Cold Chain of Chilled meals
- A case study

SP Sveriges Tekniska Forskningsinstitut

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Abstract

”Active Ageing – Personalised food and meal solutions for health and quality of life” (Aktivt åldrande – individuellt anpassade måltidslösningar för hälsa och livskvalitet hos äldre. Diarienr 2013-02780) is a project that aims to maintain the quality of life and autonomy of older persons, through individual and personalised meal solutions that fit their needs and requirements. The target group are primarily the age 75 or older. Five work packages are included in the project. One of the work packages had the scope of developing a concept for the ordering, distribution and delivery of meal to the elderly.

The final report from that work package can be found in SP Report 2015:75. An interdisciplinary approach – combining knowledge of ICT (information and communications technology) – Technology, food quality, packaging, logistic, sensory, and waste/return systems for the food that is distributed is increasingly necessary. Being able to influence food choices, for the elderly, is central and open up possibilities for different activities and the development of new products, models and services that might be facilitated by collaborating with SMEs (micro, small and medium sized enterprises) and other business partners interested in delivering solutions for the elderly consumers. The concept for the ordering, distribution and delivery of meal to the elderly developed in the project can be used by other end users and/or for other products and services.

Students at the KTH performed a case study “cold chain of chilled meals” together with participant, Medirest, from the project Active Ageing which is presented in this report.
The focus is on hospital food provisioning, which is an even more delicate branch in the general food processing panorama. The entire cold chain is mapped and analysed, from the factory up to the hospital wards, in order to ensure integrity and identify critical points. The work is done in collaboration with Medirest, a company responsible for food provision in five hospitals in Stockholm’s county. The aim of the project were to investigate if Medirest cold chain of a meal containing chicken were kept intact starting from when the frozen chicken were thawed until it was delivered in a meal box to the S:t Görans Hospital, including all storing and transportation.

Starting from the background knowledge of food regulations, production procedures, logistic technologies and delivery schemes, the overall situation can be depicted and subsequently investigated. Temperature measurements were carried out upon cooked chicken. The results shows that the chicken holds a temperature below 6°C, which is Medirest’s goal, when it is put in the holding fridge at Medirest. The temperature fluctuates a lot.
When it is put in the holding fridge at the hospital the temperature is held more constant, just above 6°C. The difference may depend on the activity and the amount of internal loads, as well as the ventilation flow required at the Medirest facility. The most exposed parts of the cold chain were during the preparation of the meal boxes, the transportation to the hospital, and during the delivery of the meal boxes to the different wards. The measurements were carried out in November, which is a relative cold month. Problems not showed in this study could however occur during the summer months when the cold chain is exposed to higher loads and higher ambient temperatures.

Key words: Cold chain, chilled meals, distribution, energy, food, elderly consumers

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Foreword

This case study “cold chain of chilled meals” was performed at KTH together with participant, Medirest. When projects of this kind have participants from academia, the obvious advantages are not only in participators from the university, but also to let the parts of the project to form part of the education of students. This creates win-win situations in that research training provides a foundation for learning for the students. The implication of this is that students can perform research work is relevant and conducted in connection with the participation of company representative, where the outcome will benefit the project as a whole. In the case of this project, student groups worked in the MJ2409 - Applied Energy technology Project course.

The main project ”Aktivt åldrande – individuellt anpassade måltidslösningar för hälsa och livskvalitet hos äldre” Diarienr 2013-02780 was financed by VINNOVA within ”En hållbar innovativ livsmedelskedja som möter framtidens behov” which is a project that aims to maintain the quality of life and autonomy of older persons, through individual and personalised meal solutions that fit their needs and requirements. The target group are primarily the age 75 or older. Five work packages are included in the project. One of the work package had the scope of developing a concept for the ordering, distribution and delivery of meal to the elderly. The final report from that work package can be found in SP Report 2015:75.

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1 Introduction

For the supply of food a well-functioning value- and cold chain is required built up in several steps. In this project we will evaluate the cold chain of a meal service to hospitals in the Stockholm area conducted by the company Medirest. Medirest is a part of the Compass Group, a supplier of meal service and other support services in Sweden. Medirest provides packaging of prepared meals that are already cooked and chilled, and deliver it to different hospitals in the Stockholm area. Medirest's responsibility of the cold chain includes the reception of the food to Medirest, the packaging and storing of the meals, as well as the transportation and in some cases also the reception of these meals at the different hospitals.

Medirest receive products delivered to their facilities and prepare and package the food as a finished product, ready to be heated up in the microwave. Throughout this process, there is a possibility that the food is temporarily stored in temperatures above their recommended storage temperature. An example of this can be when the food is carried between storage facility and the vehicle used for transportation, and until the truck is fully packed. When handling food, like Medirest is doing, it's important to control the temperatures all the way from deliverance to delivery. If certain food products are exposed to too high temperature for too long the taste and appearance of the food can be damaged, and bacteria may grow.

In order to preserve the quality of the food and due to health risks the Livsmedelsverket has a temperature requirement that the meals never should reach temperatures above 8°C [1]. Medirest has the goal to keep the meals at a temperature of 6°C to ensure quality and safety, hence even lower than the regulations. To manage to keep these temperatures a large amount of energy, planning and routines are needed. Unfortunately, it is commonly occurred in long food chains that the temperature profiles are not kept intact while packaging, transporting and storing food, or in this case meals, which will be investigated further in this case study.

What was investigated at Medirest was the effectiveness of their cold chain, especially in more sensitive food products. It was investigated that the temperatures of the meals delivered by Medirest did not reach too high temperatures, by measuring the temperature of the meal boxes all the way through the cold chain. A cold chain in this case is to keep a low temperature of the food from when it is received at Medirest and through the storage and preparation and packaging of the meals, and finally through the transportation all the way out to the recipients.

2 Aim and objectives

As previously introduced, maintaining the food temperature under certain desired values is very important in order to guarantee healthy food provision, especially for delicate context such as hospital and elder accommodation facilities. The aim of this project is to identify eventually deficits in the cold chain. The in particular specific objectives are defined as subsequently:

- Investigate temperature profiles of cooked chicken in the process of making a meal box for hospital
- Propose and discuss potential solutions to identified problems in cold chains.
  - Why do they occur and how could this be prevented.
- Propose and discuss potential solutions in Medirest's refrigeration systems.

3 Methodology

This study consists of both a literature review and practical measurements at the facility and throughout the delivery chain.

3.1 Literature review

A literature review was conducted in order to gain information about cold chains, refrigeration solutions in transportation and in fridge and freezer rooms as well as regulations and framework of temperatures in cold chains of food and prepared meals. Furthermore a literature review has been conducted regarding the refrigerant of choice in the Medirest facility and refrigerating solution in the delivery vehicles. This was done in order to be able to propose alternative solutions and improvements, both regarding a more effective and reliable provision of cooling as well as possible reductions in global warming potential. This part is presented in *Refrigerating solutions*.

