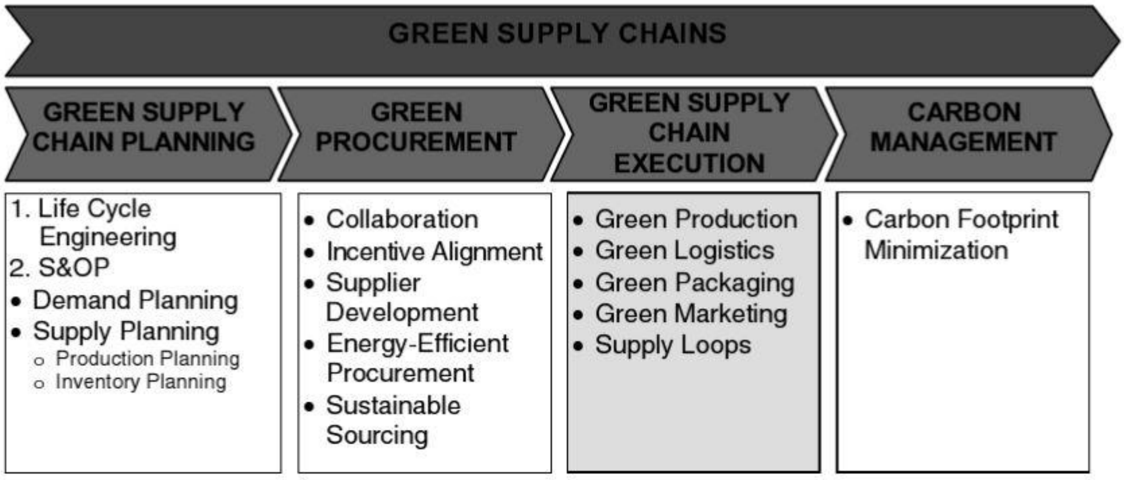


Figure 5. Green supply Chain and its four subcategories. (Emmett & Vivek 2010: 32.)

As Shown in figure five the Green Supply Chain Planning is vital part of the entire green supply chain. It considers the life cycle engineering of the whole supply chain, not only production or products but suppliers, raw materials, transportation and storage as well. Furthermore, Green Supply Planning covers also Sales and Operational Planning (S&OP) and together with Life Cycle Engineering they try to reduce costs, usage of materials, energy consumption, waste, emissions and to quantify the needed production and materials. (Emmett & Vivek 2010: 31–40.)

Green Procurement covers buying, sourcing and purchasing and is the starting point where all labor, services, products and materials enters to the supply chain. Green Procurements mission is to create collaboration between supplier, manufacturers and producers. Collaboration might require some supply chain participants to adapt new environmental standards and techniques which are required from the entire supply chain. For example, manufacturer might have specific environmental standards which are expected to meet by suppliers before further cooperation. Although, this may require additional resources from the supplier’s the long term benefits recovers them. For example, development of less wasteful packaging materials or decreasing the emissions and waste in production. In addition, this collaboration helps manufacturer to design environmentally concerned parts and material with suppliers. Green Procurements targets to reduce overall costs from products and services by extracting or lowering the waste and emissions in entire Supply Chain. Furthermore, this reduce the waste treatment in disposal of used goods throughout the Supply Chain. (Emmett & Vivek 2010: 60–65.)

Green Supply Chain Execution includes green production, green logistics, green packaging, green marketing, and supply loops. Therefore, the green execution produce the most of the waste, emissions and uses most of the energy needed in Supply Chain. Moreover, the supply chain participants focus most of the resources to the development of the Green Supply Chain Execution. New technologies are implemented, new methods are used to reduce waist, recycling is increased, life cycle cost minimized and energy consumptions are decreased. This is partly the development of the consumer’s awareness towards environmental issues and partly because reductions are straightforward to start where most of consumptions are produced. (Emmett & Vivek 2010: 95–106.) The Green Supply Chain Execution involves all the above segments to cooperate together and encourage collaboration inside the organization and between organizations. Moreover, different theories has been used for decades to improve executive level. For example, Lean production or Just-In-Time theory focus on reducing waste, energy usage and improve product quality and on time productions. The original idea was to develop more efficient and more cost effective supply chain. However, these theories had positive impact to the environment as well. Combining the environmental targets with the Lean and JIT theory new applications has risen that benefits the overall causes of green supply chain. For example, reduced inventory, reduced raw materials, minimizing reworks and lowering consumption in transport. (Emmett & Vivek 2010: 110–116.) Transport is considered as one of the main contributors of greenhouse emissions in logistics and therefore also in supply chain. This adds the severity of transport decisions in the Green Supply Chain Execution. This also creates a greater need to improve Green logistics, and a better understanding how the logistics can be proved in supply chain. (Emmett & Vivek 2010: 125.)

Across the supply chain the carbon management concentrates on the carbon footprint minimization. In an organization level carbon management can be recognized as a cycle of continues improvement. Starting from carbon measurement following by carbon minimization, carbon monitoring and carbon reporting. (Emmett & Vivek 2010: 183.) Carbon measurement raises multiple question, for example to whom the responsible of carbon measurements should be appointed in a supply chain and where the organizations CO_2 emissions starts. In a case orange juice the CO_2 emissions start from growing the oranges with fertilizer and pesticides. Then transportation to production plant emits CO_2 emissions. The production of an orange to juice emits more CO_2 emissions and the supplier how produce the carton packing emits CO_2 emissions as well while making the juice packing. After that, the temperature controlled storage for the fresh juice emits CO_2 and, finally, the transport forward to the retailers and consumers emits CO_2 emissions as well. So, it is difficult to conclude who should be in charge of the overall CO_2 emissions of the supply chain of the orange juice. The retailer how sales the juice, the producer or the orange farmer? Furthermore, it is difficult to define where the CO_2 emission measurements starts as an individual organization. For example, should the orange juice producer also take account the CO_2 emissions of the carton packing or just the production from orange to juice. And is the transport emissions appointed to retailer, producer or third party logistic supplier. This problems are decided by the particular supply chain and its participants. (Emmett & Vivek 2010: 187–192.) For CO_2 emission minimization it is important that all the participants of the supply chain are lowering their own carbon footprint when the carbon footprint of the entire supply chain also reduces. Important driver of reducing carbon emissions is the energy efficiency of production, transportation and farming. Carbon monitoring is important phase when considering continues improvement and the life cycle of the carbon management. Although, carbon monitoring does not require much resources after the CO_2 emissions measurements are implemented, it is important for the carbon reporting. Several authorizes requires environmental reports from a company, for example, governments, environmental auditors and other organization. Moreover, carbon reporting is also important for the company’s continues carbon management. (Emmett & Vivek 2010: 192–197.)

3.2 Temperature controlled supply chain

A temperature controlled supply chain is mostly considered as a food supply chain, which requires food products to be maintained in a temperature controlled environment. The expose in different temperatures and climates that supply chain might hold is not acceptable for most of the food products. In addition for the food supply chain, many chemicals and medicines also needs a temperature controlled supply chain, for example vaccines. Temperature controlled supply chain can be extremely complicated and expensive, hence it is districted much more than normal supply chain. The temperature controlled supply chain is determined by the source and nature of the product. And much like conventional supply chain, the temperature controlled supply chain can vary notable between upstream and downstream. For example, the temperature controlled upstream transport manages large cargo’s, long distances with reasonable few un-loading stops, whereas downstream transports manages short distances, reasonable small loads and multiple un-loading stops. Temperature controlled supply chain include legal and quality assurance requirements both on food safety and the distribution practice from production to consumption. (Sparks 2006: 51; Bourlakis & Weightman 2008: 179.) The main priority in temperature controlled supply chain is to keep the perishable products, such as food and medicines, in fresh and non-changeable conditions throughout the supply chain. The prior is an apparent hence the contaminated or perished products impacts not only on the economic losses but also can cause safety issues with consumers. Health problems for the consumers whom has consumed this kind of products are eminent and can cost serious health issues. This is why a reasonable part of research are studying technologies to prevent the contamination. The traceability studies of temperature controlled supply chain is also a mean to reduce the health issues and improve safety by tracing the possible breakdowns and limitations in the temperature controlled supply chain. Due the fact that the contamination of the products and the health issues are a prior in a temperature controlled supply chain, the environmental issues and energy consumption has less prior, even though, temperature controlled supply chain uses considerable amount of energy. (Sparks 2006: 53–57; Bhatt & Zhang 2013: 28–29.)

There are number of temperature levels to fit different types of products. For example, temperature groups from frozen, cold chill, medium chill and exotic chill. Frozen group means that the temperature is at least between −25 °C and −18 °C. This is suitable, for example for ice cream and for other frozen foods. Cold chill is intended to products that requires temperatures from 0 °C to +1 °C. Fresh meat and poultry, most dairy and meat based products, most vegetables and some fruit requires the Cold chill temperatures. Furthermore, medium chill temperatures means +5 °C and is meant for some pastry based products, butters, fats and cheeses. Lastly, exotic chill is +10 °C and it is intended for potatoes, eggs and fruits. (Bourlakis & Weightman 2008: 180.) These requirements can vary during the temperature controlled supply chain and adds constrains for the supply chain management (Sparks 2006: 52).

Temperature controlled supply chain’s main function is to manage product without contaminating them through the supply chain, the development in customers consuming habits and the issues with environmental changes are increasing the focus also towards energy management and emission consumption. The fast food industry, the increased consumption of ready meals and fresh fruits and vegetables has increased the demand for temperature controlled transport and the need for temperature controlled supply chain.

This change has led organizations to revalue the supply chain priors and increase the energy management in temperature controlled supply chain. (Sparks 2006: 53–55.)

4 GREEN LOGISTICS

"We are what we repeatedly do. Excellence then, is not an act, but a habit." (Durant 1991).

Logistics covers the management and movement of the goods throughout a supply chain. Therefore, it is an important factor that has impact on the environment. It is responsible for significant amounts of energy usage and emissions production. Transport and warehousing industries are key contributors of logistics and most of the reduction of emissions and energy consumption are focusing on the transportation and warehousing activities. (Emmett & Vivek 2010: 123.) Logistics manages all the movement and storage activities from the point of raw-materials to the point of consumption. Logistics can be divided in transportation, inventory management, order processing, and customer service. Transportation is concerning the physical transportation of goods and raw materials throughout the supply chain. (Kee-Hung & Cheng 2009: 4–5). Physical transportation can be managed by train, water, road air or pipe transport (Rose, Seely & Barret 2006: xvi). By means of volume and consumptions the road transport is the biggest consumer in transportation (Hill, et al. 2012: 2–3). This chapter will focus on the green logistics and, especially to the road transport.

Green logistics has attracted the most of attention when looking at all of the elements in a green supply chain (Emmett & Vivek 2010: 124). Green logistics involves the production and distribution of goods in a sustainable way, and it concerns the environmental and social factors. The objectives of green logistics are not only focusing on the economic impact of logistics, but a wider effects of the society. Green logistics, especially, focus on towards the emissions consumption and environmental issues which are caused by the logistical actions. The activities in green logistics includes measuring the environmental impact of various distribution systems. Furthermore, reducing the energy usage in logistics, managing the reduction of waste and reducing noise pollution are also objects of green logistics. The increasing concern of the global environmental effects and greenhouse gasses, which are caused by human activity, are pressuring organizations towards green logistics. Therefore, organizations are measuring their environmental impacts, for example carbon footprint, so that their activities can be monitored. Moreover, governments are setting targets for reducing emissions and environmental impacts which are required to meet by the organizations nationally as well as internationally. In other words, there is increasing need and interest in green logistics and it is driven by multiple quarters. (Sbihi & Eglese 2009: 1–3.)

Green logistic is driven by three different approaches. First is a Top-down approach where environmental values, such as energy efficiency and emissions are implemented to logistic industry by governments and other regulative authorizes. This is executed with laws and regulations that are related to environmental issues. For example, different emission regulations are implemented to decrease emissions and tax incentives to encourage new environmentally efficient investments. Second approach is bottom-up approach where environmental development are initiated by the industry. This is based on the best practice concept where industry is driven towards environmental conscious logistics by some beneficial factor. For example, decreasing costs, increasing profit for investment or better public image. The third approach is comparison of these two approaches, where the government and industry collaborate together, for example, through certifications and standards. (McKinnon et al. 2012: 141–143; Chityal, Dargopatil & Bhogade 2013: 82–84.)

The tree different approaches to influence on green logistics can be further categorized to five different levels of green logistics:

- customer, market and product level
- structure and planning level
- processes, control and measurement level
- technologies and resources
- employees, suppliers and service providers

The customer, market and product level can assist environmental improvements, for example, with more efficient packing and waste minimization in transport and reverse transport. Structure and planning level imply, for example, to the routing optimization or transport vehicle selection so that environmental impacts are taking in consideration. Process, control and measurement can improve the environmental impact by load optimization that minimize the energy and emissions consumed by transported products. Furthermore, technologies and resources level can improve green logistics by engine and fuel development or environmental friendly warehousing where, for example; biofuels, hybrid motors and renewable energy source are used. Lastly, employees, suppliers and service providers reduce the environmental impact of logistics with collaboration between each other to improve all the other levels mentioned or by training employees, for example, to drive vehicles more energy efficiently. However these levels are classified individually, the decisions towards green logistic in one level can have restricting influence on to another level. For example, defining a packing form can effect on the maximum carrying capacity in a container which can influence either positively or negatively on the emissions levels per transported product. (Chityal et al. 2013: 85–87.)

4.1 Green road transport

Road, rail, water and air freight transports has all different characteristics. The main transport modes has different roles in the transportation of goods. Water and rail transport has an advantage to carry large quantities of mass-produced products, such as petroleum and coal. However, the routing is not flexible with rail and water transport and tied to specific starting and ending point. By contrast, road transport is flexible for its routing and does not require large quantities of products to be efficient. Therefore, road transport is used with manufactured goods in the end of a supply chain, whereas, rail and water transport are used in the begging of a supply chain. Road transport caters the majority of the flows of short distance distribution, where energy usage and emissions per carried tone are higher and volume of the flows are typically smaller. (McKinnon et al. 2012: 124–128.)

Several technical improvements have been made to transport vehicles in past decades. These environmental conscious improvements are driven by top-down or bottom-up approaches. Environmental legislation requires vehicles reduce air pollution and noise, whereas, commercial pressures vehicle development to improve energy efficiency and vehicle loading. The short term and long term environmental improvements in vehicles focus on reduction of fuel consumption and CO_2 emissions. (McKinnon et al. 2012: 140.) The dual-action approach to green logistics suggest that the technological improvements in transport vehicles improves also the environmental performance of vehicles. Vehicle technology can lower the environmental impact of transportation in three different ways. First, environmental impact of transport can be reduced by increasing vehicle carrying capacity. Second, improving energy efficiency of vehicles has decreasing influence to the pollutions produced by vehicles. Third way is to reduce the externalities that are related to transport, such as air pollutions, greenhouse gasses, accidents and noise. (McKinnon et al. 2012: 141.)

The carrying capacity of road transport can be divided in two different approaches. Carrying capacity can be increased by lengthening the outer dimensions of the trailer, for example the increased height and length of the trailer would increase the total carrying capacity of the vehicle. In addition, increased weight capacity increases also the carrying capacity and lowers the energy usage and emissions of the cargo. However, governments has restrictions concerning the road vehicles length, height and maximum weight. This is based on the limitations of roads and bridges and tunnels. (McKinnon et al. 2012: 142.) The future energy efficiency of road transport is mainly based on the fuel efficiency of engines. The developments are focusing on hybrid technologies, turbocharging engines and increasing the energy efficiency auxiliary equipment's. Hybrid technologies are based on the diesel motor and electric motor powering together the vehicle and this way decreasing the fuel consumption. Turbocharging the engine means harvesting the exhaust cases for the engine to use again and this way downsizing of the actual size of the motor can be possible. With auxiliary equipment is meant all the other systems in a truck that are powered by the engine, such as heating, air conditioning and pumps. Increasing their energy efficiency decreases the utilization of engine and increases the fuel efficiency of the engine. (McKinnon et al. 2012: 143–144.) In the road transport the reduction of externalities can be related to fuel reduction or non-fuel reduction. Fuel related reduction focus on reducing air pollution and greenhouse gas emissions. On the contrary, non-fuel externalities reduces, for example, noise, vibration and accidents. Fuel related externalities is reduced with engine design, fuel development and exhaust filtering. Engine can be designed to produce less emissions or to adapt emission lowering bio fuels, and exhaust system can be designed to filter more emissions. Non-fuel externality improvements can be achieved with low noise tires, quieter refrigeration units or internal load resistant systems. (McKinnon et al. 2012: 145–146.)

In the figure six is shown the simplified structure of green logistics and its relation to actions taken through logistical system. In the middle are the levels by which green logistics can be influenced. Underneath of that is the transport means and how those can be developed towards low environmental impacts. On the bottom is presented examples of ways to develop green transport. Lastly on the side is presented the three approaches that effects on each part of the green logistics.

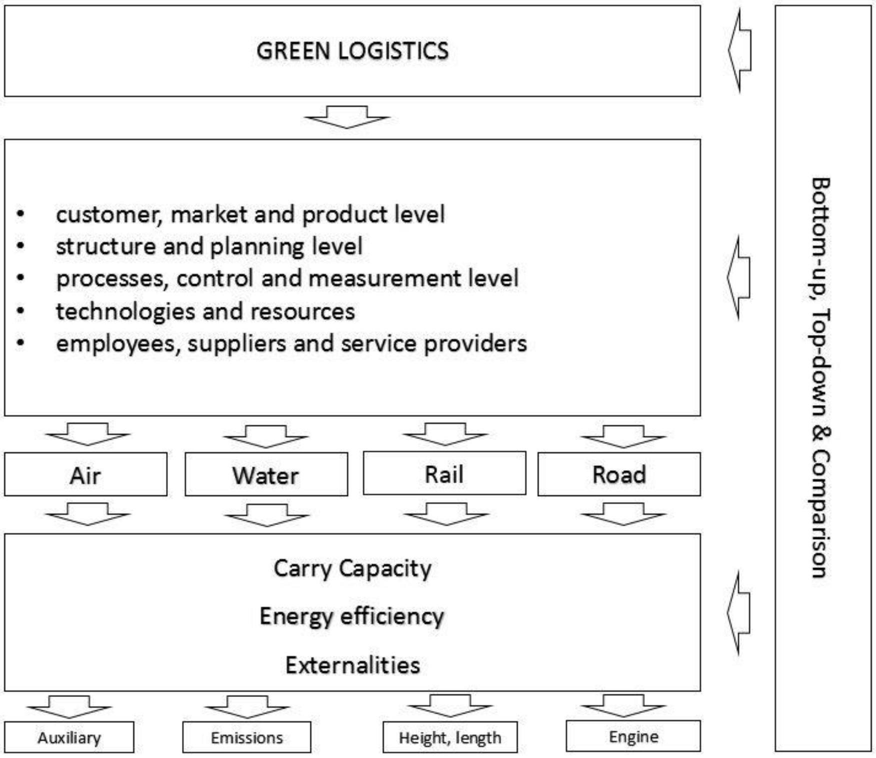
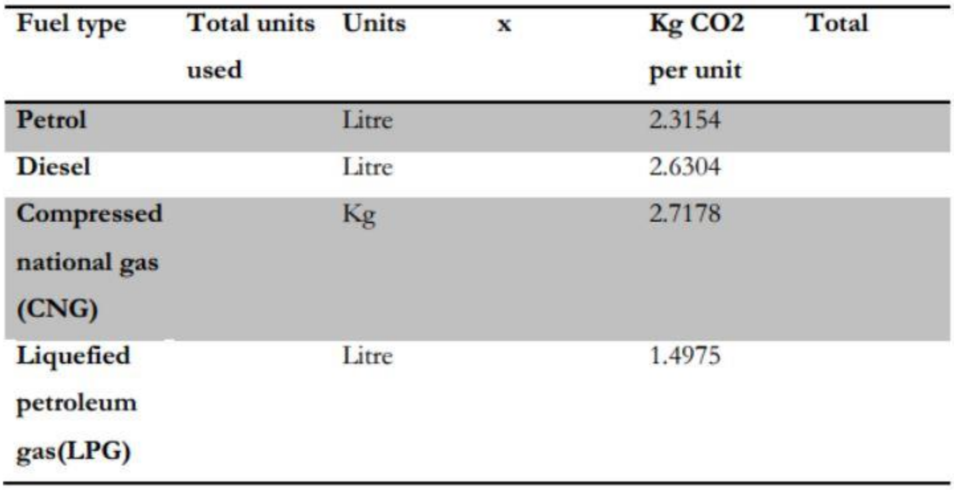


Figure 6. Simplified structure of Green Logistics.

Road transport is mainly based on two energy source: Diesel and Petrol. Emissions from transport largely depends on the type of fuel used. Diesel and petrol has different types of environmental impacts. Road transport is mainly based on diesel fuel. Diesel engines emits more CO_2 emissions than petrol engine. However, diesel engines are more fuel efficient than petrol engines, therefore, the overall CO_2 emissions are lower in diesel engines. (Holmen & Niemeier 2003: 61–79.) The fuel efficiency can be measured by the distance traveled per the used fuel unit, for example, km per liter (McKinnon et al. 2012: 230). According to Defra (2012: 41) the average CO_2 emissions for trucks was 888.9 grams of CO_2 per kilometer. This includes all the heavy goods vehicles (HGV) in United Kingdom in 2009. Furthermore, fuel efficiency can be also expressed buy the weight of goods and the travelled distance per unit of fuel, for example, ton-km per liter (McKinnon, et al. 2012: 230). The average CO_2 emissions for HGV's was 127.2 grams per ton-km (Defra 2012: 41). The Table one shows the standard conversation factors of one liter or kilogram of fuel to equivalent CO_2 emissions produced. Moreover, the table one shows that one liter of diesel produces 13.6 percent more CO_2 emissions than a liter of petrol, however, the diesel engine uses less fuel per the distance travelled to the actual difference is reduced during the transportation. (McKinnon et al. 2012: 290–232.)

Table 1. Standard fuel conversion factors to carbon dioxide (McKinnon et al. 2012: 33).



Fuel type	Total units used	Units	x	Kg CO2 per unit	Total
Petrol		Litre		2.3154	
Diesel		Litre		2.6304	
Compressed national gas (CNG)		Kg		2.7178	
Liquefied petroleum gas(LPG)		Litre		1.4975	

4.2 Green temperature controlled road transport

Temperature controlled transport is one segment of the transport in general. With temperature controlled transport is considered the transportation of temperature-sensitive commodities. Pharmaceutical products, refrigerated products and perishable goods, such as food products or vaccines are in many cases temperature-sensitive commodities which requires temperature controlled transport. Temperature controlled transports is used throughout the supply chain, however, mostly in the downstream where retail distribution operates. (Garnett 2003.) Temperature controlled road transport was proximately 8.5 percent of the entire road transport in United Kingdom in 2002 (Tassou et al. 2004: 1–2).

Temperature controlled transport is regulated by governments and other regulative organizations. This is to ensure that transported goods are delivered and storage by the safety and the health standards. Different products needs suitable climate and this can vary largely between products. Depending by the product, temperature controlled transport has to operate from +10 °C to -25 °C. The high temperature is needed for products such as sterilized and cooked meat and the lowest temperatures is needed when transporting ice cream and deep frozen foods. (Tassou et al. 2004: 3–5.)

The temperature controlled transportation can be executed by air, rail, water or road transport. However, the nature of temperature controlled goods and the development of food industry requires most of the transports made by road transport. Therefore, Road transport produces most of the emissions from the temperature controlled transports. (Smith, Watkiss, Tweddle, McKinnon, Browne, Hunt, Trevelen, Nash & Cross 2005: 19–22.) For example, in United Kingdom 2002 the road transport covered 77 percent of carbon emissions of food transport (Defra 2006: 52–53).

From the green logistics point of view temperature controlled trucks can be divided in to categories based refrigerating system, and the trailers lay-out and insulation. The refrigerating system can be powered by the vehicles engine or the by the motor attached to trailer. The refrigerated systems engine can be powered by fuel or electricity. The lay-out of the trailer can vary based on the purpose of use. The trailer can be closed in departments and select the temperature of each department. This way it is possible to ensure maximum carry even though the transported goods requires different climates. (Tassou et al. 2004: 5; Ahmed, Meade & Medina 2010: 383–384.)

Based on the different ways who the refrigerating unit is working, vehicles can be divided in two alternative categories. The first category is a self-contained type of refrigeration, where an independent motor inputs the power for a refrigeration compressor. The second one is a non-self-contained refrigeration unit, which extracts the cooling energy from the vehicle’s motor. The Refrigerator unit in both systems uses a significant amount of energy to cool down or warm up the trailer's air and maintaining the required temperature of the transported product. (Ahmed et al. 2010: 2.) Furthermore, maintaining the inside temperature of the trailer constant and managing the humidity levels of the inside air requires precise temperature and moisture monitoring a throughout the transport, which total depends on the refrigeration system. The refrigeration unit is normally placed outside and front of the truck. (Ahmed et al. 2010: 380–382.)

The green logistics initiatives in temperature controlled transports are based on the same principles as in a conventional logistics (Bourlakis & Weightman 2008: 192). The energy needed to refrigeration can be reduced with technical development of the refrigeration system, and with the insulation and with the lay-out of the trailer (Ahmed et al. 2010: 384). In addition, the importance in temperature controlled transports is to minimize the refrigerated time of transportation and storage. Although, this cannot undermine the safety requirements that are set for the transported products. Furthermore, reducing the utilization of the refrigeration system can be reduced with efficient routing and loading of the truck. For example, reducing the distance between storages and ultimately reducing the length of entire supply chain reduces the time and the energy needed in the transport. (Garnett 2003: 63–68; Bourlakis & Weightman 2008: 183–185.) In addition, Transporting the products at night time when temperature outside is cooler, reduces the utilization of the refrigeration system (Ahmed et al. 2010: 385–386). Optimizing the loading effects of the emissions per transported product can be improved, for example, multiplying departments with individual temperatures within the trailer. This provides the possibility to deliver products with different constrains. This increases the possibility to utilize the carrying capacity of the trailer. The loading time and the un-loading time in the temperature controlled transport has to be take in to account. When the trailer is open to the outside ambient the climate and temperature inside the trailer is compromised. The total time of loading and un-loading the goods can be significant, especially, in the distribution and retail transports. The temperature change inside the trailer has to be recompensed with the work of refrigeration system and this increases the energy consumption. (Defra 2006: 52–56; Bourlakis & Weightman 2008: 186–187.)

To conclude, the temperature controlled transport differs from the conventional transport in number of ways. The legislation related to temperature controlled transport is more restricted, the trailer itself is divergent from the conventional trailers and refrigerated system increases energy consumption and emissions. However, the green logistics initiatives to reduce energy consumption and emissions are pliable to the temperature controlled transport. Although, the utilization of refrigerate system has to take into account when considering green logistics. In road transport, this means attention to the routing and loading times hence this increases the utilization of the refrigerated system. From the temperature controlled transports the road transport is the largest consumer of energy and producer of emissions (Garnett 2003: 8).

4.3 Temperature controlled transport model

Modeling of temperature controlled transportation is used to help the design process and optimization of the transport (James S., James C. & Evans 2006: 947). Modeling is used widely in the area of local delivery. However the main priors in modeling temperature controlled transport has been in maintaining the requirements of transported products. This is practically important that the temperature controlled products are maintained in correct temperature during the transport to avoid the contaminations of the products. (James et al. 2006: 948; Lagurre, Duret, Hoang & Flick 2014: 121.) Contamination of the products can cost a lot and be even hazardous for consumer. This why the optimization and traceability of the transport is important issue. However, as temperature controlled transportation increases the rising interest towards energy loads and environmental issues are topical and optimization of energy consumption and environmental impacts are important issues as well. The improvement of energy consumption and environmental impacts by optimizing the routing, improving the trailer insulation and reducing vehicle weight are some areas of interest in modeling the temperature controlled transport. (James et al. 2006: 948–949; Lagurre et al. 2014: 123.)

There are several modeling approaches when temperature controlled transports designed. This mainly based on the complexity of the temperature controlled transport. The models that predicts heat and mass transfer during the transportation can be divided in two categories. The first are the models that considers the climate inside the trailer, such as the airflow inside the trailer. The Second are the models that concentrate on the temperature of the transported product. In addition, some models combines these two aspects and takes the temporal aspects under consideration as well. These temporal aspects can be the changes in ambient conditions, door openings and product loading and un-loading. (James et al. 2006: 950–951.)

Modeling a temperature controlled transport several things is needed to take account. The transport vehicle can go through of a wide range of ambient conditions. The heat transfer from outside air through trailers walls has to be taken into account. The solar radiation and the infiltration air through trailers cavity and door-opening is also important to take into account. Furthermore, the transport is not static and in the model aspects such as vehicle speed, vibration and orientation related to sun are needed. (James et al. 2006: 951–954.) The computational fluid dynamics (CFD) is used to model the airflow in cold-storages or trailers and through the doorways. The CFD has been used to investigate the optimization of airflow in temperature controlled trailer and decrease the temperature variation within the trailer. Another way to model airflow is with the Reynolds stress model (RSM). (James et al. 2006: 949; Lagurre et al. 2014: 121.) With CFD a model simulated during which two minute door-opening the inside temperature was risen by 24 °C. Although, with air curtain and plastic strip curtain the temperature change did to 17 ºC, the temperature change was noticeable. X And during the outbound delivery the un-loading stops can rise to 50 stops. (James et al. 2006: 949; Lagurre et al. 2014: 122.) Another study stated that a precooling of the products is vital before the transportation, hence normally the refrigeration unit does not have the capacity of cooling the cargo. (James et al. 2006: 951.) This kind of modeling, especially combined modeling requires great deal of data to be able calculate accurate results. Data can be divided to product specifications, ambient conditions, trailer specifications and to refrigeration units' specifications. Product specifications can be for example, the initial temperature of product, the packing material and the products specifications itself. Ambient conditions can mean the outside temperature, humidity and the amount of solar radiation. Trailer specifications can mean the dimension of a trailer, the size of doorways, the thinness and heat conduction k-factor of the walls. Refrigeration units' specifications can be for example, the airflow capacity, refrigeration temperature and power on and off cycles. (James et al. 2006: 951.) In the figure seven is show a mathematical model from a model called Coolvan.

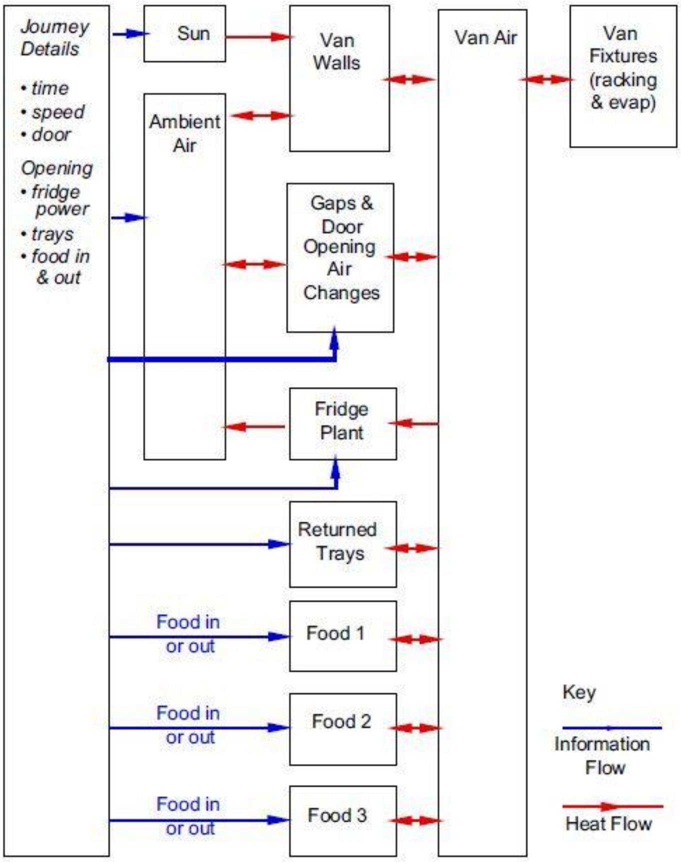


Figure 7. Coolvan model. The information flow and heat flow between considered variables in temperature controlled transport. (James et al. 2006: 952.)

In the figure seven can be seen the heat and information flows of the Coolvan model. On the right hand side is the journey details, or routing details, such time and speed. The second section from right shows the ambient specification, such as air specification. The third section shows the trailer, refrigeration unit and product specification. Lastly, the right hand side shows the vans' air. The red arrows are heat flow between different sections and blue arrows are the information flow. (James et al. 2006: 952; Lagurre et al. 2014: 121.) The Coolvan model was considered a good outline structure for the models made in this paper.

Laguerre et all (2014: 121–123) conducted a research where a simplified model was designed. The model was designed to illustrate the temperature changes in the temperature controlled load. The model was conducted with numerical study where input variables such as trailer dimensions, airflow rate, insulation and ambient settings. Input variables effects where modelled for basic domestic refrigerator, for refrigerated storage and for temperature controlled vehicle. A result was that the load temperature differ based on where it is placed in the refrigerated area. Furthermore, in the temperature controlled transport the model showed that the length of the trailer has influence on the product temperature. (Lagurre et al. 2014: 130.) The product temperature is higher at the opposed end from the refrigeration unit. In addition, the conducted model showed that door-openings has more influence on the temperature of the products that were placed closer to the doorway. The outside and inside temperature has notable effect on the infiltration air and door-openings and the duration increases especially the product temperature in the rear part of the trailers. (Lagurre et al. 2014: 131.) However, increasing the airflow rate the rear end product temperature can be decreased and the effects above can be reduced. Laguerre et all (2014: 132) concluded that studying the energy efficiency more variables should have taken into the model.

To conclude, the temperature controlled transport is a complex and interactive system. To be able to model accurate heat loads the temperature controlled trailer model needs to conclude variable information. Heat conduction through the trailers wall, solar radiation heat to the trailers outside wall, Heat transfer between the cargo and the refrigerated air, air infiltration from ambient into trailer from door-openings or from small cavities in a trailer and removed heat load by the refrigeration unit. (James et al. 2006: 954.) In addition these factor can change notable according to the weather conditions, time of day and climate zones that the vehicle go through. The model should be able to model all the variations of the variables or specified input variables to be accurate in temperature and energy calculations. (James et al. 2006: 955.)

5 THERMAL CHARASTERISTIC OF A TRAILER

Temperature controlled systems are needed throughout the supply chain. The supply chain can include temperature controlled long distance haulage from farmers to factories. In the factories the temperature controlled products has to be maintained in certain climate. This is executed with temperature controlled storages. Furthermore, the finished products are distributed to distribution centers and retailers, which sets different kind of constrains to road transport than the long distance haulage. (McKinnon et al. 2012: 195–198.) In outbound distribution the distance is shorten, and the vehicles stops to unload products is increased. Road transport refrigeration system is normally used in more challenging environments that the storage refrigeration systems. There is less base, the outside conditions changes and during the delivery refrigeration system is influenced with different physical conditions, such as vibration, and weather conditions. This means that refrigeration systems in road transport is less efficient than refrigeration systems in storages and terminals. (Tassau, De-Lille & Ge 2009: 1467.)