3.2 Case study in Medirest

In order to access information about potential problems in the cold chain, on of the participants of the project Active Ageing, Medirest, was selected to perform a case study. To gain insight into Medirest's facilities and processes several study visits to the packaging factory was made. Temperature measurements were carried out during their process of making a meal box that should be delivered to one of their clients, S:t Görans hospital. The measurements started. The specific part of the cold chain that in this case was stuidedd, was from when the cooked chicken was taken out from the freezer to thaw until the chicken arrives to the individual fridges at each ward at S:t Görans hospital. In the factory the different storage rooms and chillers and freezers were displayed, as well as the process for packaging the food.

3.2.1 Measurement instruments

Temperature measurements are one of the central parts of the project workflow. It is therefore important to spend some words on the measurement equipment available, in order to clarify the procedures and the uncertainties of measurements. For this project investigation three temperature loggers were used, all manufactured by Testo. Specifically one 177-T4 model and two 175-T3 models. These instruments can measure temperatures from respectively four or two different channels at the same time. Measurements are done through thermocouples connected to the instrument and the results are stored at every user-specified time interval. Their range of application is more than suitable for the temperatures expected in the food cold chain, indeed it is possible to measure from -50°C up to 1000°C, while the food is estimated to have a maximum interval between -30°C and +30 °C. The measurements are stored into SD card and can be read and analysed via the provided software by Testo. These instruments are portable so they are battery powered but their autonomy is sufficient to cover the whole chain measures [2][3].

The collected data from the temperature loggers were downloaded using the software "Comfort Software" by Testo. This is a basic software for programming and readout of the Testo data loggers used in this investigation. The collected data were exported to Microsoft Office Excel where graphs showing temperature variations over time were made to visualise the recorded data.

3.2.1.1 Sensitivity analysis

The temperature of food is not always uniform. There could be a significant difference between the core and surface temperature. This is a phenomenon that can be noticed when microwaving frozen food and the surface is hot but the core is still frozen. If the food is supposed to be a certain temperature and is exposed to higher loads it is the surface that is affected first. This is a problem that has to be accounted for during the measurements of when the chicken was thawed, as the thermocouples couldn't be put into the chicken. In order to get correct and reliable results it is furthermore important that the measurement equipment is correctly calibrated. A thermoelement converts the temperature measurement into a signal transferred to the instrument. This conversion is relatively complicated, however done automatically. The thermoelement used in this study was of the T-type, copper-constantan, and was of relative high age. Today most T-thermoelements are exchanged to N (NiCrSi-NiSi) or K (chromel-alumel) types, which are more robust. However, the T-type is suitable for low temperature regions and is often used for temperatures below or near zero °C, which is the case in this study. It also has a good repeatability. The drawbacks when using thermoelements is that a good calibration is needed and that experience is required to avoid sources of error [4]. The source of error in the temperature measurements is an error of ±0.3°C. In this project the measurement devices were calibrated by inserting its thermocouples into a bucket if ice water. Each measurement device indicated temperatures of around 0.3°C.

3.3 Limitations

The project has certain limitations, one of them are that only a specific part of the cold chain at a specific company could be studied. This was due to time limitations and logistics. The specific part of the cold chain studied in this project is from when the chicken is taken out of the freezer at Medirest to thaw until when it is delivered to the individual fridges at the wards at S:t Görans hospital. Measurements are also only carried out at S:t Görans Hospital, and not at any of the other clients were the procedure may differ. Also other solutions such as home delivery were not investigated.

Only cooked chicken was studied in terms of cold chain and temperatures in this project. No consideration is taken to the rest of the viands that are handled within the cold chain of companies that provides food to the elderly. Furthermore, since measurements were carried out when the chicken left the freezer, it was frozen which made it hard to make measurements inside the food until it had thawed. This leads to uncertainties as the core temperature may differ from the surface temperature. Due to time limitations the temperature measurements of the cold chain was only carried out once. A more accurate result could have been achieved if the procedure would have been repeated several times as faultiness could occur.

The project was initiated and performed during late September until late November. During this time the outdoor temperatures in Sweden are relatively low, hence the food is not exposed to the high temperatures that can be reached during the summer. The high temperatures are more likely to cause a higher load in the refrigeration system within the cold rooms and the delivery trucks. The high temperatures also make the cold chain more vulnerable. However, due to the time restriction of the project this was not a problem that aroused and could hence not be evaluated.

4 Cold chain

4.1 Cold chain introduction

Supplying of perishable goods is done via a so-called cold chain, which is basically an uninterrupted series of events in which the temperature is kept regulated and around a desired target value suitable for the goods. This implies that the products are kept cold during every phase, from the production up to the selling location. It is easy to see that an entire cold chain could easily stretch out for thousands of kilometers and several steps and locations. The raw materials can be cultivated in a certain country, processed in a different continent and sold in a third one. It is therefore significant to monitor not only the temperature, but a more efficient indicator is a time-temperature control.

With the term Perishable Goods is indicated a wide variety of products; meat, vegetables, but also medical equipment are some examples. Any loss that eventually occurs throughout the process may potentially affect and damage the products, therefore is of extreme importance to ensure the integrity of the cold chain. [5]

Requirements for the temperature target values, handling procedures and so on are defined on national basis by the concerning agency. With focus on the cold chain analyzed in this project, Livsmedelverket is the reference authority for regulations and guidelines concerning nourishment for Sweden. However is it also important to note that many of the handling procedures and requirements are almost equal for the whole European Union [6]

4.2 Framework and guidelines

When handling food products, such as fish and chicken, it’s important to follow certain rules and guidelines. To make sure the food doesn’t go bad, neither bacterially or taste wise, both the storage and the cooking of the food needs to be handled in a certain way. To maintain food quality during distribution there are regulations both on European level as well as on national level. The Swedish laws are based upon the directives and regulations by the European Parliament and the Council of Europe. It is Livsmedelverket (National Food Agency) that is responsible to make sure that the Swedish legislation is adapted to these directives and regulations. It is then Livsmedelslagen (SFS 2006:804) and Livsmedelsförordningen (SFS 2006:813) that are the applicable legislation for food in Sweden [7]. Livsmedelslagen intends to ensure a high level of protection of human health and of the consumers’ interest when it comes to food, while Livsmedelsförordningen states which authority that should monitor each type of system [8].

Föreningen Fryst och Kyld Mat (The Association of Frozen and Chilled Food), FFKM, is a Swedish association that aims for all of the stakeholders involved in both the cold and frozen chain to keep the chains within the right temperatures. This is in order to preserve the quality of the food and reduce the food waste. They have developed several guidelines for the industry with different focuses such as on shellfish, temperature discipline, transport of mince, etc. [9].

The safety and quality of frozen and chilled food is affected by handling, storage and transport by chemical, biochemical and physical changes. Chilled food is affected by microbial changes. The changes depends on temperature, the lower the temperature the slower the changes are, however these changes may sometimes be necessary. Chilling and freezing to the appropriate temperature is key and has to be conducted in the right way. The temperature should be selected so that no health hazard may occur, which is a general rule to keep the indicated temperature on the packaging throughout the whole distribution if no other is mentioned in the legislation or other guidelines [7].

Due to the normal food handling routine it required to have a temperature reserve which means that the food has a lower temperature than required. The temperature reserve for chilled food is 2 °C, in other words 2 °C below the required temperature. For frozen food the temperature reserve should be 2 to 7 °C, which corresponds to a temperature about -20 to -25 °C. The temperature of frozen food shouldn't be higher than -18 °C (by the law) which means that the temperature of the product and the air throughout the whole distribution system should not be higher than -18 °C [7]. For shorter periods of time, such as when defrosting a freezer, a temperature of -15 °C can be tolerated [1]. Exactly which air temperature that should be kept varies and needs to be tested and analysed. In every new step in the distribution line the temperature has to be checked. Documentation is very important. The transporter is responsible for the air temperature [7].

Thawing frozen food should be done at temperatures at/or under the temperatures of what the food should have in the thawed condition. When cooling the food after cooking it, the temperature should go to under +8 °C in under four hours. A refrigerator is not suitable if there is a large quantity of warm food that needs to be chilled since the food would increase the temperature inside of the refrigerator. What is often used instead is so called “blast chillers”, big fans that cool down the food to the appropriate temperature [1].

4.2.1 Temperatures of certain foods

Bacteria start to grow at between +8 °C to +60 °C. However the highest growth rate of bacteria is between temperatures of +20 °C and +40 °C [10]. This is why it's so important to keep the food at a temperature below +8 °C. Primarily the recommendations are to follow the max temperature that is written on the package of the food, but most of the time a temperature below +8 °C is enough. For chicken the recommendations are to keep the temperature below +4°C and this also applies to most fish products. However, raw and fresh fish are kept in ice and the storage temperature is at the same as the temperature for melting ice, at around +2 °C. For pre-packaged food the recommended temperature is at between +4 °C - +8 °C. The storage of unpackaged meat products should not be in the same cooling space as for example raw vegetables [1].

5 The cold chain of Medirest

Medirest is a part of the Compass Group, a supplier of meal service and other support services in Sweden. One of their trademarks is Medirest who provides meal services within the health care sector. Medirest develops and operates meal solutions for patients, visitors and personnel at hospitals and care homes as well as people with need for care within their homes, among others. [11]. The mainly use a method called *Steamplicity*. With *Steamplicity* the raw ingredients are placed in a special pressure proof and heat resistant plastic container with a patented (by Compass Group) top film and valve. In this way the food is cooked with help of the water molecules in the food as steam is created when heated in the microwave oven, which builds up a pressure within the container. Cooking can only be done in microwave ovens and takes between 3-5 minutes [12].

Medirest deliveries are addressed to five hospitals in Stockholm's county, Danderyd hospital, S:t Görans hospital, S:t Erik hospital, Långbro hospital and Jakobsbergs hospital. Their services consist of delivery of a variety of prepared meals from chicken to meatballs. These meals could be adjusted to fit persons with food allergies such as gluten and lactose intolerance. They also prepare meals with high nutrition for those who are not able to eat an ordinary portion of food. In addition to the prepared meals they also deliver other food like milk, ice cream, yoghurt, etc. The factory is open every day producing meals but the food is not transported to the hospitals every day, it depends on the need and agreement with the different hospitals.

To visualize how the part of the cold chain within Medirest is, specifically cooked chicken is studied. For this specific case it is analysed how the chicken is handled from the arrival from the supplier to the delivery to the fridges in the wards at S:t Görans hospital. Measurement of temperatures throughout Medirest's cold chain was gathered for a week, and then further analysed to detect any potential problems in the cold chain. The temperature measurements were conducted by acceptance sampling of the temperatures of the delivered commodities. The studied cold chain is divided into two parts, the cold chain in Medirest and the cold chain in S:t Görans hospital. The results of how the cold chain looks like are presented below.

5.1 Cold chain and temperature measurements at Medirest

Some of the meals prepared by Medirest have chicken fillets as a part of it. The precooked chicken filets is mostly used within the company, hence it was decided to investigate the cold chain of these frozen precooked chicken filets. The chicken arrives in plastic bag within a carton box to Medirest from their supplier. The different steps in the cold chain are described below and a scheme for where the different steps are taken in Medirest is presented in Figure 10.

1. The frozen cooked chicken filets arrive from one of Medirest's suppliers to the reception of goods which is not a cold room. Temperature controls are carried out.

2. The chicken is then directly transported to the freezer which should keep a temperature of about -20 °C or lower. The time the chicken is stored in this freezer varies, from a day to approximately one month.
    a. Chilled products are stored in a holding fridge for arriving food in direct correlation to the reception hall until there is time to take it to its actual fridge. This is done to avoid that the food is exposed to warm temperatures for longer times.

3. Two days before the chicken is going to be prepared, it is taken to the unpacking room where the chicken is removed from the carton box and put in a stainless steel container, still in the plastic bag.
    a. Three thermocouples were put inside the plastic bags stuck between the chicken fillets. It was hard to put them inside the frozen chicken. Measurements were made both in a bag put in the bottom of the container and in a bag put above the other one. See Figure 1.

Figure 1. Start of measurement of frozen chicken.

4. The chicken is then put in a special fridge designated for poultry in order to thaw the food, see Figure 2. The chicken is kept here for approximately two days. The fridge is kept at about 4 °C.

Figure 2. Chicken put in fridge to thaw.

5. The chicken is taken to the meal preparation room and put in the meal box together with the rest of the foods for the specific meal. This room is kept at about 12 °C.
    a. The measurement equipment was exchanged and as the chicken fillet now had thawed the threads was put inside four of the chicken fillet. The fillets were put inside two meal boxes together with potatoes, vegetables and sauce in order to correspond to an actual meal preparation. See Figure 3.

Figure 3. Measurement of chicken during meal preparation.

b. The meal boxes were held in the preparation room for approximately 30-40 min which correspond to the time it takes for all meal boxes to be prepared and sealed. See Figure 4 for a typical meal preparation at Medirest

Figure 4. Meal preparation at Medirest.

6. The prepared meals are sealed and labelled in a machine.
    a. The temperature loggers had to be removed before the package was sealed with the plastic lids, due to the relatively high amount of heat added in order to seal the packages. In Figure 5 the machine conducting the sealing of the meal boxes can be seen.

Figure 5. Sealing of meal boxes at Medirest.

7. The prepared meals are then put and stored in the holding room before they are delivered to the hospitals. This fridge room is kept at a temperature of about 4 °C.
    a. The thermocouples were then put inside the chicken again in the meal boxes, and properly sealed to reduce the possible effects of the leaking air. The meal boxes were then placed in a special transportation box in the holding room for storage of two more days before transportation to S:t Görans hospital, on the Friday. This can be seen in Figure 6.

Figure 6. Meal boxes placed in holding fridge for storage before transportation.

8. The meals are moved to the reception of goods before the meals are moved into one of the trucks of Medirest, see Figure 7.

Figure 7. Storage room in a Medirest truck.

9. The meals are transported to the hospitals in the Medirest trucks which should keep a temperature of about -2 °C.

    a. The measurement equipment was continuing to log the temperature in the vehicle during transportation to S:t Görans hospital
    b. Weather data was collected from Stockholm’s Luft- och Bulleranalys [13] in order to identify the variation of temperature inside the meal boxes to the ambient outside air temperature during transport.