The road transport operates under an ATP agreement that defines united regulations for refrigeration systems and the characteristic of the trailer. The agreement regulates the insulation needed in a trailer and the power of refrigeration unit. (Tassau et al. 2009: 1469.) The trailer insulation regulations can be divided in two categories: IN (isotherme normal) and IR (isotherme renforcé). The IN standard means that the insulation a trailer cannot conduct more energy than 0.7 $W/m^2/°C$ through the trailers body. The IR standard means that the energy conducted through trailer insulation cannot reach over 0.4 $W/m^2/°C$. These are called k-factors and are based on how much energy conduct through a one square meter are of insulation when the temperature difference between inside and outside the surface is 1 ºC. Furthermore, based on the IN and IR insulation standards two classifications are placed to regulate the temperatures where IN and IR can be operated. FNA is based on the IN and is only used in transports that are between 0 ºC and +12 ºC, and FRC is based on the IR and can operate temperatures between -20 ºC and +12 ºC. The refrigeration unit is also included to the ATP agreement. The agreement states that the refrigeration unit onboard must have a heat extraction capability of 1.35 times the heat transfer through the surface in a 30 ºC outside temperature. (Evira: 2007; Refrigerated Vechile Test Centre 2014.)

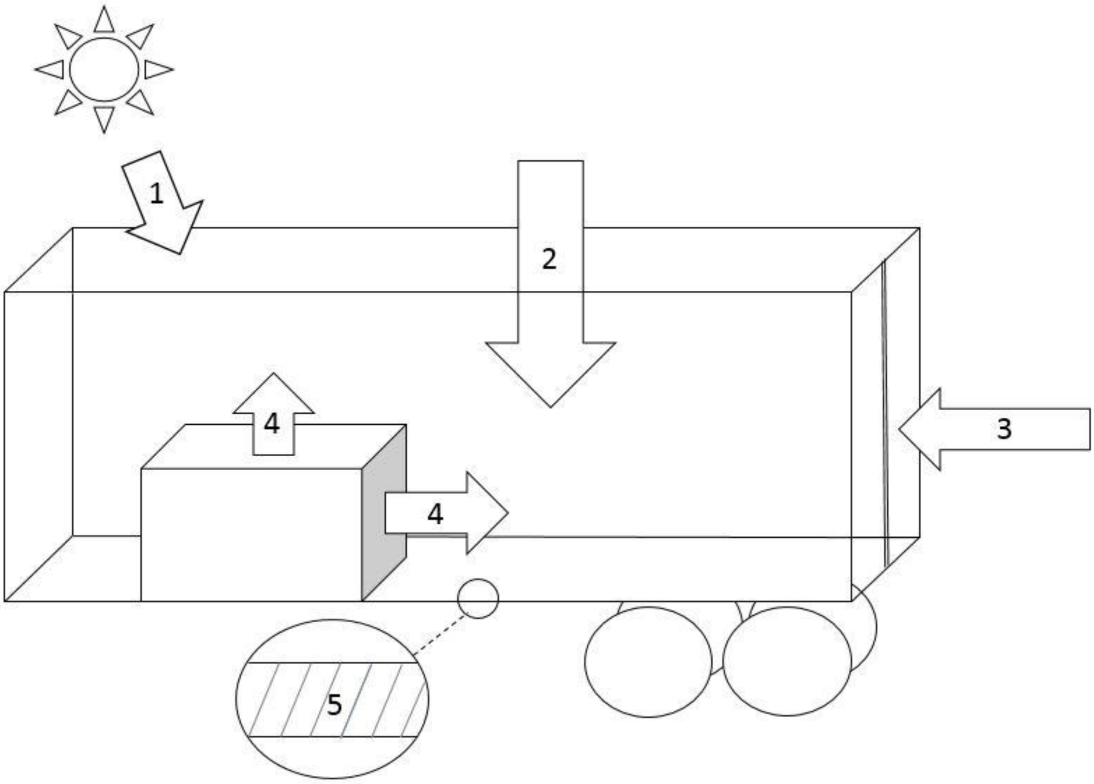
The ATP agreement insures that the trailer and refrigeration unit is tested by the third party. The ATP certificate is valid for six years, however, it can be extended by three more years if the classifications are passed. This is based on the deterioration of insulation material, which is studied to be up to 5 percent per year. This leads to considerable increase of thermal conductivity after time. For example, after nine years of use the original k-factor measured to 0.4 W/m²/°C is increased to 0.62 W/m²/°C and means that energy consumption and emissions are risen by 50 percent to compare to the original values of thermal conductivity. (Tassau et al. 2009: 1468.)

5.1 Energy loads of a temperature controlled trailer

During the road transport the trailer is under the influence of multiple sources of heat. The sources of heat ingress into trailer are conduction, radiation and convection. The sources that generates heat can be divided in five main loads as shown in picture one:

1. Solar radiation load, which comes from the solar radiation that is absorbed by the surface of the trailer.
2. Transmission load, which is outside heat transferred into the refrigerated space through the trailer surface.
3. Infiltration air load, which is heat gain associated with outside air entering in the trailer, for example, during the door openings.
4. Product load, which is heat produced by the delivered products in the trailer.
5. Precooling load, which is heat removed from the trailer to bring its inside climate and interior of the surfaces to the set temperature. (Hadawey & Tassou 2009: 4–

8; ASHRAE: American Society of Heating, Refrigeration and Air-Conditioning Engineers 2006.)



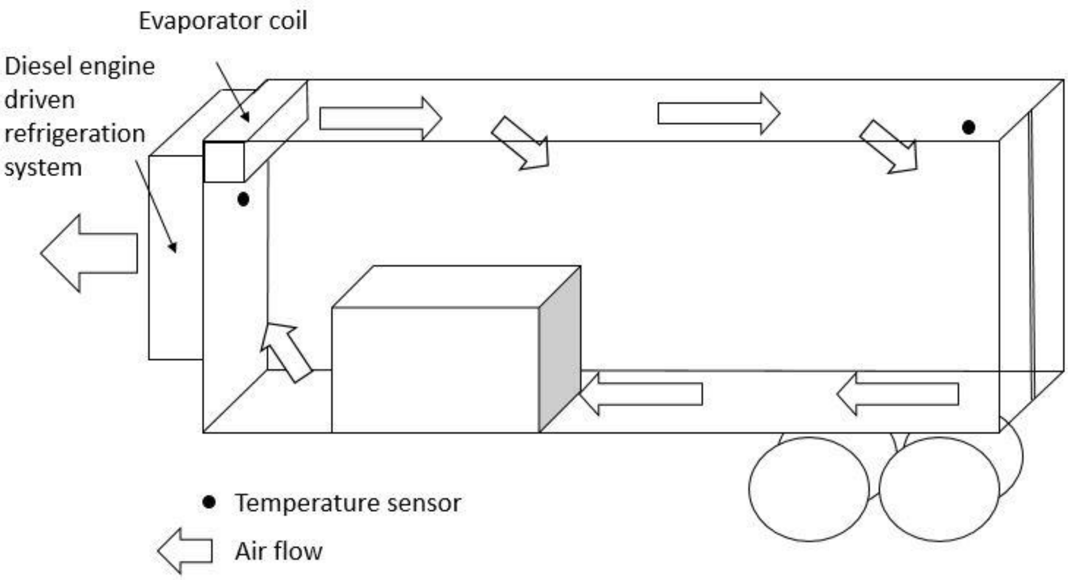
Picture 1. The energy loads that has influence on refrigerated trailer: 1. Solar radiation, 2. Transmission, 3. Infiltration, 4. Conduction from products, 5. Precooling the trailer.

Solar radiation heats up the surface of the trailer and that heat transfers inside the trailer. The effect of the solar radiation depends on the ambient and the material and the color of the surface. The cooling requirements of stationary trailer can be increased by 20 percent when exposed to the solar radiation. That is why aluminum plates and reflective paints are usually used on the surface of the refrigerated trailer to reduce the heat load gain from radiation. (Hadawey & Tassou 2009: 9.) The Transmission load is heat gain through conduction from the ambient temperature to the inside climate of the trailer. However, the conduction is limited to through the insulation around the trailer. The insulation standards are defined in ATP regulations. The heat conduction is based on the area of the surface of the trailer and the temperature difference between ambient temperature and internal temperature. Furthermore, the k-factor of insulation and the thickness is also needed to calculate the transmission load. (Elliston & Dennis 2009: 3–4.) The infiltration air load has notable heat losses especially in short distance distribution, where doors are open multiple times during the transport. The heat loss during door opening is difficult to calculate. When the doors are opened during the loading or un-loading of products the ambient air is mixed with the air inside the trailer and influences the internal climate. The influencing factors are the height and width of the open area and the temperature difference between internal air and ambient air. Product load is the heat transferred from the delivered products to internal air of the trailer. That heat must be decreased to achieve the products delivery temperature. In addition, the heat generated by the products is needed to reduce. The first load should be reduced as much as possible with precooling in the storage. Products that are improperly precooled produces a considerable heat and is increasing the load of the trailer unit. The heat generated by the products is related to the characteristics of the product. For example, perishable food products such as fruits and vegetables continues ripen during the delivery and this process produces heat to the surrounding air. (Vigneault, Thompson, Wu, Hui & LeBlanc 2009: 8–9.) The precooling load is the action to set the internal climate on the desired temperature before loading the products. In the precooling the inside air as well as the inner surface has to be cooled in right temperature. For this the mass of air and material of the surface is critical. After this, the needed refrigeration can be calculated from the desired temperature change. (Hadawey & Tassou 2009: 10.)

5.2 Refrigeration system

In the temperature controlled trucks the most in common refrigeration system is based on vapor compression. Mechanical refrigerator with vapor compression cycle provides multiple choices for compressor driver methods. The restrictions that refrigeration systems are required to overcome are related to weight, noise, maintenance requirements, and installation costs or environmental constrains. The two most used drive systems for refrigerated trucks are: auxiliary alternator unit and auxiliary diesel unit. Auxiliary alternator unit is driven by the traction engine, powering the refrigeration unit’s electrical motor, fan motors and other refrigerate unit’s appliances. The auxiliary diesel unit has a build in diesel motor inside the refrigeration unit and it powers the entire refrigeration system. In this system particle filters and catalyst can be used to decrease the emissions of the diesel engine. The auxiliary diesel unit is used in most medium and large vehicles. (Tassau et al. 2009: 1469.) The power of the refrigeration system is scaled with the trailer size, so that the defined temperature inside the trailer can be achieved (Kaapola, Hirvelä Jokela & Kianta 2011: 17–18).

The typical refrigeration system has one or several evaporator coils inside the trailer and one refrigeration unit outside the trailer. The number of evaporator coils depends on the inner layout of the trailer. If the trailer has only one compartment, only one evaporator is needed. However, if there is several compartments inside the trailer, each compartment needs also an evaporator coil. (Tassau et al. 2009: 1469.) Evaporator coils transfers refrigerated air to the trailer and absorbs the convection and infiltration heat back to evaporator coils. The heat from trailer is transferred outside with refrigerant where it released to the outside air. The heat transfer happens by the change of refrigerant from liquid to vapor. This implies to the name of vapor compression refrigeration system. The picture two illustrates the air flow and refrigeration systems installed to trailer. The outside refrigeration unit contains the engine that generates the power to the entire refrigeration system, and the outside evaporator coil that relieves the heat absorbed by the refrigerant. (Aittomäki, Alijoki, Hakala, Hirvelä, Kaapola, Mentula & Seinelä 2012: 269–270.) Trailer usually has at least two temperature sensors: one in front of the trailer and another in the back. However, depending on the specifications of the delivery and number of compartments the number of sensors can be much higher. The inside temperature is monitored throughout the delivery, however, a uniformed distribution of temperature is difficult to achieve in the trailer. (Tassau et al. 2009: 1470.)



Picture 2. Refrigeration system and air flow in and out the trailer.

6 STUDY METHODOLGY

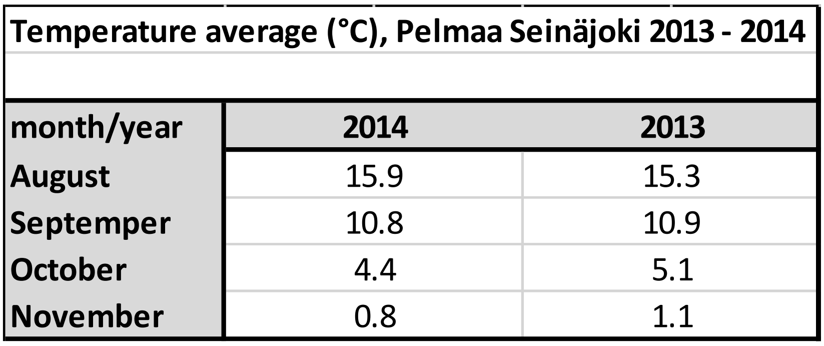
6.1 Case presentation

The case study data collection was conducted during November of 2014 and mostly during a night time. The data collected from the truck was measuring the inside temperature of the trailer. The delivered products were pre-cooled to the same temperature than trailer. During the distribution the temperature sensor collected momentarily temperatures in fixed time intervals throughout the delivery route. This case study data is the basis of the research and calculations conducted in this study.

6.1.1 Case routing

The collected temperature data were measured during the distribution route from factory or distribution center to retailers. For this kind of delivery routes it is characterized that there is multiple product un-loading stops and relatively short distances between retailers. This means that during the delivery the trailer’s doors is open often and the cargo is under the influence of ambient conditions. The ambient weather conditions changes considerably during the year and during the time of the day. The data collection was conducted during November, and the table two illustrates the average temperatures in Seinäjoki during months August to November. The temperatures has little variation between 2013 and 2014, which implies that the ambient conditions are not exceptional. However, the specific ambient temperature remained unknown so, in the heat and energy calculation the temperature estimation is made based on the ambient conditions in November. (Ilmatieteen laitos 2014.)

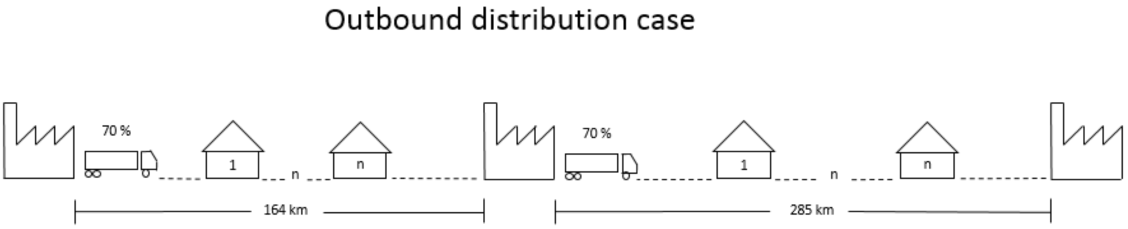
Table 2- The average temperature during autumn months in Seinäjoki, Pelmaa (2013 - 2014). (Ilmatieteen laitos 2014.)



Temperature average (°C), Pelmaa Seinäjoki 2013 - 2014

month/year	2014	2013
August	15.9	15.3
Septemper	10.8	10.9
October	4.4	5.1
November	0.8	1.1

According to the study conducted by GreenLC projects the delivery route of the temperature measured transport was loaded so that 70 percent of the trailer was full. After this the truck was send to the delivery route that was 164 km long in which time the whole cargo was delivered. The number of un-loading stops was un-known. After delivering all the products the truck returned back to the starting point for another cargo. The second delivery route was 285 km long and the whole cargo was distributed. However, the number of un-loading stops remained un-known. The delivery route finished again to the starting point. The entire distribution lasted approximately 12 hour (736 min). The temperature measured delivery was conducted in mid-November mostly during night time when the temperature and solar heat was lower. Before the actual temperature measurements, the cargo was estimated to be pre-refrigerated to the same temperature than the trailers’ body, so that no additional temperature changes occurred from the cargo or the trailer. The starting temperature for both was 2 ºC. The case routing is illustrated in the picture three.



Picture 3. Outbound distribution case. Illustration of the case routing: transportation length, un-loading stops, and product percentage of product loading.

6.1.2 Case vehicle

The vehicle used in the case study was a semi-trailer truck that was suitable for FNR certificated transports. The delivered products were kept in temperature between 0 ºC and 6 ºC targeting the mean temperature of 2 ºC. The Truck uses an auxiliary diesel unit to refrigerate the trailer and it is based on vapor refrigeration. The refrigeration power is generated from a standard diesel motor. The trailer had one temperature sensors that collected the data used in the case study.

6.1.3 Transported products

The content of the trailer was in this case unknown, however the product load was estimated to be un-perishable products so that no additional heat produced from the respiration breathing. The temperature inside the trailer was estimated to hold 2 ºC because the average temperature in the trailer was 1.8 ºC. This estimation had been made from the collected temperature data, which is shown in diagram one. The products was estimated to be precooled in the storage to a temperature of 2 ºC. This meant that no addition product load cooling is required during the outbound delivery.

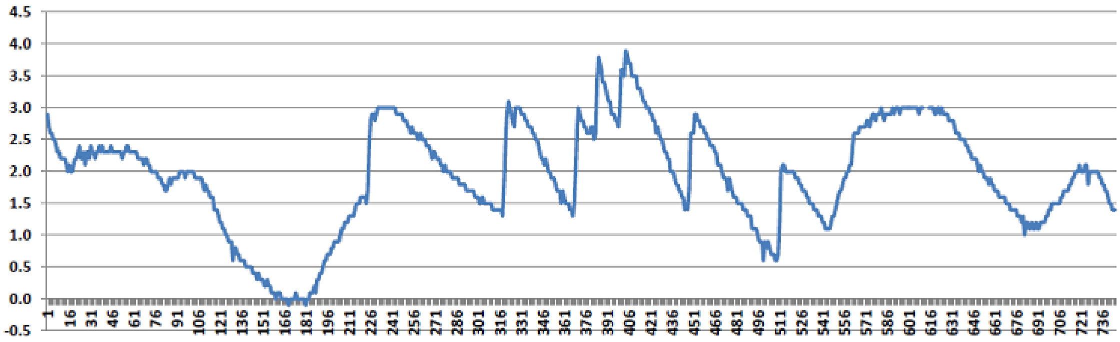


Diagram 1. GreenLC projects temperature measurement diagram. the temperature (in celsius) is on the verical axcel and the time (min) is in the horizontal axcel.