5.2 Cold chain and temperature measurements at S:t Görans hospital

One of the hospitals that Medirest delivers food to is S:t Görans hospital, situated about 23 km from Medirest [14]. In Figure 13 an approximate route for the delivery truck can be seen. In S:t Görans hospital Medirest has employees that deliver the food to all of the wards. Medirest is responsible for the food until it is delivered to the fridges of the ward. S:t Görans hospital is currently being renovated, hence Medirest use temporarily cold rooms to store the meal boxes. This means that the cold room has asphalt as floor at the moment, and there are probably some air leakages through these openings. Below the different steps in the cold chain of the prepared meals in S:t Görans hospital is presented.

10. Meals are transported from Medirest in Rotsunda.
11. Meals arrive to the cold room at ground floor and are stored here until they are needed in the wards, which could be up to a few days.
12. Meals are put in transportable mini fridges, se Figure 8.
    a. The mini fridges are just for storage and are actually not fridges.

Figure 8. A transportable mini fridge at S:t Görans hospital.

13. The food is delivered to each ward (nine in total) and put in their individual fridges in their kitchens, see Figure 9. The Medirest employee starts the delivery at the top floor (floor 8) and then takes floor by floor until reaching the last ward at floor 4. The food is delivered twice a day, one time for lunch and one time for dinner.

a. The two meal boxes with the measurement threads are never put inside a fridge at a ward, but measurements of the temperatures are logged during the whole round. The equipment is then collected and all temperature data is downloaded and analysed in order to identify temperature deviations and verify how the temperature profile reacts to the changing ambient temperature.

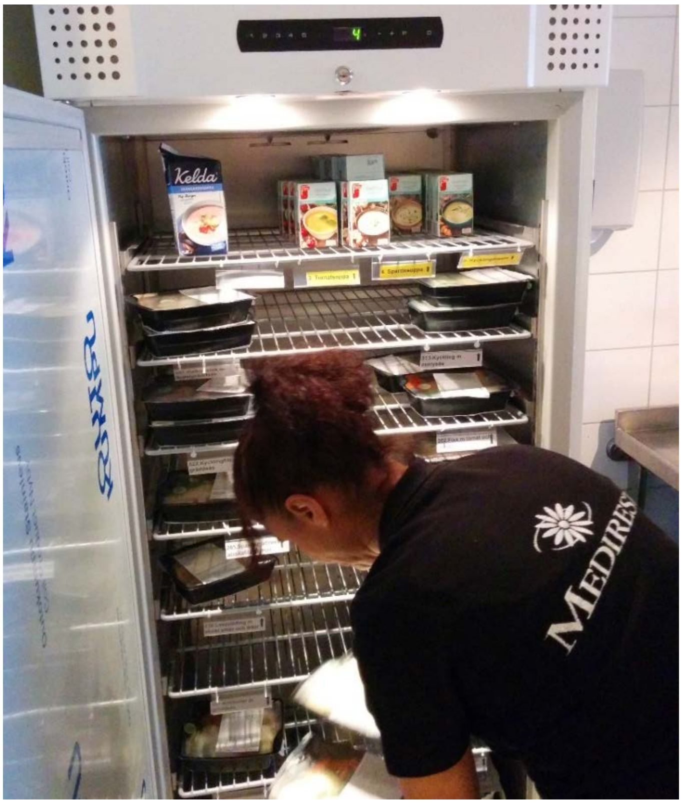

Figure 9. Meal boxes put in a fridge at a ward at S:t Görans hospital.

14. Food is heated in the small kitchen at the ward.
    a. However, no measurements are made after the meals have been delivered to the wards.

15. The food is delivered to the patients of the hospital.

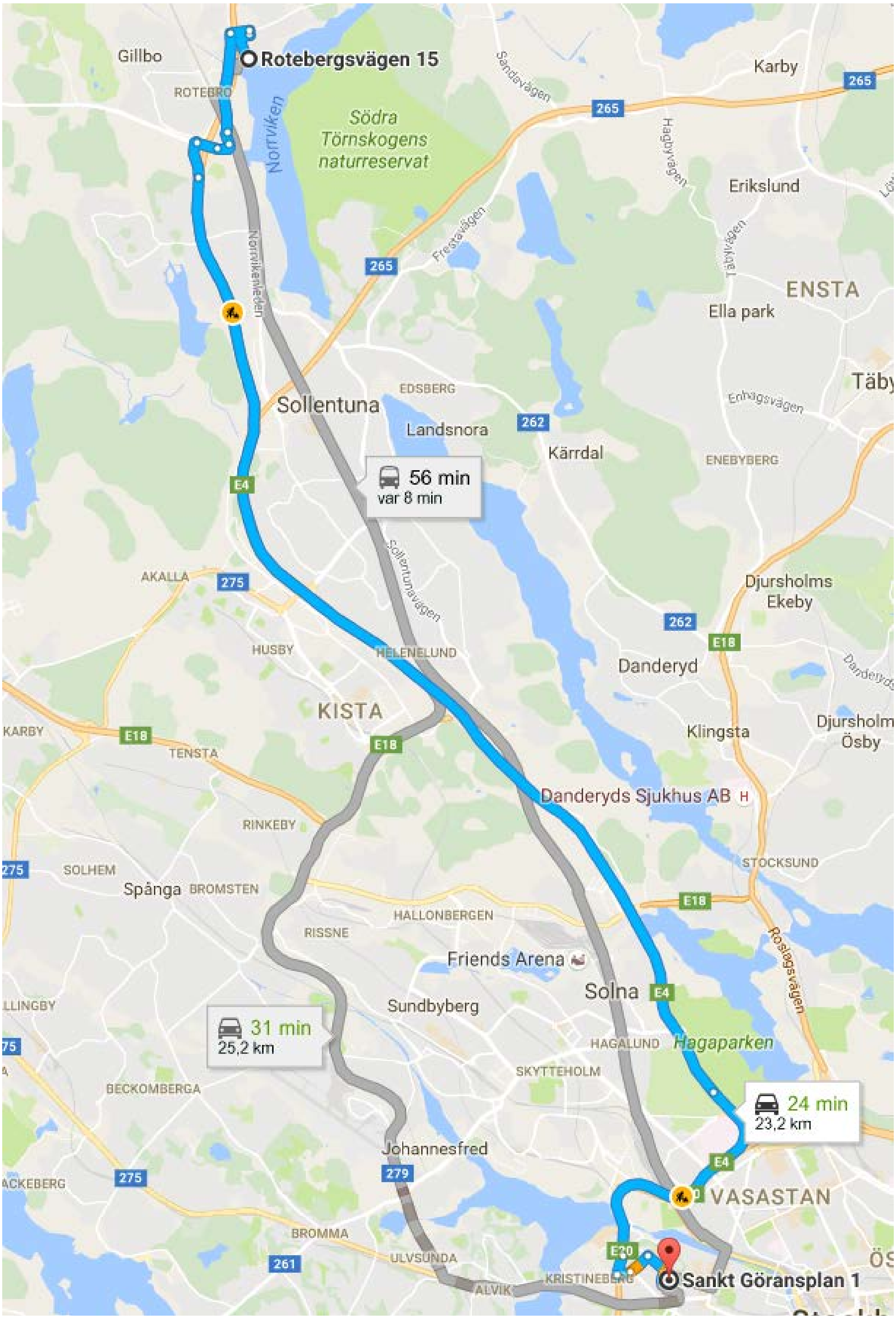

Figure 10. Approximate route for the Medirest delivery trucks from Medirest to S:t Görans hospital.