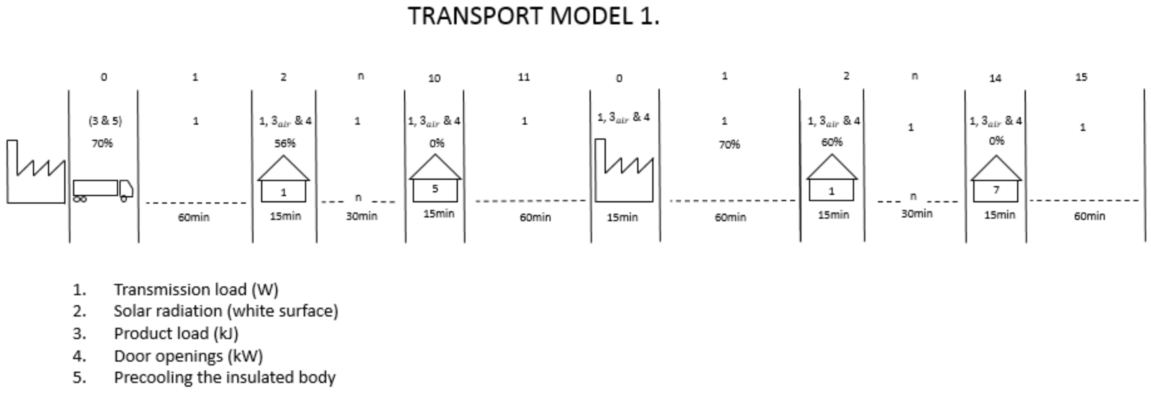
6.2 Modeling delivery routes based on the case study

To determinate the possibility of modeling energy consumption of an outbound transport two models were made. Both had mostly the same constrains, such as ambient conditions, delivery time and trailer features. In addition, some estimations had to be made to so that energy and heat calculations could have been conducted. Most of these estimations was identical between models, however some of them estimations needed alteration between the models one and two. The estimations changes considering the number of un-loading stops, the un-loading time and the time between the stops. On the contrary, the trailer measurements, insulation and door infiltration was estimated to be the same in both models. In addition, ambient conditions, such as weather, temperature and solar heat were estimated to be the same as well. Also, the total traveling time and climate inside the trailer were estimated to be the same in both models.

The model number one was constructed more closely to the possible routing of the actual case study route. For example, transport time periods, un-loading stops and timing between stops was arranged in more detail to estimate better the energy consumption of the case study. The model number two was more general and the estimations were not as detailed as in the model number one. This was due the fact that the case study routing was not clear in all details, and more general model was considered to give an illustration of the trailer heat loads and give another comparative for the whole study. The heat load calculations and the energy consumption calculations were based on in both of the models to ASHRAE Handbook (2006) refrigeration heat load equations. The heat loads were divided in five different loads that were considered to have major affect when calculating trailers total heat load. However, due the ambient conditions two of the heat loads were not used in the models. The first one was solar radiation load and the second one was precooling load both in the trailers body and in the cargo.

6.2.1 Routing model number one

In this model the basic idea was to design a routing the model for an outbound delivery that could represent closely the actual case study and its energy consumption. The model number one focus on to imitate the driving distance, the number of un-loading stops and un-loading time as closely as possible. In the picture four the model number one is illustrated more closely.



Picture 4. Illustration of the transport model one. The picture contains the sections of applied heat loads, numbers and time of the un-loadings and the cargo's decrease rate.

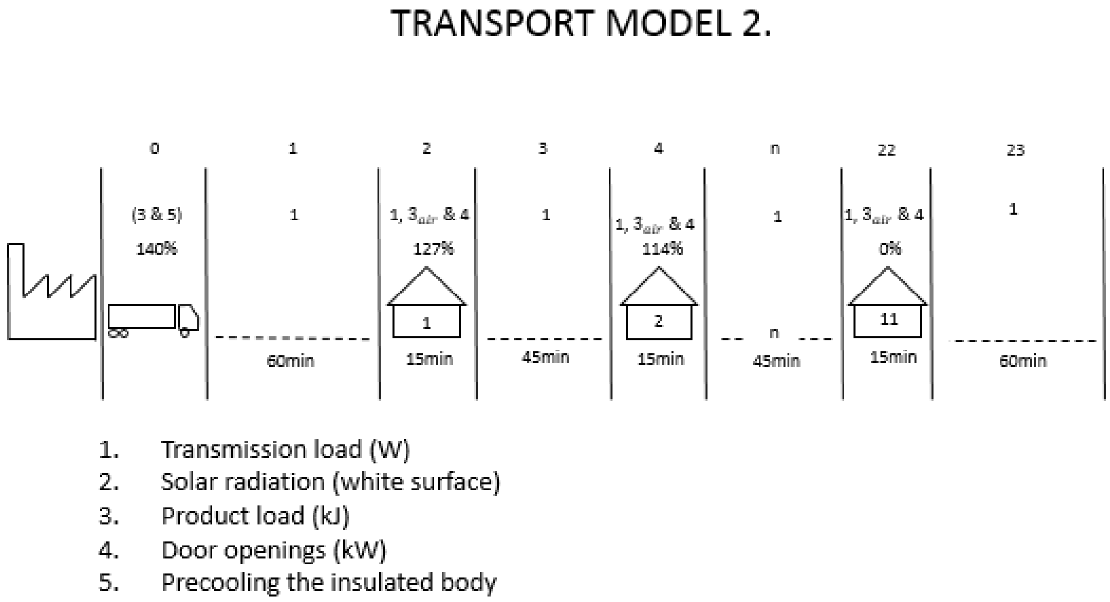
In the picture four, the first row from top illustrates the number of sections where heat load are added to the model. For example, in the Section “0” the truck is stationary on the factory’s loading dock and under the influence of precooling the trailers body. On the same section precooled cargo is loaded until the trailer is 70 percent full from the maximum capacity. However, in Section “0” the heat loads are inside brackets, which means that these loads were not took into the calculation. This is due the fact that neither of them were not in the temperature measurements of the case study. Under the section number is each heat load that is added during that section. The heat loads are numbered to ease the calculation and illustration of the model. The percentage number illustrates the loading changes at each point of the route. The houses represent the retailers or other un-loading stops and the number inside the house illustrates, which stops it is. The time presented in minutes is underneath the model.

The model number one took 736 minutes in total, which is approximately 12 hour in total. The delivery time was estimated to take place mostly at night time, according to the GreenLC Case study. The outside temperature was estimated to be 0 ºC. The route was divided in two parts, according to the GreenLC Case study, so that the first delivery was shorter and ended up back to the starting point. The travelled time from the factory (starting point) to first un-loading stop took 60 minutes. Also, from the last un-loading stop to the factory (ending point) the travelled time was 60 min. In between these were the rest of the un-loading stops distributed evenly so that between every stop was a 30 min travelling time. The un-loading stop took each time 15 minutes, and the cargo was un-loaded evenly to each stop. In the first part of the route there were 5 un-loading stops in total and the cargo was decreasing with rate of 14 presents in every stop. The second part of the route started also from the factory and the trailer was again loaded with 70 present of precooled products. The travelled time between the factory and the second first stop was again 60 minutes long, and after this the truck droves 30 minutes and un-loaded again 15 minutes. This second part was longer, as it was in the case study, and this time there were seven un-loading stops in total. This means that the un-loading rate of the cargo was 10 present in every stops. The entire route and modeling ended up with 60 minutes travel back to the factory.

In the model one the heat loads were divided according to the characteristics of each section. In the section one, that was the first section that was taken into account, there was 60 minutes of travelling and only one heat load. The transmission load (1) was effecting on the trailer during that time period. In the section 2, there was three heat loads that were influencing the trailer during 15 minutes. The heat loads was the transmission load (1), the product load (3) and infiltration load from door openings (4). The product load came from the replacement air of the un-loaded cargo, and the infiltration heat came from the time while doors were open. Based on this model a calculation was made to determinate what was a total energy used in the model one and how it was distributed throughout the delivery. This calculation is conducted and showed in details later on in this chapter.

6.2.2 Routing model number two

The second model was more simplified than the model number one. However, the same constrains and heat loads stayed the same. The same heat loads were added at the same way in the sections, for example, while travelling the trailer was only under the transmission load and during the unloading stops the product load from air and infiltration air was added to the loads that trailer had to cope with. The most radical changes was in cargo’s size, in the travelling time, un-loading time and in the number of un-loading stops. The picture five illustrates the model number two more closely.



Picture 5. Illustration of the transport model one. The picture contains the sections of applied heat loads, numbers and time of the un-loadings and the cargo's decrease rate.

In the model number two the heat loads were divided the same as they was in the model number one. However, in the model number two the total number of sections was altered to 23 and in the model number two the entire route was conducted with one delivery, without any additional product loading. This meant also that the entire routing was evenly distributed with un-loading stops and the travelled time between them. Furthermore, in this model the theoretical cargo load was doubled to imitate the known constrains of the case study and to minimize the heat load changes during the modelled route number two. This was due the original assumption that the un-loading stops in the case study were unknown and to minimize the route modeling effect on energy consumption the model number to was designed to be simple and continues throughout the model. The travelled time between un-loading stops was altered from 30 minutes to 45 minutes. The un-loading time was kept the same as in model number one and so was the travelled time in the first section and in the last section.

6.3 Calculations needed in the modeling

The heat load equations used in the model calculations were based on the ASHREA handbook (2006) calculations for refrigeration loads. All the heat loads that a trailer might be effect on were not applied in the models. This is due the ambient conditions of the case study where the estimations was made to the left out heat loads that has only little or no effect at all on the case study trailer. The left out heat loads were solar radiation load and trailer's precooling load. On the other hand, transmission load, Product load and infiltration load. Some additional estimations were made for the equations be pliable.

Transmission load is a heat load, which effects through trailers' body when the temperatures are different outside and inside the insulated trailer. The equation

$$Q_2 = \mathrm{U}A_t(T_o - T_i) \tag{1}$$

represent the heat energy gained from transmission in watts (W). The U is the overall heat transfer coefficient (W/m²K), A_t is the total area of trailers surface (m²). T_o is the ambient temperature outside the trailer in Kelvin (K) and T_i is the inside temperature of the trailer in Kelvin (K). The heat transfer coefficient is calculated from an equation

$$\mathrm{U} = \frac{1}{\frac{x_i}{k_i}+\frac{1}{c_i}+\frac{1}{c_o}}, \tag{2}$$

where the x_i is the thickness of the insulated body in meters (m). The k_i is the thermal conductivity of insulation material and in model calculations it is the ATP-certified FRC factor 0.4 W/mK. Inside surface conductance c_i and outside conductance c_o are based on ASHRAE handbooks' (2006) calculations. In the model calculations c_i is 1.6 W/m²K and c_o is 8.8 W/m²K.

In the model one and two the product load is calculated when products are un-loaded and the empty space is filled with outside air. In addition, the energy required to alter the air temperature in the GreenLC case study was also calculated with the product load equation

$$Q_3 = C_p V \rho (T_o - T_i), \tag{3}$$

where C_p is the specific heat of air inside the trailer (kJ/kgK). Volume V is the space inside the trailer (m^3) and ρ is the density of air in the trailer (m^3/kg). The temperature change is calculated from the outside temperature minus the inside temperature (K).

The infiltration load is added to the models when estimated un-loading stops are occurring and the door ways are open. At this point the outside air is mixed up with trailers' inside air and altering the temperature inside the trailer. This requires work (W) to rebalance the target temperature. The infiltration load is calculated from an equation

$$Q_4 = q D_t D_f (1 - E), \tag{4}$$

where q is the infiltration load. D_t is the door open-time factor, D_f is the doorway flow factor and E is the factor of the effectiveness of the doorways protective device. The doorway flow D_f estimated to be 1.1 in the model calculations and the estimation is based on Downing and Meffert (1993) founding's. The effectiveness of doorway protective factor E is estimated to be 0.8, which is typical for temperature controlled trailers (ASHRAE Handbook 2006). The infiltration load q is calculated from an equation

$$q = 0{,}221 A_d (h_i - h_r) \rho_r \sqrt{\left(1 - \frac{\rho_i}{\rho_r}\right)} \sqrt{(gH)} F_m\ , \tag{5}$$

where A_d is the area of doorway, the h_i is the enthalpy of infiltration air and the h_r is the enthalpy of refrigerated air (kJ/kg). The ρ_r is the density of a refrigerated air and the ρ_i

is the density of infiltration air (m^3/kg). The g is the gravitation constant (9.81 m/s^2) and the H is the height of the trailers door. Furthermore, the density factor F_m is calculated from an equation

$$F_m = \left(\frac{2}{1+\sqrt[3]{\left(\frac{\rho r}{\rho_i}\right)}}\right)^{1,5}, \tag{6}$$

where ρ_r and ρ_i are again the enthalpies of refrigerated and infiltrated air. The door opening time factor D_t is calculated from an equation

$$D_t = \frac{P\theta_p - \theta_o}{3600\theta_d}, \tag{7}$$

where P is the number of doorway passages, the θ_p is the door open and closing time in seconds (s). The θ_o is the time when the door is fully open (s) and the θ_d is the total time of the delivery (s).

7 CALCULATIONS AND RESULTS

7.1 Case study calculations

The temperature measurements made by GreenLC projects were used as a data source to have a reliable comparison for the two models. However, the temperature measurements needed to be changed to energy loads before further comparison could be made. This meant that the measurement data needed to be changed so that energy used for cooling and heating the trailer could be calculated. The temperature values was read from the data source in 15 minute intervals from which a diagram two was made of.

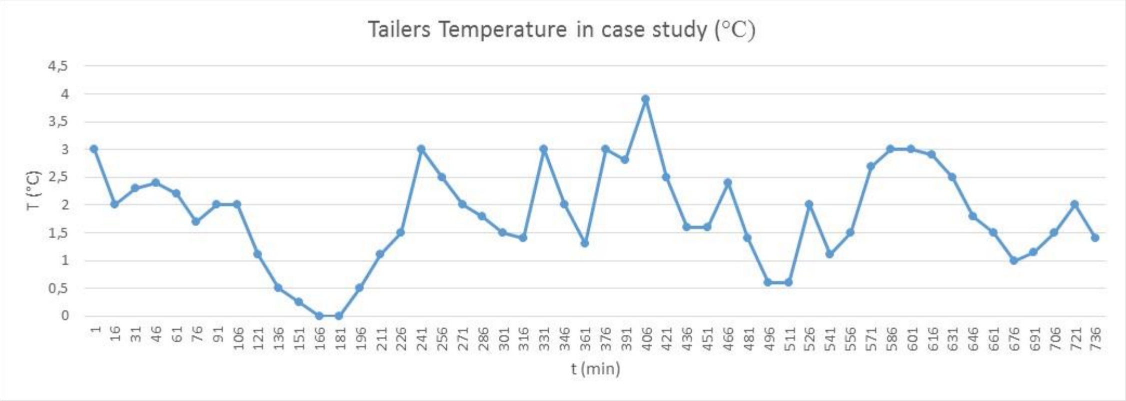


Diagram 2. Case study. Trailer temperature's in 15 min intervals.

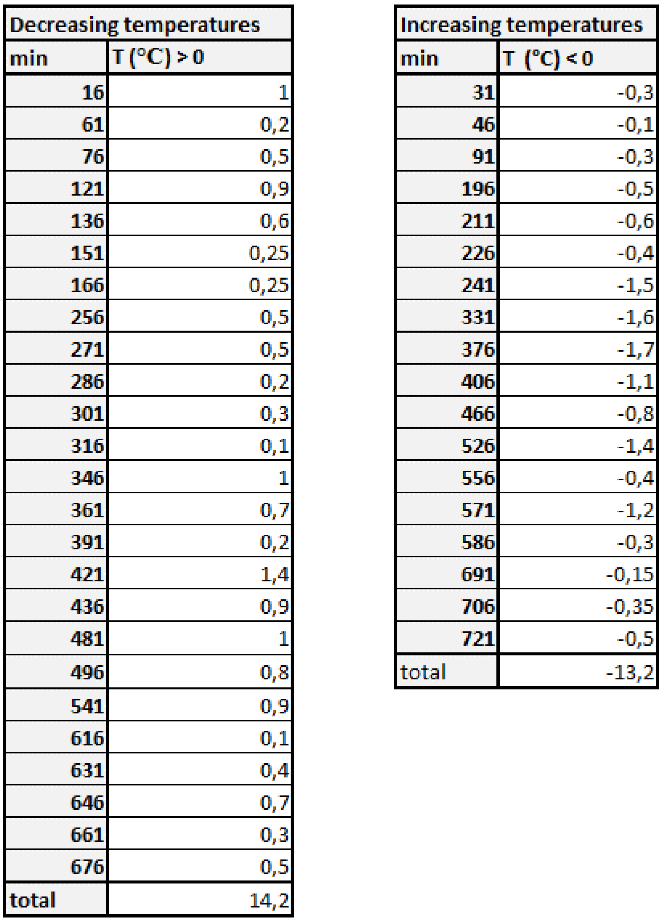
From the diagram two can be seen that the temperatures changes throughout the case study delivery and the temperatures are between 0 °C and 4 °C averaging close to 2 °C, which is used later on in the model calculations. The entire delivery continued 736 minutes in total and the temperature measurements were conducted for the entire time.

In order to calculate the energy used in the case study delivery the temperature changes were calculated in the 15 minute intervals. In the equation eight is shown an example how the calculation was made.

$$T_n - T_{n+15} = \Delta\mathrm{T}, \qquad (8)$$

where the T_n is the temperature at the time (t) point n minute and the T_{n+15} is the temperature at point 15 minutes after time point n. This calculation was conducted throughout the measured temperatures and as a result two tables were made. In the table three are collected all the temperature changes (ΔT) together. On the left is collected all the temperature changes that are decreasing and on the right all the temperature changes where delta T (ΔT) is increasing.

Table 3. Case study temperature changes during the delivery. On the left are the time periods where temperature is decreasing and on the left time periods where temperature is increasing (T_n - T_(n+15)).

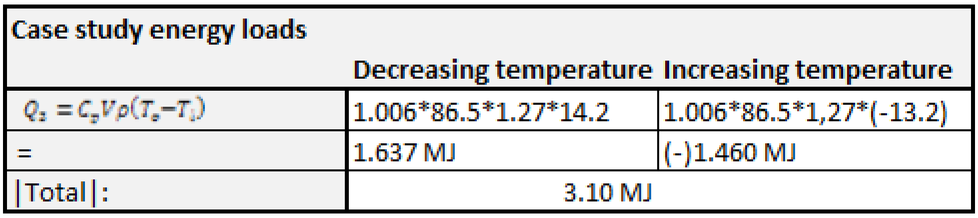


Decreasing temperatures	
min	T (°C) > 0
16	1
61	0,2
76	0,5
121	0,9
136	0,6
151	0,25
166	0,25
256	0,5
271	0,5
286	0,2
301	0,3
316	0,1
346	1
361	0,7
391	0,2
421	1,4
436	0,9
481	1
496	0,8
541	0,9
616	0,1
631	0,4
646	0,7
661	0,3
676	0,5
total	14,2

Increasing temperatures	
min	T (°C) < 0
31	-0,3
46	-0,1
91	-0,3
196	-0,5
211	-0,6
226	-0,4
241	-1,5
331	-1,6
376	-1,7
406	-1,1
466	-0,8
526	-1,4
556	-0,4
571	-1,2
586	-0,3
691	-0,15
706	-0,35
721	-0,5
total	-13,2

From the table three it is possible to calculate the energy loads that are needed to cool and heat the air inside the trailer. The calculation was made based on the product load equation (3) for air. The entire case study temperature calculations can be seen in the attachment three.

Table 4. Case study energy loads: Decreasing temperature and increasing temperature.



Case study energy loads		
	Decreasing temperature	**Increasing temperature**
$Q_3 = C_p V \rho (T_e - T_i)$	1.006*86.5*1.27*14.2	1.006*86.5*1,27*(-13.2)
=	1.637 MJ	(-)1.460 MJ
|Total|:	3.10 MJ	

The total energy for temperature decrease was calculated in the following as illustrated in table four. In the table four the degreased and increased temperature energy loads were calculated with C_p and ρ values when air temperature is 0 °C. From the table four can be seen that when the temperature is decreasing in the trailer the total energy needed to cool the air is 1.637 MJ and when the temperature is increasing in the trailer the energy load for that was 1.460 MJ. The total amount of energy needed for cooling and heating the trailers air was approximately 3.10 MJ. The temperature calculations was important to conduct in both ways because it was un-known in the case study did the trailer needed to be heated up or cooled down during the delivery.

The energy load needed for the case study can be also presented in a cumulative form, where the individual energy loads are calculated according to the 15 minute intervals. Based on the table three the cooling energy and the heating energy were calculate separately. However, to maintain the 736 minute time period in both calculations the opposed temperature change was interpreted as a zero. This due the estimation that when for example cooling energy is calculated, possible temperature rises do not change the cooling energy at the selected time period. When temperature is increasing in the trailer, no cooling energy is applied.

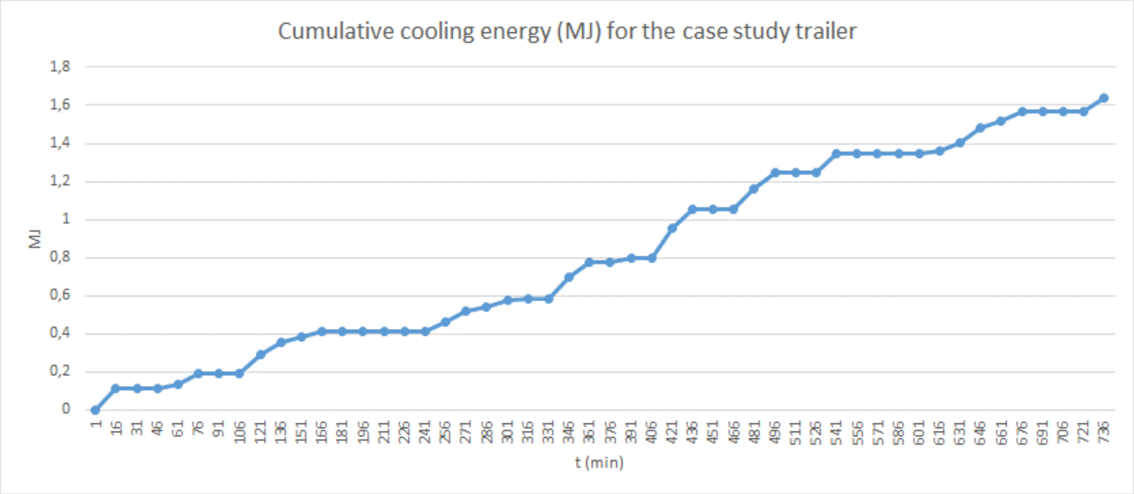


Diagram 3. The cumulative cooling energy in MJ calculated for the case study's temperature decreasing.

The diagram three shows the cumulative cooling energy for the case study trailer. The cumulative cooling energy is increasing throughout the delivery towards the calculated total of 1.637 MJ. However, in the diagram three there is notable increases in the energy consumption, which can be seen as small spikes in the diagram. This illustrates the need of relative high increase of the cooling energy in selected time periods. Furthermore, between the time periods 331 minute and 556 minute a rapid increase of cooling energy consumption can be detected.

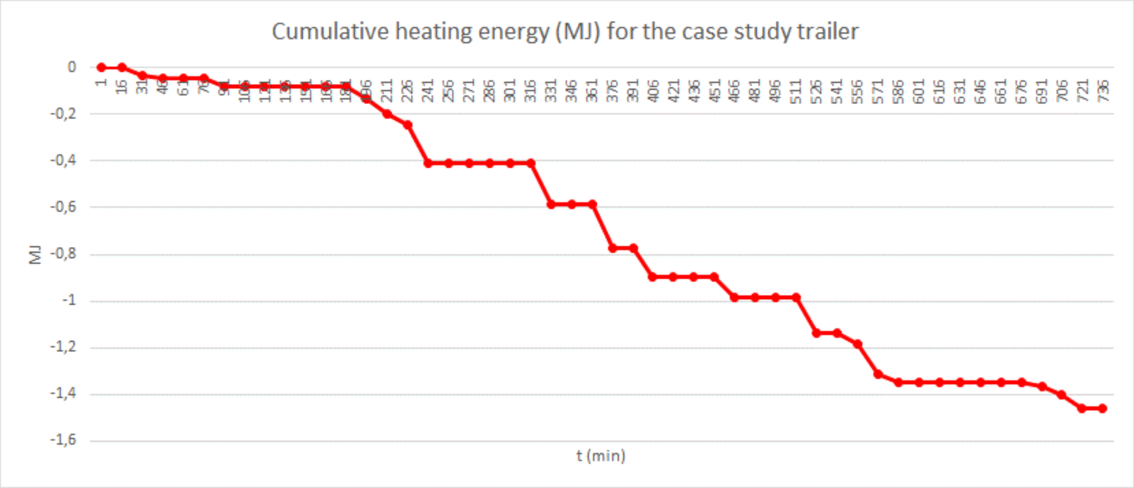


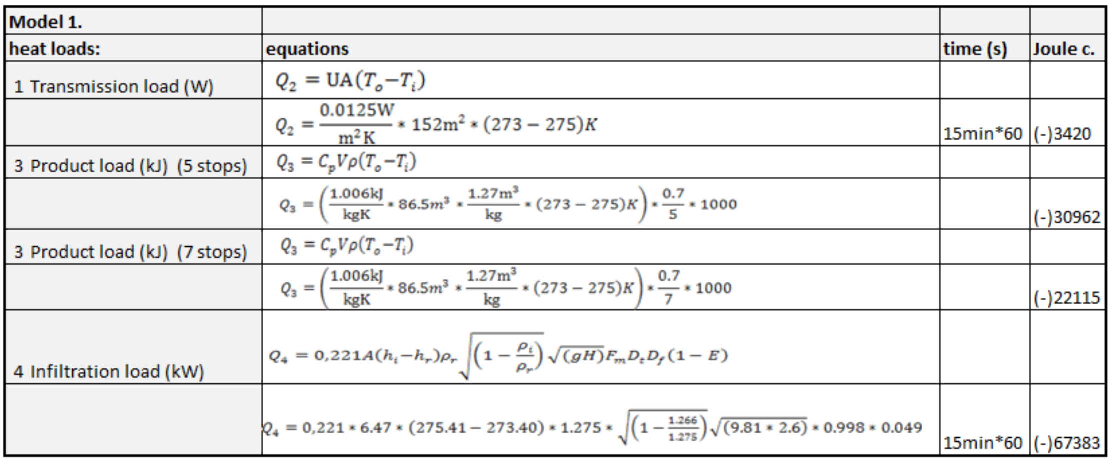
Diagram 4. The cumulative cooling energy in MJ calculated for the case study's temperature increasing.

In the diagram four can be seen the cumulative change of the heating energy that was needed to the temperature increases during the case study delivery. The cumulative heating energy is increasing throughout the delivery towards the calculated total of (-) 1.460 MJ. Furthermore, in the diagram four there is also a notable increases in the energy consumption, which can be seen as small spikes in the diagram. This illustrates the need of relative high increase of the heating energy in selected time periods. In addition, between the time periods 326 minute and 541 minute a rapid increase of heating energy consumption can be detected and slower increase in beginning and in the end of the case study delivery. The heating energy is shown here as a negative value, this is only due the assumption that cooling energy is positive.

7.2 Calculations in model number one

The model number one calculations was based on the heat load equations from ASRHAE Handbook (2006), the GreenLC project's case study and the routing model designed from that (picture three). The used equations was the transmission load (1), Product load (3) and Infiltration load from door opening (4). The equations that were not taken into account was precooling load and solar radiation load. The calculations were based on the routing model number one. The heat load calculations were divided between 15 minute intervals and the total time was 736 minutes. In the model number one was 12 un-loading stops, one reloading stop and 37 traveling intervals in total. In the table five is shown the calculations on the 15 minute un-loading stop.

Table 5. Calculations in model number one. The heat load calculations in a 15 minutes period.

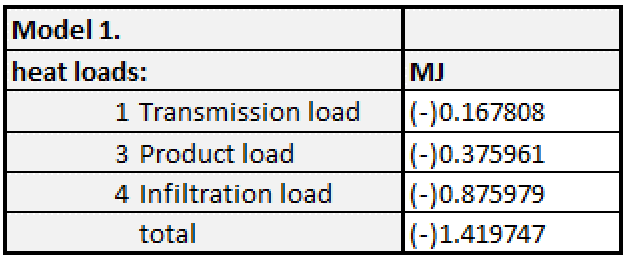


Model 1.			
heat loads:	**equations**	**time (s)**	**Joule c.**
1 Transmission load (W)	$Q_2 = \mathrm{UA}(T_o - T_i)$		
	$Q_2 = \frac{0.0125\mathrm{W}}{\mathrm{m^2K}} * 152\mathrm{m}^2 * (273 - 275)K$	15min*60	(-)3420
3 Product load (kJ) (5 stops)	$Q_3 = C_p V \rho (T_o - T_i)$		
	$Q_3 = \left(\frac{1.006\mathrm{kJ}}{\mathrm{kgK}} * 86.5m^3 * \frac{1.27\mathrm{m}^3}{\mathrm{kg}} * (273 - 275)K\right) * \frac{0.7}{5} * 1000$		(-)30962
3 Product load (kJ) (7 stops)	$Q_3 = C_p V \rho (T_o - T_i)$		
	$Q_3 = \left(\frac{1.006\mathrm{kJ}}{\mathrm{kgK}} * 86.5m^3 * \frac{1.27\mathrm{m}^3}{\mathrm{kg}} * (273 - 275)K\right) * \frac{0.7}{7} * 1000$		(-)22115
4 Infiltration load (kW)	$Q_4 = 0{,}221A(h_i - h_r)\rho_r \sqrt{\left(1 - \frac{\rho_i}{\rho_r}\right)} \sqrt{(gH)} F_m D_t D_f (1 - E)$		
	$Q_4 = 0{,}221 * 6.47 * (275.41 - 273.40) * 1.275 * \sqrt{\left(1 - \frac{1.266}{1.275}\right)} \sqrt{(9.81 * 2.6)} * 0.998 * 0.049$	15min*60	(-)67383

In the model number one calculations the ambient air and the trailers inside air was estimated to have two decrease difference in temperatures. Based on this the air enthalpy and density values were selected. The selected temperatures was $T_o = 0$ and $T_i = 2$. The transmission load during a 15 minutes time was (-)3420 Joules, where to production load was calculated to be (-)30962 Joules with five on-loading stops and with seven un-loading stops it was (-)22115 Joules. The infiltration load from door openings was calculated to be (-)67383 Joules. The negative values indicates which way the energy appears to be moving, and when the outside temperature is estimated to two decrease higher the energy is moving out of the trailer. However, this does not have effect on the quantity of energy. The entire model calculation can be seen in the attachment one.

In the table number six is shown the total sums of heat loads during the model number one calculations. The total energy needed for model number one was approximately (-) 1.42 MJ. The transmission load in model number one was approximately (-)0.17 MJ, the product load was approximately (-)0.37 MJ and the infiltration load was approximately (-)0.88 MJ.

Table 6. The calculations in model number one. The total energy of the heat loads and their sum.



Model 1.	
heat loads:	**MJ**
1 Transmission load	(-)0.167808
3 Product load	(-)0.375961
4 Infiltration load	(-)0.875979
total	(-)1.419747

In the diagram five is illustrated the cumulative heating energy that was calculated for model number one. In the horizontal axle is the modelled routing time in 15 minutes intervals and in the vertical axle is the energy in mega Joules (MJ). In the diagram five can be seen that the amount of heating energy required increases throughout the model calculation in frequent spikes with the exception of the beginning, end and the time periods between 271 minutes and 406 minutes.

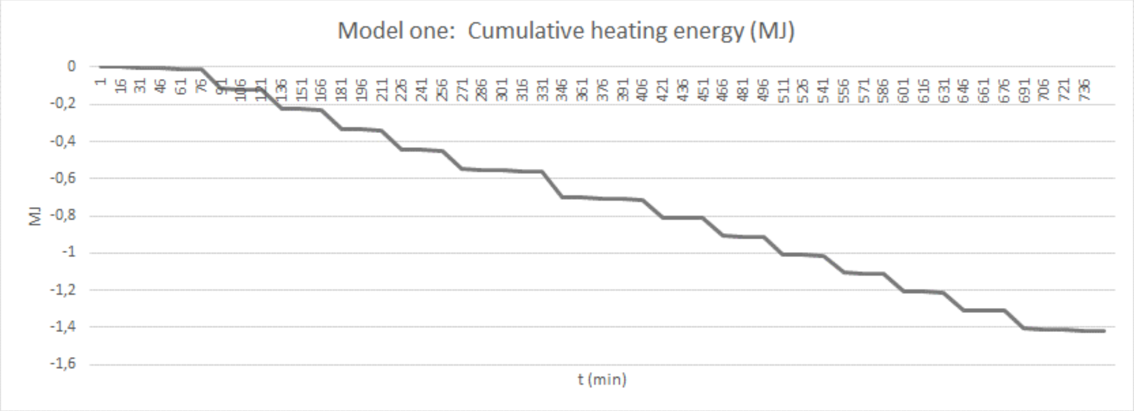
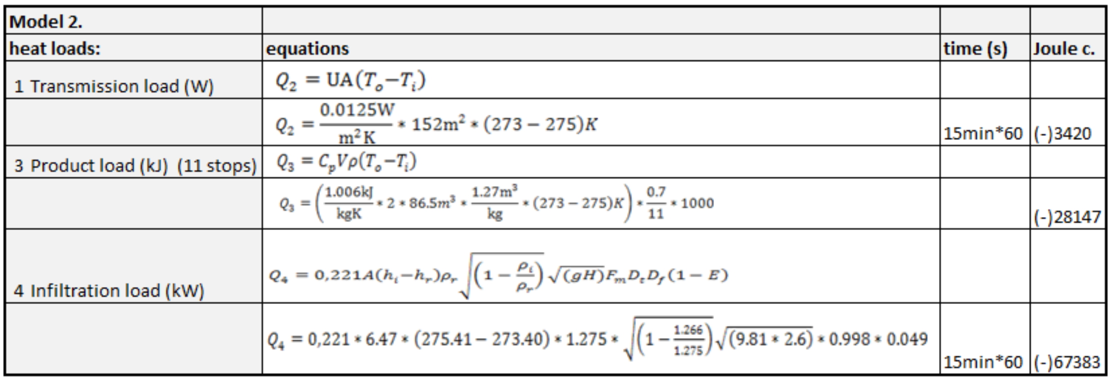


Diagram 5. The cumulative heat load energy of model number one. In the vertical axle is the energy in MJ and in the horizontal axle the modelled duration of time.