6 Refrigeration solution in Medirest facility and transport

Here the refrigeration solutions within the Medirest facility together with the solution for their transportation vehicles is presented.

6.1 Building

At Medirest in Rotsunda one big refrigerant system is used for both chilled and frozen food refrigeration, with the condensers placed on the roof of the building. The refrigerant used is R404A and is in the category of Hydrofluorocarbons (HFCs). This refrigerant became popular in the middle of the 1990s as ozone depleting refrigerants primarily consisting of Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs), such as R12 (CFC) and R502 (HCFC), were faced out. It has become the dominant refrigerant in Europe in the supermarket sector, but is also widely used for cold storage, industrial refrigeration and other commercial systems. So R404a became the "refrigerant of choice" in several applications. R404a is easy to use and is non-toxic, if not released in large volumes. Even though, there are several better performing refrigerants available on the market [15].

However, HFCs, including R404A, have several drawbacks that make it less reliable and more costly to maintain [16]. R404A does not provide the best efficiencies (COP) in several applications resulting in higher energy demand and running costs, for providing electricity to the compressor, and hence potential higher carbon dioxide emissions from the power station. With other refrigerants an increased efficiency of 7-12% could be obtained [15]. HFCs have also high cost for both special oils, and the refrigerant itself, as well as have a decreased chemical stability and high discharge pressure, compared to HFCF or CFC systems [16]. Furthermore, with the increasing awareness and concern of climate change R404A has a particularly high global warming effect (GWP). So in case of a leakage R404a, of 1 kg, has a GWP of two to three times worse than other HFCs [15].

But to change the entire refrigerant plant on order to be designed to another refrigerant would be very expensive. However, if retrofitted to other HFC refrigerants such as R407A or R407F with medium GWP, the major design could be kept with only minor and low cost changes needed, such as replacement of the expansion valves. This would lead to better performance of the system with lower CO2 emissions and a GWP of less than half of the one for R404A. Furthermore, to reduce the risk of leakage with around 50%, valves, seals and joins could be upgraded, requiring small investments. However, the system is newly built and should still be more or less intact. No further investigation has been made. Overall, the electricity use reduction would gain cost savings, and both direct GWP and indirect CO2 emissions could be saved with around 75% respectively 10-15%, with a payback time of only 3 to 5 years [15].

Another alternative is to convert the system to so called natural refrigerants with a very low GWP, such as Ammonia, CO2 and hydrocarbons (HCs) [15]. These refrigerants were actually the mostly common used prior to 1930, until the ozone depleting refrigerants were introduced, called the "safety refrigerants”. These can give very good efficiencies if designed properly, but have some drawbacks and is usually also more expensive. Ammonia for example is highly toxic and only suitable for large industrial systems. HCs are highly flammable and safety becomes an issue in medium and large sized applications, and it's hence only suitable for small hermitically systems. CO2 has however showed a great potential in supermarket refrigeration, but it requires very high operating pressure and has a high investment cost. However, the high pressure may be effectively coped with modern technology, and the refrigerant is safe, also in the event of a fire [16]. CO2 could hence be a good alternative when the current system needs to be replaced and a new one will be installed [15]. However, CO2 is not working efficient in a single stage system, but can efficiently be used in a cascade system, that sufficient keeps the condensing temperature low, avoiding transcritical operation [16].

6.2 Transport

An introduction to different refrigerating solutions in different refrigerated transporting techniques is given below, followed by the solution used at Medirest (in their delivery vehicles).

6.2.1 Refrigeration solutions in food transportation

Maintaining products on a certain desired temperature has been a growing problem throughout the centuries, in addition to that, many regulations require certain goods to be delivered and dispatched according to specific temperature ranges. To keep the cold chain in transportation automatically regulated a refrigeration system is needed. Three of these systems are: dynamic, semi-dynamic and static cooling systems. A dynamic system (also known as mechanical system) is a cooling system that produces its own cooling. This is done by connecting the engine to the system. The cooling is then created by compressing and evaporating a refrigerant. A semi-dynamic system carbon dioxide or liquid nitrogen is used for cooling. In addition the system is using a ventilation system to circulate the air in the cooling space. The refrigerants cooling capacity makes the system static but the ventilation makes it dynamic. This is what makes it semi-dynamic. A static cooling system is one that limits the heat exchange with the environment. Refrigerants then absorb the heat from the environment and cools down the space.[17]. Many refrigerated transporting techniques have been developed. Below, some of them are described further [18]:

- Dry ice, where the cargo is insulated using CO2 in a solid state (temperature around -80°C), it has a good capability to maintain frozen products at desired state, however it is more used for pharmaceutical and dangerous goods
- Gel packs, are special substance that can absorb external heat while melting before, avoiding it reach the goods, this solution is used for chilled products around 2-8 °C
- Eutectic or cold plates, working in a way similar to the gel packs, these plates are filled with liquid, with the advantage that they can be used many times. They are quite commonly used in shipping vehicles for short distances or in rolling transport systems.

- Liquid nitrogen, this element liquefies at -196°C and therefore can maintain low temperatures for long period, however it is dangerous and used mainly in biological and pharmaceutical cold chains
- Quilts, are insulating materials that act as a buffer, limiting heat exchanges in order to maintain the good's temperature almost constant, is a good solution to maintain products at room temperature despite seasonal variations, and can also be used when using a refrigerated container is not strictly necessary
- Reefer, this is the actually most common way adopted to maintain the cold chain unbroken during long distances transport. These insulated containers come with an own refrigerating unit that can control the inside temperature. It can also be used in ship transport as well as road or railway routes. Disadvantages are such as the need of an electric power source and the lower storage volume compared to a simple container, this is actually due to the space needed for insulation and refrigerating components, resulting in up to 12% less volume.

It is important to notice that transport refrigeration systems ensuring an unbroken cold chain are designed to maintain temperatures in a certain range around the target, not to reach it. Therefore is always necessary to bring the goods to the desired conditions in specified facilities, before transporting them. This involves that a good transportation refrigeration system requires optimal planning in terms of road, traffic, weather condition and goods treatment facilities, a constant temperature-time monitoring and not only adequate containers. [18]

6.3 Refrigeration solution in Medirest transportation

The pre-made meals are all transported from loading dock at Medirest to a selected hospital. Before transportation all meals have been stored in a cold storage room at 4°C. Leaving the loading dock, the meals are put into a truck set to keep a temperature of -2°C. The refrigeration system of the trucks at Medirest is of the same model – Mitsubishi TDJS35HP. The refrigeration system is driven by the truck's main engine. The refrigerant is R404a and the system is dimensioned to operate at an outside air temperature range of -10°C - +40°C [19]. During winter time the trucks refrigeration system is turned on after the truck is loaded. In the summer the truck's refrigeration system is turned on a while before the truck is loaded in order to maintain an adequate temperature in the vehicle and not break the cold chain more than necessary.