7.3 Calculations in model number two

The model number two calculations were based on the routing model number two. The heat load equations used in the model number two was the transmission load (1), Product load (3) and Infiltration load from door opening (4). The equations that were not taken into account was precooling load and solar radiation load. The calculations were based on the routing model number one. The heat load calculations were divided between 15 minute intervals and the total time was 736 minutes. In the model number two was 11 un-loading stops and 39 traveling intervals in total. In the table seven is shown the calculations on the 15 minute un-loading stop.

Table 7. Calculations in model number two. The heat load calculations in a 15 minutes period.

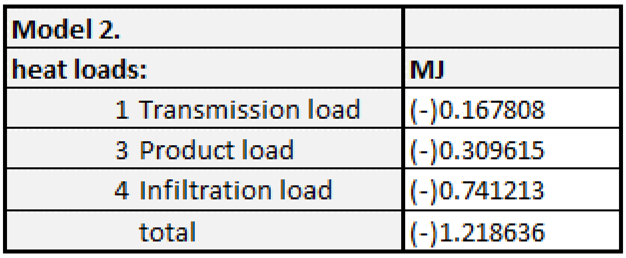


Model 2.			
heat loads:	**equations**	**time (s)**	**Joule c.**
1 Transmission load (W)	$Q_2 = \mathrm{UA}(T_o - T_i)$		
	$Q_2 = \frac{0.0125\mathrm{W}}{\mathrm{m^2K}} * 152\mathrm{m}^2 * (273 - 275)K$	15min*60	(-)3420
3 Product load (kJ) (11 stops)	$Q_3 = C_p V \rho (T_o - T_i)$		
	$Q_3 = \left(\frac{1.006\mathrm{kJ}}{\mathrm{kgK}} * 2 * 86.5m^3 * \frac{1.27\mathrm{m}^3}{\mathrm{kg}} * (273 - 275)K\right) * \frac{0.7}{11} * 1000$		(-)28147
4 Infiltration load (kW)	$Q_4 = 0{,}221A(h_i - h_r)\rho_r \sqrt{\left(1 - \frac{\rho_i}{\rho_r}\right)} \sqrt{(gH)} F_m D_t D_f (1 - E)$		
	$Q_4 = 0{,}221 * 6.47 * (275.41 - 273.40) * 1.275 * \sqrt{\left(1 - \frac{1.266}{1.275}\right)} \sqrt{(9.81 * 2.6)} * 0.998 * 0.049$	15min*60	(-)67383

In the model number two calculations the ambient air and the trailers inside air was estimated to have also two decrease difference in temperatures. Based on this the air enthalpy and density values were selected. The selected temperatures was $T_o = 0$ and $T_i = 2$. The transmission load during a 15 minutes time was (-) 3420 Joules, where to production load was calculated to be (-) 28147 Joules. The product load was divided into 11 parts. In addition the cargo was doubled, as in the case study, and evenly distributed throughout the delivery. The infiltration load from door openings was calculated to be (-) 67383 Joules. The negative values indicates which way the energy appears to be moving, and when the outside temperature is estimated to two decrease higher the energy is moving out of the trailer. However, this does not have effect on the quantity of energy. The entire model calculation can be seen in the attachment two.

In the table number eight is shown the total sums of heat loads during the model number two calculations. The total energy needed for model number one was approximately (-) 1.22 MJ. The transmission load in model number one was approximately (-) 0.17 MJ, the product load was approximately (-) 0.31 MJ and the infiltration load was approximately (-) 0.74 MJ.

Table 8. The calculations in model number two. The total energy of the heat loads and their sum.



Model 2.	
heat loads:	**MJ**
1 Transmission load	(-)0.167808
3 Product load	(-)0.309615
4 Infiltration load	(-)0.741213
total	(-)1.218636

In the diagram six is illustrated the cumulative heating energy that was calculated for model number two. In the horizontal axle is the modelled routing time in 15 minutes intervals and in the vertical axle is the energy in mega Joules (MJ). In the diagram six can be seen that the amount of heating energy required increases throughout the model calculation in frequent spikes.

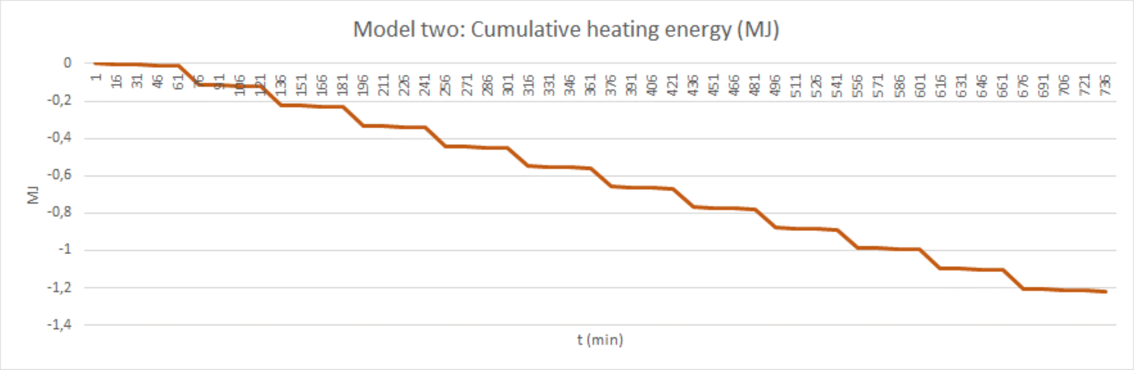


Diagram 6. The cumulative heat load energy of model number two. In the vertical axle is the energy in MJ and in the horizontal axle the modelled duration of time.

7.4 Equivalent CO_2 emission calculations

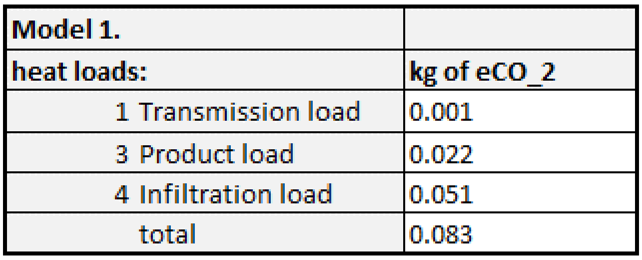
Based on the energy calculations of the case study and the models an estimation of the CO_2 emission could have been made. According to the table one a liter of diesel produces approximately 2.63 kilograms of equivalent CO_2 emissions. Diesels density (ρ_d) is 0.85 kg/dm³ and the fuel economy of a diesel motor is typically 40 percent. (Alakangas 2000: 150–154.) Furthermore, the refrigeraion units Coefficiency of Performance (COP) value was estimated to be 2 (Liikala 2015). Based on this an equation for produced equivalent CO_2 emissions is

$$P_{co2} = \frac{QE_{co2}(1+(1-E_f))}{E_d \rho_d COP}, \tag{9}$$

where the P_{co2} is the produced equivalent CO_2 emissions (kg). The Q is the energy heat load (MJ) calculated from the Case study and from the designed models. The E_{co2} is the factor for equivalent CO_2 emissions in kilograms produced by one liter of diesel fuel (CO_2/kg/dm³). Furthermore, the E_f represent the fuel efficiency factor of a diesel motor and the E_d is the energy density for the diesel fuel (43.1 MJ/kg). The ρ_d is the density (g/dm³) of diesel fuel and COP is the Coefficiency of Performance value. Based on the equation nine calculations for produced equivalent CO_2 emissions was made separately for the designed models.

In the table nine is shown the results of the model number one's equivalent CO_2 emissions for all the calculated heat loads. The energy needed for transmission load produced approximately 0.001 kilograms of equivalent CO_2 emissions, the energy needed for the product load produced approximately 0.022 of equivalent CO_2 emissions and the energy needed for the infiltration load produced approximately 0.051 kilograms of equivalent CO_2 emissions. In total the model number one produced approximately 0.083 kilograms of equivalent CO_2 emissions.

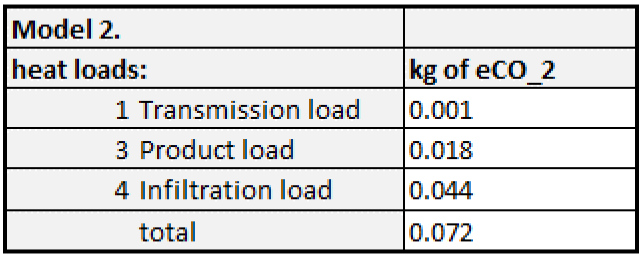
Table 9. The produced equivalent CO_2 emissions in kilograms for the energy needed in heat loads in the model number one when used a diesel fuel and powered by diesel engine.



Model 1.	
heat loads:	**kg of eCO_2**
1 Transmission load	0.001
3 Product load	0.022
4 Infiltration load	0.051
total	0.083

In the table 10 is shown the results of the model number two's equivalent CO_2 emissions for all the calculated heat loads. The energy needed for transmission load produced approximately 0.001 kilograms of equivalent CO_2 emissions, the energy needed for the product load produced approximately 0.018 of equivalent CO_2 emissions and the energy needed for the infiltration load produced approximately 0.044 kilograms of equivalent CO_2 emissions. In total the model number one produced approximately 0.072 kilograms of equivalent CO_2 emissions.

Table 10. The produced equivalent CO_2 emissions in kilograms for the energy needed in heat loads in the model number two when used a diesel fuel and powered by diesel engine.



Model 2.	
heat loads:	**kg of eCO_2**
1 Transmission load	0.001
3 Product load	0.018
4 Infiltration load	0.044
total	0.072

Hao, Yu, Song & Xu (2009: 237) conducted a research where fuel consumptions and emissions was measured for truck trailers. The average consumption of diesel was calculated to be 18.6 liters per 100 kilometer. This result is used to calculate the case study truck's energy consumption and equivalent CO_2 emissions. The equation is

$$P_{CO2\ truck} = E_{DA}\frac{d}{100}E_{CO2}, \tag{10}$$

where $P_{CO2\ truck}$ is the equivalent CO_2 emissions produced by the truck engine in the case study. E_{DA} is the average diesel consumption per 100 kilometers (dm³/100km) and d is the distance (km) that truck travelled during the case study. E_{CO2} is the factor for equivalent CO_2 emissions in kilograms produced by one liter of diesel fuel (CO_2/kg/dm³). The average consumption of diesel was 18.6 dm³/100km, the total distance travelled in case study was 449 km and the E_{CO2} was 2.63 CO_2/kg/dm³, which gives approximately the total of 220 CO_2/kg.

8 DISCUSSION

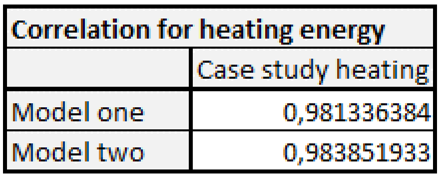
In the task of solving the temperature controlled outbound transport modeling possibilities the main questions was to define the important heat loads that are effecting the transport and the modeling. Is it possible to determine the energy consumption based on the case study temperature measurements and can a model be designed based on the outbound transport of the case study? Furthermore, is it possible to define how much CO_2 emissions the modelled delivery would produce based on the energy calculations?

The case study energy calculations were simply calculated from the temperature measurements with product load equation. Although, some estimations need to be done concerning the specifications of the trailer and the cargo. Furthermore, the actual heat change process was not clear so an energy calculations was made for both increased temperature and decreased temperature. This required additional designing for the model calculations and model routing so that both situations could have been possible.

Defining the important heat loads that an outbound trailer would undergo were selected based on the GreenLC project's case study and the principles presented by Aitomäki et all (2012) and Tassou et all (2004), and the studies made by ASHRAE handbook (2006). According to this authors all the important heat load was taken into an account when considering heat loads throughout the outbound delivery. The calculated energy consumptions in the model number one and in the model number two compared to the case study heat loads shows that close to similar total energy results can be calculated by adding theoretical heat loads together and calculating energy consumption from actual case study measurements. The energy consumptions were not high approximately between 1.2 MJ and 1.6 MJ. This is due the fact that the temperature differences were not high either, which did not increase the energy consumption. Furthermore, the correlation presented in the table 11 and the cumulative heat loads in diagram seven shows that also the designed models one and two are closely related to the case study.

In the table 11 can be seen that the modelled heating energies for model one and two has a good correlation factors. The model on has correlation factor of 0.981 with case studies heating energy and model two has a correlation factor of 0.984, where correlation factor 1.0 would represent total correlation. However, the model number two has even higher correlation with case study heating than the model number one, which was considered to be modeled more closely to simulate the specifications of the actual case study.

Table 11. The correlation factor between models and the cumulative heating energy of case study.



Correlation for heating energy	
	Case study heating
Model one	0,981336384
Model two	0,983851933

In the diagram 7 can be seen the cumulative heating loads that were calculated for the case study, model number one and to the model number two. The spikes of increased requirement of heating energy can be identified based on the models calculations. Therefore, the spikes can be recognized as an infiltration heat from door openings and production load from ambient air. Similar spikes can be seen in the cumulative case study heating energy loads. However, it is not certain that these spikes are from door openings and production load changes, even though, some of the spikes are very similar that in the models. More information would be required to identify the un-loading stops from the case study.

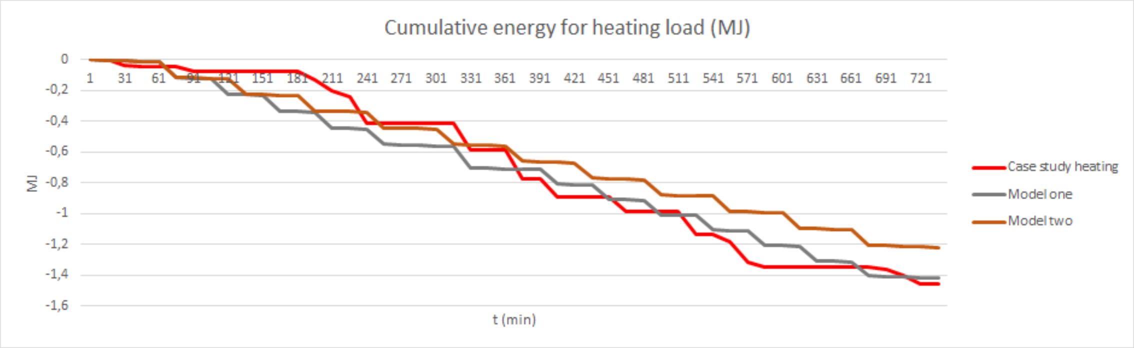
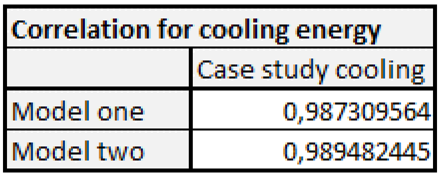


Diagram 7. The cumulative energies for heating loads: Model one, Model two and Case study calculations in heating energy. Vertical axles shows the energy consumption in mega joules (MJ) and horizontal axels shows the time duration in minutes (min).

In the case of cooling the trailers inside air the models cooling energy calculations was conducted simply reversing the reversing the climate conditions between inside air of the trailer and the ambient outside air. The table 12 shows that the modelled cooling energies for the model one and two has also a good correlation factors. The model on has correlation factor of 0.987 with the case studies cooling energy and model two has a correlation factor of 0.989 when total correlation would be 1.0. Again the model number two has even higher correlation with case study cooling than the model number one, which was considered to be modeled more closely to simulate the specifications of the actual case study. However, the models one and two has both a higher correlation with the case study cooling requirement that with the heating requirement.

Table 12. The correlation factor between models and the cumulative cooling energy of case study.



Correlation for cooling energy	
	Case study cooling
Model one	0,987309564
Model two	0,989482445

The cumulative cooling energy between the models and the case study is shown in the diagram eight. The spikes of increased requirement of cooling energy can be identified based on the models calculations. The spikes can be recognized as an infiltration heat from door openings and production load from ambient air, which in this case means warmer air mixing up with the trailers air and replacing the empty spaces. Similar spikes can be seen in the cumulative case study cooling energy loads. However, it is not certain that these spikes are from door openings and production load changes, even though, some of the spikes are very similar that in the models. More information would be required to identify the un-loading stops from the case study.

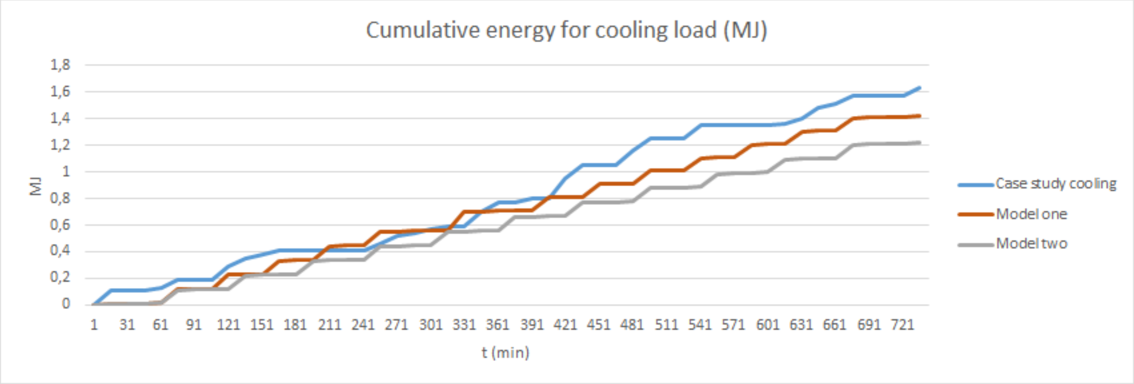


Diagram 8. The cumulative energies for cooling loads: Model one, Model two and Case study calculations in heating energy. Vertical axles shows the energy consumption in mega joules (MJ) and horizontal axels shows the time duration in minutes (min).

The equivalent CO_2 emissions calculations was based on the energy consumption calculated from the models. The amount of produced emissions were not considerable high due the fact that energy consumption was also modest. The total amount of equivalent CO_2 emissions calculated for entire delivery was between 0.083 and 0.072 kilograms depending on the model. However, the un-loading stops and door opening produced a significant amount of the equivalent CO_2 emissions in both models. The model number one produced approximately 62 percent of the trailer total emissions and in the model number two the percentage was approximately 61 percent. Furthermore, based on the modeling calculations infiltration load produces a significant amount of the delivery's equivalent CO_2 emissions. However, if we consider the equivalent CO_2 emissions produced by truck, the trailer emissions are insignificantly small. In these ambient conditions the equivalent CO_2 emissions produced by trailer compared to trucks emissions was in the heating process approximately 0.0003 percent and in cooling process approximately 0.0004 percent.

In a general contexts the ambient conditions of this case study are not common. The trailer temperature and ambient temperature difference would be more severe in many more cases. Therefore a more practical and general example calculation was added. If the modeling case is presented from global point of view, the temperature difference between ambient conditions and trailers inside climate would be more likely considerable larger. An estimation was made from this to illustrate the more general situation of the energy loads that were modelled and the equivalent CO_2 emission consumption in higher ambient temperatures. In the nine is shown the cumulative energy for cooling load of model number one and model number two in ambient temperature 22 °C. The model number one uses approximately 37 MJ during the modelled delivery. The model number two uses approximately 32 MJ of energy in 22 °C ambient temperature. This increase of cooling energy are solely related to the temperature change and with 20 ºC increase in temperature the model number one and two uses over 26 times more cooling energy.

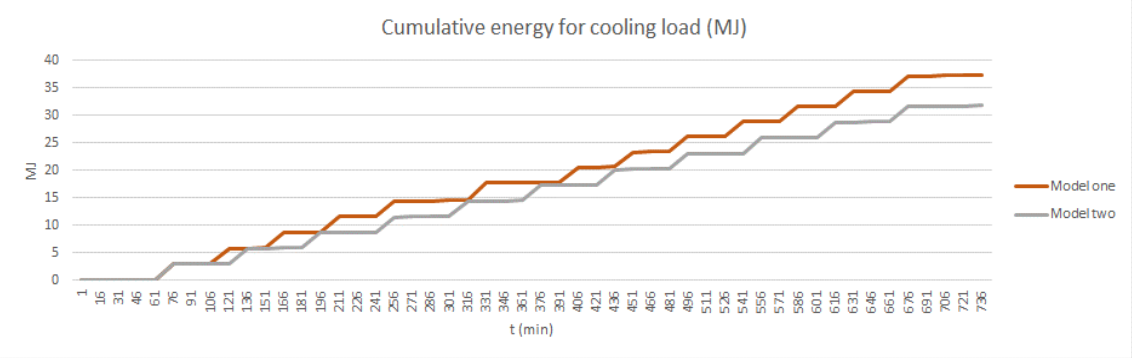
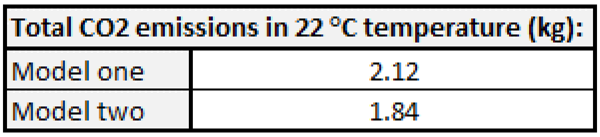


Diagram 9. Cumulative energy for cooling load in 22 ºC ambient temperature. Vertical axles shows the energy consumption in mega joules (MJ) for model number one and for model number two. Horizontal axels shows the time duration in minutes (min)

In this example the ambient conditions has also impact on the trailers total emission production. From the table 13 can be seen the trailers equivalent CO_2 emissions if the model number one and the model number two would be applied under 22 °C ambient temperature. The equivalent CO_2 emissions was calculated from the produced equivalent CO_2 emission equation nine. In this general example, the model number one produced approximately 2.12 kg of equivalent CO_2 emissions and model number two produced approximately 1.84 kg of equivalent CO_2 emissions. These value are remarkable larger than in the case study models, however compared to the truck's equivalent CO_2 emissions the trailer's emission production is reasonable small.

Table 13. The model number one and two trailers equivalent CO_2 emissions total in 22 °C ambient temperature (CO_27kg).



Total CO2 emissions in 22 °C temperature (kg):	
Model one	2.12
Model two	1.84

9 CONCLUSION

The original study problem, defining a model for a temperature controlled outbound transport based on energy consumption and emission production, was reached and proven to be possible. The study questions related to the problem was also answered and proven results indicated. However, there was irregularities between the case study and the models. The total energy calculated for models and case study varied and the correlation between designed models and the case study had also interesting variations. This can be related to many different reasons, although, the largest individual reason for irregularities of the result might be the lack of information from ambient condition and from the trailers specifications. However, the estimations that was made during the study were carefully selected and presented to avoid errors in modeling.

The energy calculations were successfully calculated from the temperature changes inside the trailer. The case study was based on these calculations. However, the one temperature sensor might not have been sufficient to illustrate the real temperature around the trailer. Although, the one temperature sensor measurement simplified the energy calculations and enabled the energy loads calculations from entire trailers point of view. This was purpose-built choice from the point of view of the total emissions and calculation of the equivalent CO_2. Furthermore, in the energy calculations the product temperature estimated to be pre-cooled to the inside temperature and no respiration heat energy was estimated to be produced by the products.

The model number one and the case study had close to the same total amount mega Joules consumed in the heating process. The difference was less than 0.04 mega Joules, and it can be said that the model number one illustrates the case study closely in the total heating energy required. Furthermore, the model number two had a bigger difference in the total mega joules calculated. The difference between model number two and the case study was 0.22 mega Joules. This suggest that model number one follows more closely the case study than the model number two when focusing on the total energy needed for the heating process. However, the correlation factor in the cumulative heating shows that the case study's cumulative energy of the heat load process follows more closely the model number two. Although, model number one and model number two had both high correlation factors, the model number two had 0.003 higher correlation factor. This indicates that in the cumulative heating energy process the routing design differences did not had much of a difference compared to the case study. In the cooling process the total energies needed had bigger differences between the calculated values. However, the model number one illustrated the case study more closely this time as well. Between the total cooling energy needed the difference was 0.22 mega Joules between the model number one and the case study. Whereas, the difference between model number two and the case study was 0.42 mega Joules. This suggest that model number one follows more closely the case study than the model number two when considering on the total energy needed for the cooling process. However, the correlation factor in the cumulative heating shows that the case study's cumulative energy of the cooling load process follows more closely the model number two. Although, both models had high correlation factor, the model number two had 0.002 higher correlation factor than the model number two. The models one and two comparison indicates that the model number one illustrates more closely the total heating and cooling energy needed.

The model number one was designed represent the actual case study routing more closely than the model number two and the total amount of energy needed in the model number one was indeed closer to the actual case study than the model number two. However, model number two's cumulative energy calculations, which represent the designed routing and specific energy consumption in 15 minute sections had actually higher correlation factor with the case study than the model number one. This was not expected during the modeling, however, this shows the importance of the starting information's from the delivery route that is being modelled. Especially important is the number of the un-loading stops and the duration of the door-opening time because they consumed the greatest amount of energy in the models. Moreover, the cumulative energy load diagrams five and six showed frequent spikes of energy consumption in both models and in the case study. The rapid changes of energy loads were allocated to be from infiltration loads and product loads in the model calculations. However, the same kind of interpretations could not have been done from the case study and its product un-loading stops, even though, the similarities were noticeable. More information from the case study routings should have been available to confirm the energy spikes were actually infiltration heat loads from the un-loading stops. In conclusion, the model number one illustrated the total energy consumption better than model number two and the model number two represented better the case study routing than model number one. However, both models illustrated generally the actual case study quite closely. It would be important to have more specific information about the routings to reach better modeling. Furthermore, the ambient conditions should have been known better, especially the outside temperature to confirm the heating or cooling process and to get even more accurate total energy consumptions.

In the emissions calculations, the selected emission was equivalent CO_2 (eCO_2). The conclusion from emission calculations was that the emission load can be conducted based on the estimations made in energy models. In addition, remarkable was to notice that infiltration load had over 60 percent of the total emissions produced in the models. Based on this the number of un-loading stops are recommended to be reduced in the outbound transport and the delivery routings designed so that un-loading stops and un-loading time could be reduced. However, compared to the truck's CO_2 emissions the trailers total emissions were insignificantly small. This can be explained with the small amount energy consumed in the heating and cooling processes by the trailer and further to the small temperature differences between estimated ambient air and the inside air in the trailer. However, in higher ambient temperatures and in day time transport might have notable changes in CO_2 emissions produced by the trailer. The example emission calculation in 22 ºC ambient temperature shows that the temperature difference between trailer and surrounding air has notable effects on emission production.

In conclusion, modeling could be a significantly usable way to estimate and calculate energy consumption and emission production in all outbound transports, and this way optimize the outbound logistics. Energy loads can be calculated based on the temperature changes inside the trailer, if ambient conditions and trailers' dimensions are also known. Approximated calculation of equivalent CO_2 emissions are simple to calculate based on the information provided. Modeling the energy consumption and emission productions are interesting also when estimating the environmental impact in an outbound delivery route or in an entire logistic organization. However, to design a model that illustrates the actual case, the background information from ambient conditions, trailer specifications and route specifications should be defined in details. Based on this study especially the outside temperature and un-loading stops the duration of door-opening are important when modeling energy loads and emissions production. Due the small temperature differences between ambient air and inside air the trailers production of equivalent CO_2 emissions was insignificantly small compared to the trucks produced emissions, However, if temperature difference was greater and the transport took place in day time the equivalent CO_2 emissions could much greater. This could be also be an interesting future research to study a model in an outbound transport in higher temperatures and under the solar radiation. Furthermore, further research would be interesting to conduct with different cargo's, for example with perishable products that would produce respiration heat during transport. From the emissions point of view an interesting future research would be to study different fuels and their equivalent CO_2 emissions in outbound logistics. Biodiesels or hybrid motors might reduce the emission production.

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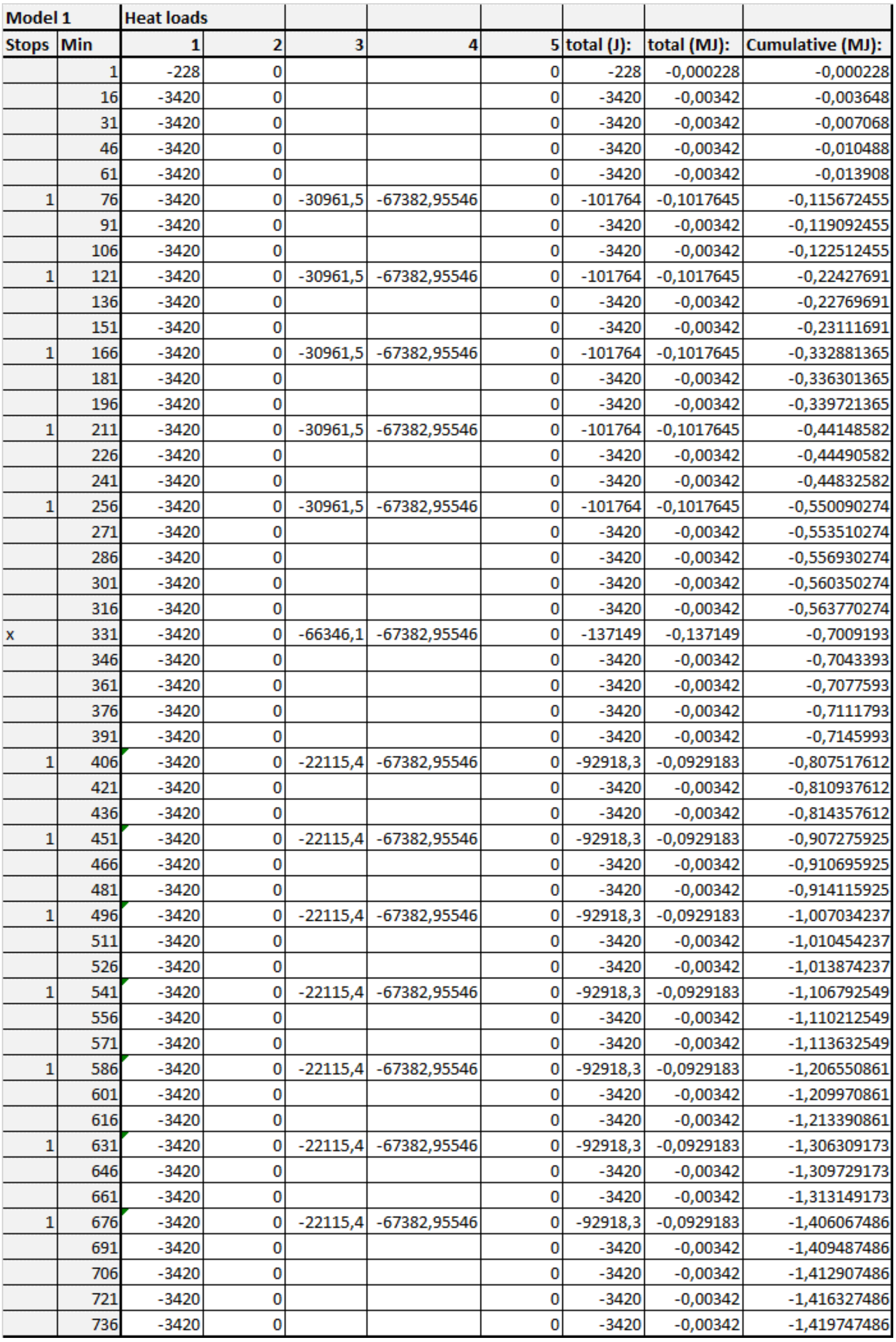
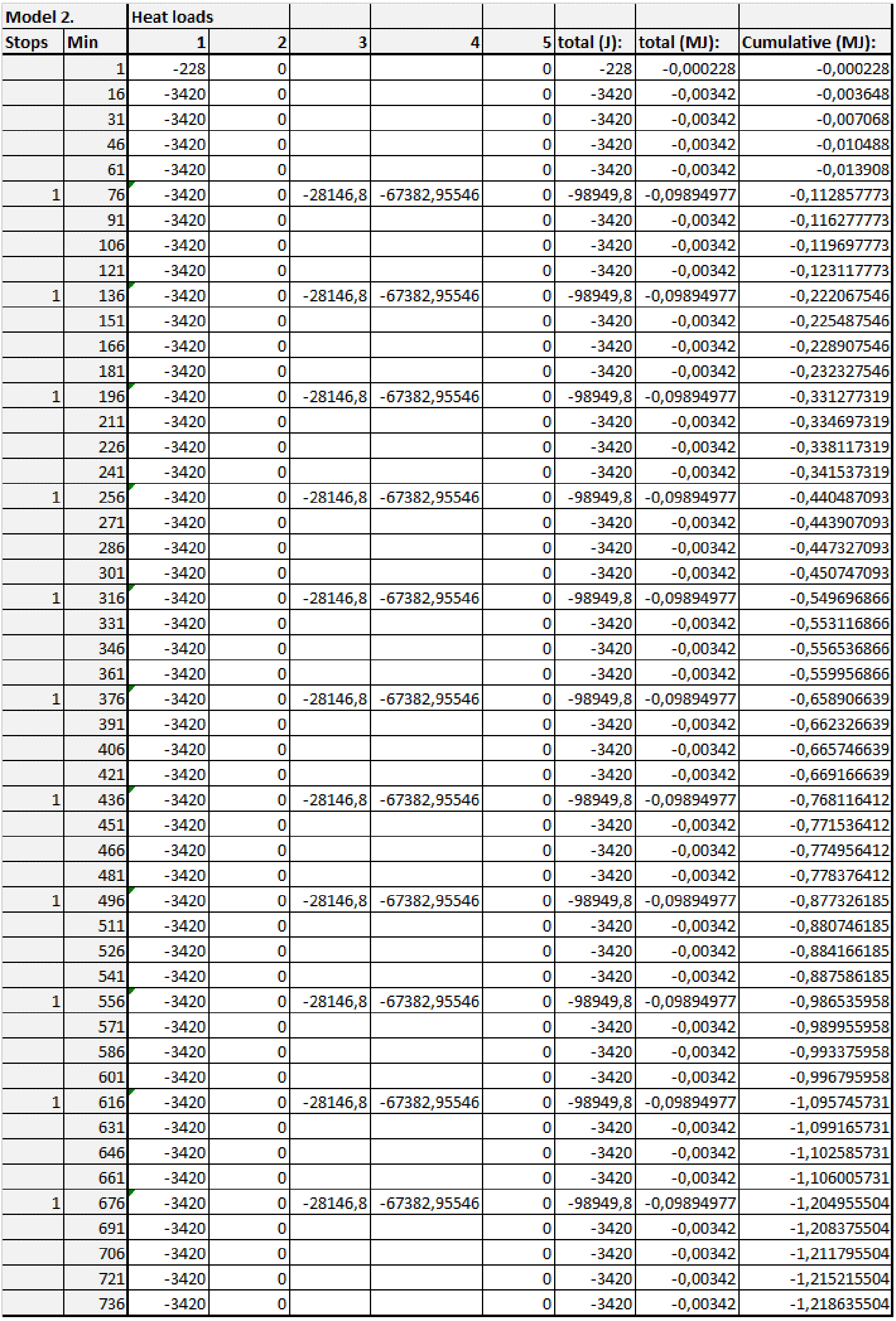
APPENDICES

APPENDIX 1.