7 Results

The first part of measurements was performed on defrosting chicken. The packages delivered to Medirest were taken out from the holding room and put in a defrosting room where the temperature was set to 4 °C. The defrosting timespan was around two days, and from the log no problems were encountered during this time. However the graph present a curious curve, see Figure 11, and it is possible to see that thermocouples T1 and T3 have an oscillating behaviour.

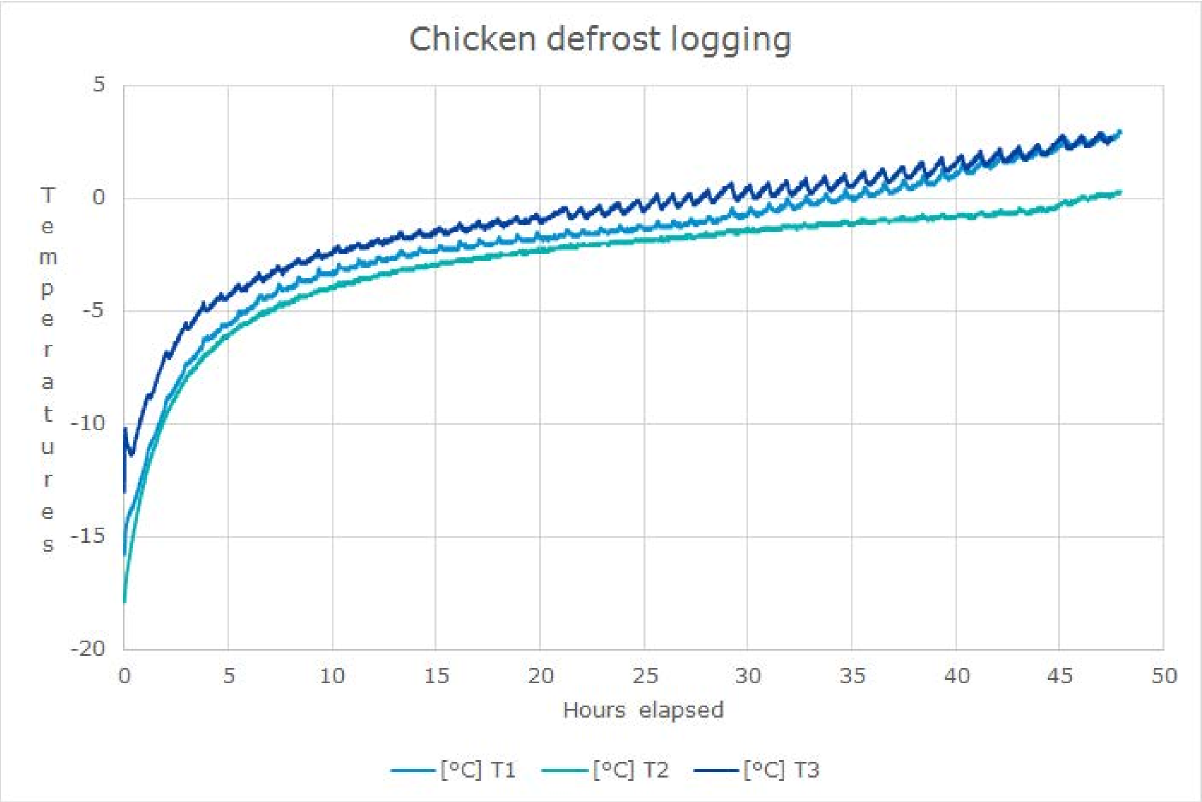

Figure 11. The result of the temperature logging of the chicken during defrosting.

The next part of the measurements was to do temperature logging of two meal boxes from the time they are started to be prepared until they are delivered to the wards at S:t Görans hospital. Figure 12 shows the results from temperature logging of meal boxes during a five day period. The red lines indicate the different days and the green lines indicate the time when the food arrives to the hospital fridge and when the delivery of the meal starts at the hospital. It can be seen that the meal boxes reaches a more stable, but also higher, temperature after arriving to S:t Görans hospital.

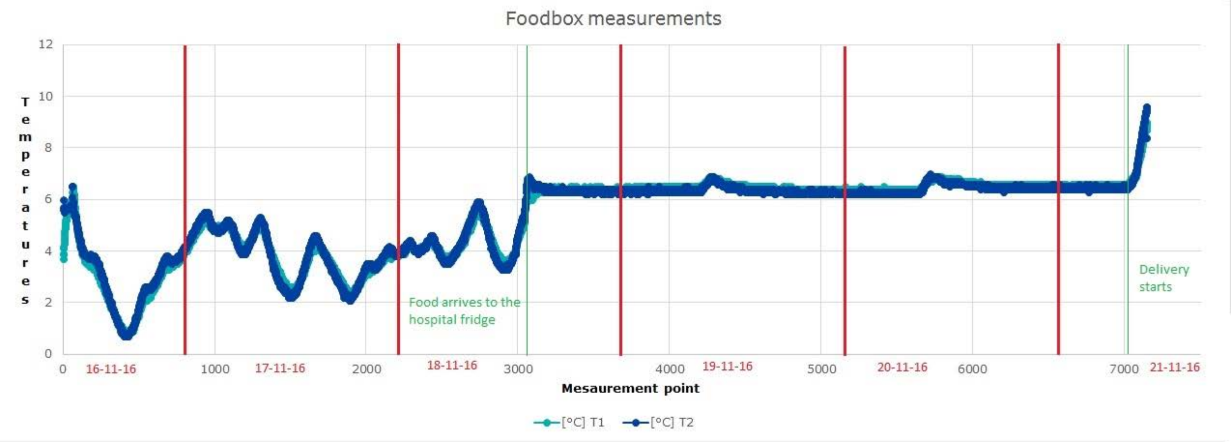

Figure 12. The result of the food box measurement during a five day period, from it is prepared until it is delivered to the wards at the hospital.

In Figure 13 a zoomed in view of the first day of measurement, Wednesday (after the chicken have been thawed) is shown including the time when the meal box preparation ends, shown in green. It can be seen that when the meal box is put inside the cold room the temperature drops, but after a certain time it starts to increase again.