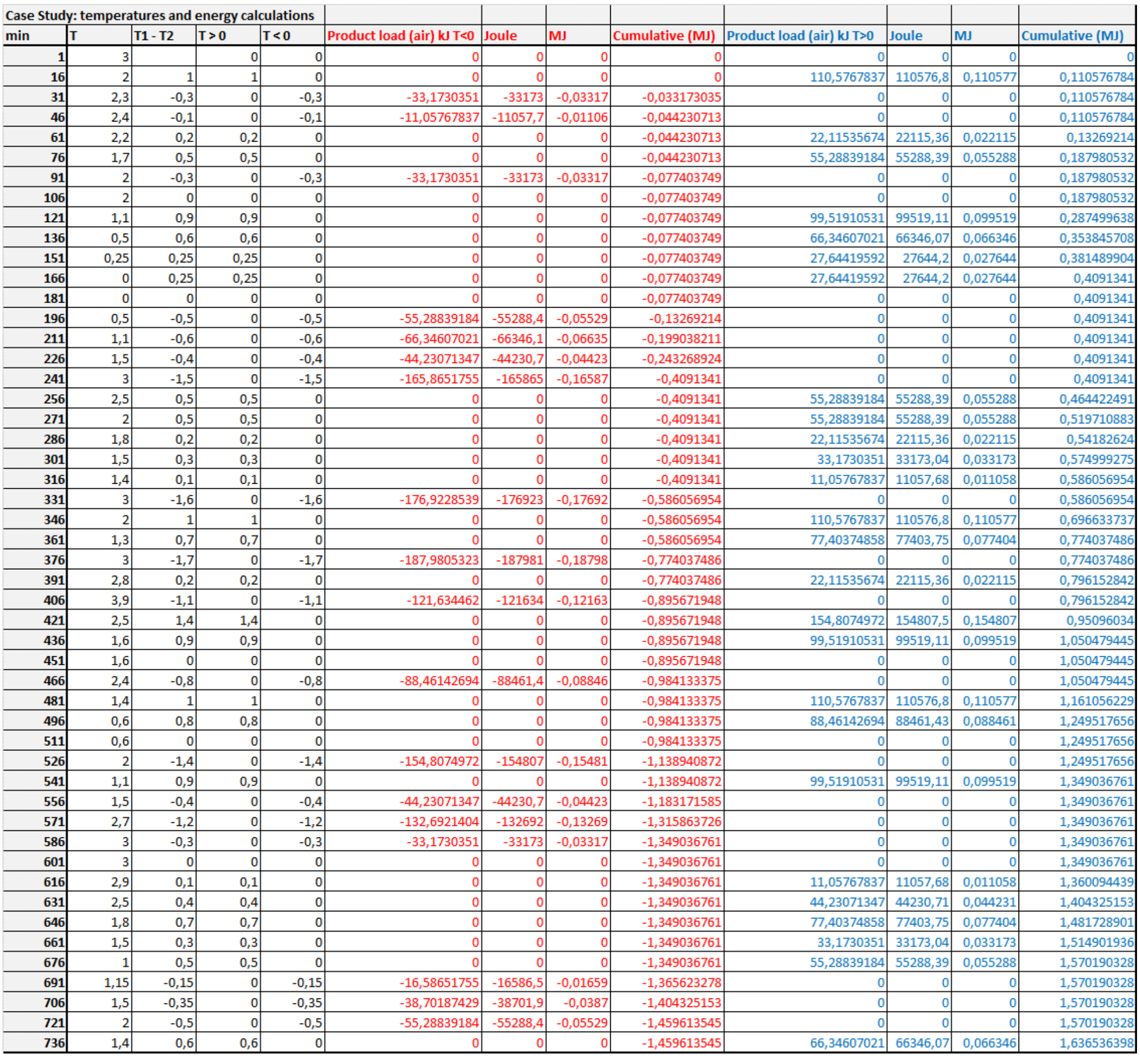
Model 1		Heat loads							
Stops	**Min**	**1**	**2**	**3**	**4**	**5**	**total (J):**	**total (MJ):**	**Cumulative (MJ):**
	1	-228	0			0	-228	-0,000228	-0,000228
	16	-3420	0			0	-3420	-0,00342	-0,003648
	31	-3420	0			0	-3420	-0,00342	-0,007068
	46	-3420	0			0	-3420	-0,00342	-0,010488
	61	-3420	0			0	-3420	-0,00342	-0,013908
1	76	-3420	0	-30961,5	-67382,95546	0	-101764	-0,1017645	-0,115672455
	91	-3420	0			0	-3420	-0,00342	-0,119092455
	106	-3420	0			0	-3420	-0,00342	-0,122512455
1	121	-3420	0	-30961,5	-67382,95546	0	-101764	-0,1017645	-0,22427691
	136	-3420	0			0	-3420	-0,00342	-0,22769691
	151	-3420	0			0	-3420	-0,00342	-0,23111691
1	166	-3420	0	-30961,5	-67382,95546	0	-101764	-0,1017645	-0,332881365
	181	-3420	0			0	-3420	-0,00342	-0,336301365
	196	-3420	0			0	-3420	-0,00342	-0,339721365
1	211	-3420	0	-30961,5	-67382,95546	0	-101764	-0,1017645	-0,44148582
	226	-3420	0			0	-3420	-0,00342	-0,44490582
	241	-3420	0			0	-3420	-0,00342	-0,44832582
1	256	-3420	0	-30961,5	-67382,95546	0	-101764	-0,1017645	-0,550090274
	271	-3420	0			0	-3420	-0,00342	-0,553510274
	286	-3420	0			0	-3420	-0,00342	-0,556930274
	301	-3420	0			0	-3420	-0,00342	-0,560350274
	316	-3420	0			0	-3420	-0,00342	-0,563770274
x	331	-3420	0	-66346,1	-67382,95546	0	-137149	-0,137149	-0,7009193
	346	-3420	0			0	-3420	-0,00342	-0,7043393
	361	-3420	0			0	-3420	-0,00342	-0,7077593
	376	-3420	0			0	-3420	-0,00342	-0,7111793
	391	-3420	0			0	-3420	-0,00342	-0,7145993
1	406	-3420	0	-22115,4	-67382,95546	0	-92918,3	-0,0929183	-0,807517612
	421	-3420	0			0	-3420	-0,00342	-0,810937612
	436	-3420	0			0	-3420	-0,00342	-0,814357612
1	451	-3420	0	-22115,4	-67382,95546	0	-92918,3	-0,0929183	-0,907275925
	466	-3420	0			0	-3420	-0,00342	-0,910695925
	481	-3420	0			0	-3420	-0,00342	-0,914115925
1	496	-3420	0	-22115,4	-67382,95546	0	-92918,3	-0,0929183	-1,007034237
	511	-3420	0			0	-3420	-0,00342	-1,010454237
	526	-3420	0			0	-3420	-0,00342	-1,013874237
1	541	-3420	0	-22115,4	-67382,95546	0	-92918,3	-0,0929183	-1,106792549
	556	-3420	0			0	-3420	-0,00342	-1,110212549
	571	-3420	0			0	-3420	-0,00342	-1,113632549
1	586	-3420	0	-22115,4	-67382,95546	0	-92918,3	-0,0929183	-1,206550861
	601	-3420	0			0	-3420	-0,00342	-1,209970861
	616	-3420	0			0	-3420	-0,00342	-1,213390861
1	631	-3420	0	-22115,4	-67382,95546	0	-92918,3	-0,0929183	-1,306309173
	646	-3420	0			0	-3420	-0,00342	-1,309729173
	661	-3420	0			0	-3420	-0,00342	-1,313149173
1	676	-3420	0	-22115,4	-67382,95546	0	-92918,3	-0,0929183	-1,406067486
	691	-3420	0			0	-3420	-0,00342	-1,409487486
	706	-3420	0			0	-3420	-0,00342	-1,412907486
	721	-3420	0			0	-3420	-0,00342	-1,416327486
	736	-3420	0			0	-3420	-0,00342	-1,419747486

APPENDIX 2.



Model 2.		Heat loads							
Stops	Min	1	2	3	4	5	total (J):	total (MJ):	Cumulative (MJ):
	1	-228	0			0	-228	-0,000228	-0,000228
	16	-3420	0			0	-3420	-0,00342	-0,003648
	31	-3420	0			0	-3420	-0,00342	-0,007068
	46	-3420	0			0	-3420	-0,00342	-0,010488
	61	-3420	0			0	-3420	-0,00342	-0,013908
1	76	-3420	0	-28146,8	-67382,95546	0	-98949,8	-0,09894977	-0,112857773
	91	-3420	0			0	-3420	-0,00342	-0,116277773
	106	-3420	0			0	-3420	-0,00342	-0,119697773
	121	-3420	0			0	-3420	-0,00342	-0,123117773
1	136	-3420	0	-28146,8	-67382,95546	0	-98949,8	-0,09894977	-0,222067546
	151	-3420	0			0	-3420	-0,00342	-0,225487546
	166	-3420	0			0	-3420	-0,00342	-0,228907546
	181	-3420	0			0	-3420	-0,00342	-0,232327546
1	196	-3420	0	-28146,8	-67382,95546	0	-98949,8	-0,09894977	-0,331277319
	211	-3420	0			0	-3420	-0,00342	-0,334697319
	226	-3420	0			0	-3420	-0,00342	-0,338117319
	241	-3420	0			0	-3420	-0,00342	-0,341537319
1	256	-3420	0	-28146,8	-67382,95546	0	-98949,8	-0,09894977	-0,440487093
	271	-3420	0			0	-3420	-0,00342	-0,443907093
	286	-3420	0			0	-3420	-0,00342	-0,447327093
	301	-3420	0			0	-3420	-0,00342	-0,450747093
1	316	-3420	0	-28146,8	-67382,95546	0	-98949,8	-0,09894977	-0,549696866
	331	-3420	0			0	-3420	-0,00342	-0,553116866
	346	-3420	0			0	-3420	-0,00342	-0,556536866
	361	-3420	0			0	-3420	-0,00342	-0,559956866
1	376	-3420	0	-28146,8	-67382,95546	0	-98949,8	-0,09894977	-0,658906639
	391	-3420	0			0	-3420	-0,00342	-0,662326639
	406	-3420	0			0	-3420	-0,00342	-0,665746639
	421	-3420	0			0	-3420	-0,00342	-0,669166639
1	436	-3420	0	-28146,8	-67382,95546	0	-98949,8	-0,09894977	-0,768116412
	451	-3420	0			0	-3420	-0,00342	-0,771536412
	466	-3420	0			0	-3420	-0,00342	-0,774956412
	481	-3420	0			0	-3420	-0,00342	-0,778376412
1	496	-3420	0	-28146,8	-67382,95546	0	-98949,8	-0,09894977	-0,877326185
	511	-3420	0			0	-3420	-0,00342	-0,880746185
	526	-3420	0			0	-3420	-0,00342	-0,884166185
	541	-3420	0			0	-3420	-0,00342	-0,887586185
1	556	-3420	0	-28146,8	-67382,95546	0	-98949,8	-0,09894977	-0,986535958
	571	-3420	0			0	-3420	-0,00342	-0,989955958
	586	-3420	0			0	-3420	-0,00342	-0,993375958
	601	-3420	0			0	-3420	-0,00342	-0,996795958
1	616	-3420	0	-28146,8	-67382,95546	0	-98949,8	-0,09894977	-1,095745731
	631	-3420	0			0	-3420	-0,00342	-1,099165731
	646	-3420	0			0	-3420	-0,00342	-1,102585731
	661	-3420	0			0	-3420	-0,00342	-1,106005731
1	676	-3420	0	-28146,8	-67382,95546	0	-98949,8	-0,09894977	-1,204955504
	691	-3420	0			0	-3420	-0,00342	-1,208375504
	706	-3420	0			0	-3420	-0,00342	-1,211795504
	721	-3420	0			0	-3420	-0,00342	-1,215215504
	736	-3420	0			0	-3420	-0,00342	-1,218635504

APPENDIX 3.



Case Study: temperatures and energy calculations												
min	T	T1 - T2	T > 0	T < 0	Product load (air) kJ T<0	Joule	MJ	Cumulative (MJ)	Product load (air) kJ T>0	Joule	MJ	Cumulative (MJ)
1	3		0	0	0	0	0	0	0	0	0	0
16	2	1	1	0	0	0	0	0	110,5767837	110576,8	0,110577	0,110576784
31	2,3	-0,3	0	-0,3	-33,1730351	-33173	-0,03317	-0,033173035	0	0	0	0,110576784
46	2,4	-0,1	0	-0,1	-11,05767837	-11057,7	-0,01106	-0,044230713	0	0	0	0,110576784
61	2,2	0,2	0,2	0	0	0	0	-0,044230713	22,11535674	22115,36	0,022115	0,13269214
76	1,7	0,5	0,5	0	0	0	0	-0,044230713	55,28839184	55288,39	0,055288	0,187980532
91	2	-0,3	0	-0,3	-33,1730351	-33173	-0,03317	-0,077403749	0	0	0	0,187980532
106	2	0	0	0	0	0	0	-0,077403749	0	0	0	0,187980532
121	1,1	0,9	0,9	0	0	0	0	-0,077403749	99,51910531	99519,11	0,099519	0,287499638
136	0,5	0,6	0,6	0	0	0	0	-0,077403749	66,34607021	66346,07	0,066346	0,353845708
151	0,25	0,25	0,25	0	0	0	0	-0,077403749	27,64419592	27644,2	0,027644	0,381489904
166	0	0,25	0,25	0	0	0	0	-0,077403749	27,64419592	27644,2	0,027644	0,4091341
181	0	0	0	0	0	0	0	-0,077403749	0	0	0	0,4091341
196	0,5	-0,5	0	-0,5	-55,28839184	-55288,4	-0,05529	-0,13269214	0	0	0	0,4091341
211	1,1	-0,6	0	-0,6	-66,34607021	-66346,1	-0,06635	-0,199038211	0	0	0	0,4091341
226	1,5	-0,4	0	-0,4	-44,23071347	-44230,7	-0,04423	-0,243268924	0	0	0	0,4091341
241	3	-1,5	0	-1,5	-165,8651755	-165865	-0,16587	-0,4091341	0	0	0	0,4091341
256	2,5	0,5	0,5	0	0	0	0	-0,4091341	55,28839184	55288,39	0,055288	0,464422491
271	2	0,5	0,5	0	0	0	0	-0,4091341	55,28839184	55288,39	0,055288	0,519710883
286	1,8	0,2	0,2	0	0	0	0	-0,4091341	22,11535674	22115,36	0,022115	0,54182624
301	1,5	0,3	0,3	0	0	0	0	-0,4091341	33,1730351	33173,04	0,033173	0,574999275
316	1,4	0,1	0,1	0	0	0	0	-0,4091341	11,05767837	11057,68	0,011058	0,586056954
331	3	-1,6	0	-1,6	-176,9228539	-176923	-0,17692	-0,586056954	0	0	0	0,586056954
346	2	1	1	0	0	0	0	-0,586056954	110,5767837	110576,8	0,110577	0,696633737
361	1,3	0,7	0,7	0	0	0	0	-0,586056954	77,40374858	77403,75	0,077404	0,774037486
376	3	-1,7	0	-1,7	-187,9805323	-187981	-0,18798	-0,774037486	0	0	0	0,774037486
391	2,8	0,2	0,2	0	0	0	0	-0,774037486	22,11535674	22115,36	0,022115	0,796152842
406	3,9	-1,1	0	-1,1	-121,634462	-121634	-0,12163	-0,895671948	0	0	0	0,796152842
421	2,5	1,4	1,4	0	0	0	0	-0,895671948	154,8074972	154807,5	0,154807	0,95096034
436	1,6	0,9	0,9	0	0	0	0	-0,895671948	99,51910531	99519,11	0,099519	1,050479445
451	1,6	0	0	0	0	0	0	-0,895671948	0	0	0	1,050479445
466	2,4	-0,8	0	-0,8	-88,46142694	-88461,4	-0,08846	-0,984133375	0	0	0	1,050479445
481	1,4	1	1	0	0	0	0	-0,984133375	110,5767837	110576,8	0,110577	1,161056229
496	0,6	0,8	0,8	0	0	0	0	-0,984133375	88,46142694	88461,43	0,088461	1,249517656
511	0,6	0	0	0	0	0	0	-0,984133375	0	0	0	1,249517656
526	2	-1,4	0	-1,4	-154,8074972	-154807	-0,15481	-1,138940872	0	0	0	1,249517656
541	1,1	0,9	0,9	0	0	0	0	-1,138940872	99,51910531	99519,11	0,099519	1,349036761
556	1,5	-0,4	0	-0,4	-44,23071347	-44230,7	-0,04423	-1,183171585	0	0	0	1,349036761
571	2,7	-1,2	0	-1,2	-132,6921404	-132692	-0,13269	-1,315863726	0	0	0	1,349036761
586	3	-0,3	0	-0,3	-33,1730351	-33173	-0,03317	-1,349036761	0	0	0	1,349036761
601	3	0	0	0	0	0	0	-1,349036761	0	0	0	1,349036761
616	2,9	0,1	0,1	0	0	0	0	-1,349036761	11,05767837	11057,68	0,011058	1,360094439
631	2,5	0,4	0,4	0	0	0	0	-1,349036761	44,23071347	44230,71	0,044231	1,404325153
646	1,8	0,7	0,7	0	0	0	0	-1,349036761	77,40374858	77403,75	0,077404	1,481728901
661	1,5	0,3	0,3	0	0	0	0	-1,349036761	33,1730351	33173,04	0,033173	1,514901936
676	1	0,5	0,5	0	0	0	0	-1,349036761	55,28839184	55288,39	0,055288	1,570190328
691	1,15	-0,15	0	-0,15	-16,58651755	-16586,5	-0,01659	-1,365623278	0	0	0	1,570190328
706	1,5	-0,35	0	-0,35	-38,70187429	-38701,9	-0,0387	-1,404325153	0	0	0	1,570190328
721	2	-0,5	0	-0,5	-55,28839184	-55288,4	-0,05529	-1,459613545	0	0	0	1,570190328
736	1,4	0,6	0,6	0	0	0	0	-1,459613545	66,34607021	66346,07	0,066346	1,636536398