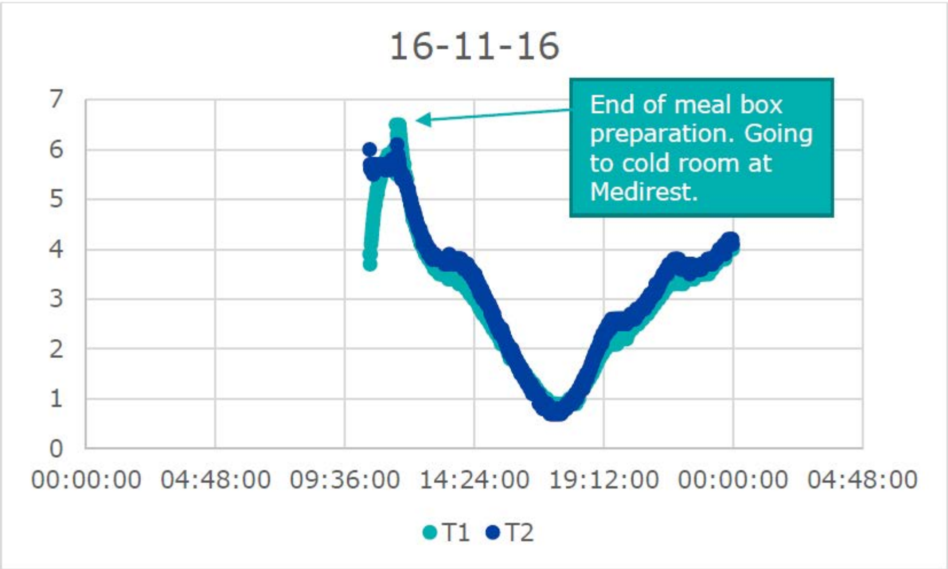

Figure 13. Showing the first day of measurements and the time for when the end of meal box preparation is.

In Figure 14 a more zoomed-in view for the measurement of the meal boxes at the Friday, the day of delivery to the hospital. The time of arrival of meal boxes to S:t Görans hospital is pointed out in green. It can be seen that the temperature becomes more stable when put in the holding fridge at S:t Görans hospital, see also Figure 15 (the whole five day period).

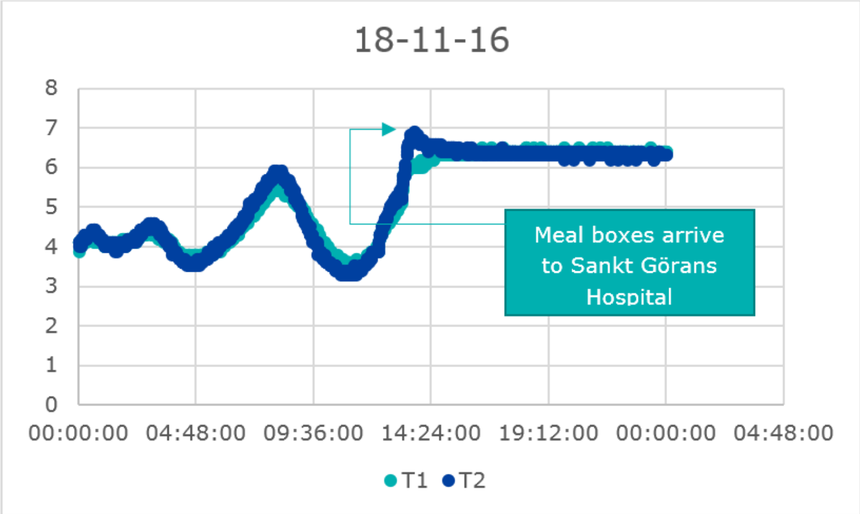

Figure 14. Showing the delivery of meal boxes to S:t Görans hospital.

In Figure 18 a more detailed view is shown of the transportation of the meal boxes from Medirest to S:t Görans hospital. Figure 15 is showing the variation of the temperature of the meal boxes to the ambient outside air temperature [13].

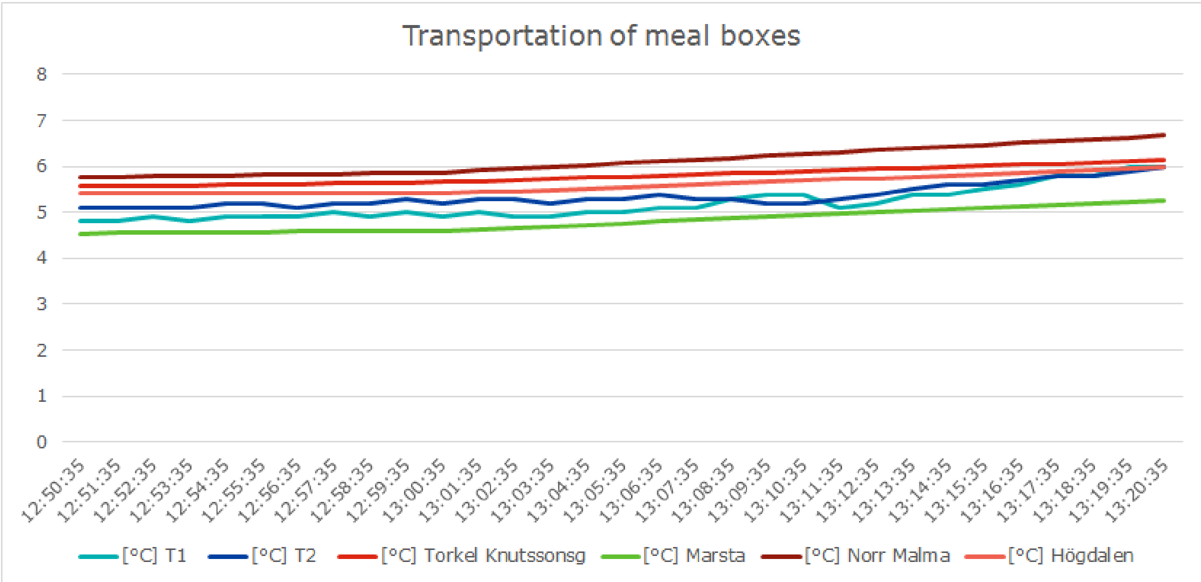

Figure 18. Showing the transportation of meal boxes from Medirest to S:t Görans hospital.

In Figure 15 a more zoomed-in view for the last day of measurement is shown (Monday). The time when the meal boxes are started to be delivered at the hospital is pointed out in green. It can be seen that the temperature rises as the meal boxes are put inside the transportable mini fridges.

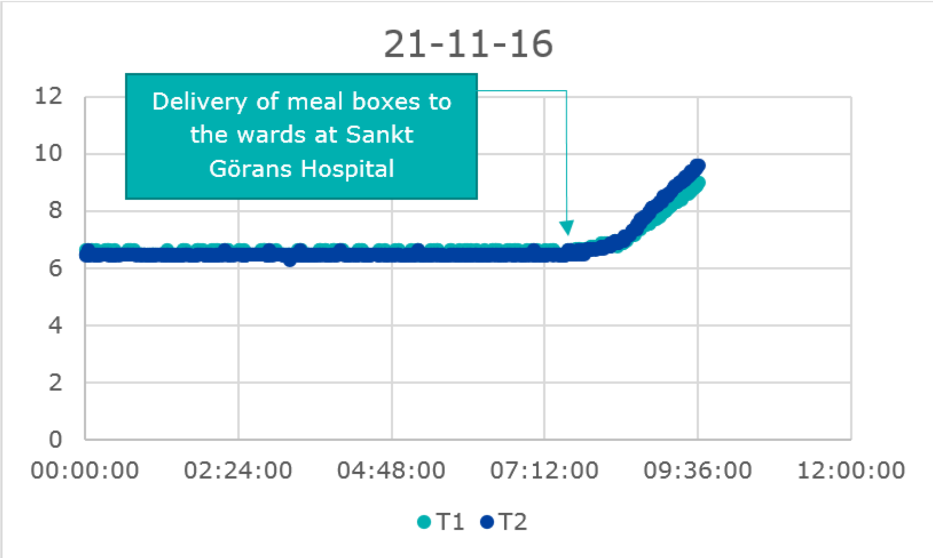

Figure 16. Showing the last day of measurements with the time of when the meals boxes were delivered to the wards at S:t Görans hospital.

In S:t Görans hospital the temperature of the fridges at the wards was noticed during a visit, and is presented in Table 1. Most fridges hold the temperature of 4 °C.

Table 1. Temperatures in fridges at the wards at S:t Görans hospital.

Ward	Temperature in fridges (°C)
Floor 8 Ward 1	4.0
Floor 7 Ward 1	5.0
Floor 7 Ward 2	No access
Floor 6 Ward 1	4.0
Floor 6 Ward 2	4.0
Floor 5 Ward 1	4.0
Floor 5 Ward 2	6.0
Floor 4 Ward 1	4.0
Floor 4 Ward 2	6.8

8 Analysis and discussion

In the previous sections it has been showed how the data were collected and which steps of the cold chain has been logged. In the introductory part it was mentioned that the cold chain is a very complex and long sequence of events that can takes weeks and even thousands of kilometers from the origin up to the final delivery. However, for practical reasons and limited time availability, the focus on this project has been posed only on the last part of the whole chain, from that the chicken is put to thaw.

These are clear limitations to the investigation process and there is therefore a possibility that the results collected and displayed previously are not enough to prove the integrity of the cold chain. Eventual issues occurred at earlier stages can still affect the quality of the final products. It should be mentioned also that Medirest performs controls on the goods provided by external companies, in order to reduce the risks mentioned before. It can be therefore stated that the limitations of this investigations can be a critical point for the overall evaluation, but the chances of this being the case are relatively small, making the overall study still an interesting and valid starting point for further works.

As mentioned in the result section, the data logging concerning the defrosting process presents an odd behaviour, see Figure 14. It is possible to see that thermocouple T3 and T1 periodically show peaks in their measurements. However the data from T2 have a smoother curve, nevertheless some minor oscillations are present anyway. The most reasonable explanation for the oscillations is within the control system for the fridge. The compressor in the cooling unit most probably have an on-off function with a time span of around 15 minutes, which results in small temperature oscillations. Also a bias error in the instrument used for temperature measurement in the chicken may be a part of the explanation, that may resulted in a periodical divergence between logged data and real temperatures.

Another possible explanation, but less likely to be the right one, is the possibility that a draft or some other force has been affecting the measures. If the thermocouples were placed in unstable positions, the contact between them and the defrosting chicken may have been affected, resulting in this wavy logging curve. The second set of measures cover a larger timespan, see Figure 15, and a deeper analysis shows that, even considering just a shorter span, there is no hint of the oscillating behaviour that characterized the defrost phase. Considering that the second phase has been monitored with a different instrument set, the hypothesis of an instrumental error seems reasonable.

During the preparation of the meal boxes it may be seen that the temperature increases, but with fluctuating elements (Figure 16). The difference between the blue and the green line may originate in that the different chicken filets were in different stages of thawing as the measurements started. Furthermore, the thermal couples were exposed to air as the meal boxes were going through the sealing machine. The first three days in which the meal boxes stayed in Medirest holding cellar the temperatures have been going up and down, reaching up to 5.5 °C, while in the remaining days at the hospital fridge the conditions remained almost unchanged until deliveries (Figure 15). The temperature in the holding room was set to be around 4 °C, and the chicken never trespassed 6 °C, so there was no real problem in the cold chain.

Once again, the most reasonable explanation for the temperature fluttering is the control system for the temperature in the fridge. The system has a temperature set point of 4 °C and the temperature is most likely to be controlled by a the "real" temperature in the fridge. Depending of where the temperature sensor is placed in the room it could both be affected by internal gains both from people an goods which may have a higher temperature than the room when entering the fridge. Presence of people may also affect the ventilation flow, which may increase the temperature in the room. Other factors may be doors opening, and to some extent also outdoor temperatures, and so forth. The cooling demand is always adapting to the room's temperature, so due to the level of activity and the amount of internal loads, as well as the ventilation flow required at the Medirest facility the cooling demand differs. Since the response is not immediate it can happen that an increase in cooling demand results in a temperature variation for the food several hours later.

Another explanation may be that the meal boxes were placed quite close the door, this could explain the variations in measurement as people coming in and out of the room causing draft from the nearby rooms with higher temperatures. The critical point of this theory is that the temperature change was present also during night, when no doors were supposed to be open. It could also be mentioned that the dishing room is placed next to the holding fridge, which may cause temperature variations. Still, diches is only done during the day. How this could affect the temperature during night would need further investigation.

During the transport of the meal boxes from Medirest to S:t Görans hospital, the temperature increases within the chicken in accordance to the increased outside air temperature (Figure 18) however, not to a significantly higher level and no inadequate temperatures are reached. During summer a higher fluctuation and response to the higher outside air temperatures could be expected, this however would need more measurement and further investigation to be verified. The increase of temperature could depend on the exposure to air, because during the time of measurements the outdoor air temperature has been higher than normal in November. However Medirest's routines with the refrigeration system of the truck could counteract those factors. Because during summer the truck's refrigeration system is turned on a while before loading starts and in the winter the system is turned on after the truck is loaded. The distance between Medirest and the hospitals is relatively small. Hence the food probably will not be affected in terms of temperature during the transport if the truck would not keep the desired temperature. If long queues would occur due to traffic, the temperature could be affected depending on for how long the truck is stuck in traffic.

It is important to notice that the storage temperature in S:t Görans holding fridge is significantly more stable than at the factory, but it is always above 6 °C, which is the storage threshold temperature set by Medirest. The estimated time above 6 °C is around 44 hours (Figure 15), which is the time passed from the dispatching from Rotsunda up to the delivery to the hospital kitchens. The logged values are around 6.5 °C, which is not far over the limit but still something that could be worth a deeper investigation, in order to reduce every possible risk and improve the product quality. It should be mentioned that construction works are going on at the hospital and the cold rooms are only temporary. Bad insulation and insufficient refrigerating capacity with in the cold room might be an explanation for this problem. Probably it will be solved when switching to the new properly designed cold rooms. However, the temperature never increase over 8 °C which is the limitation set by Livsmedelsverket, so no actual problem in the cold chain were detected.

The temperature increased during the delivery of the meal boxes to the different wards at S:t Görans Hospital, as they were placed in the transportable mini fridges. At the end of the delivery round, food reaches above the temperature limit of 8 °C for 20 minutes. The problem could indeed be even more significant in the summer time when ambient temperatures are higher. This part of the cold chain would need further investigation. Afterwards, the meals are put in the fridges at the wards. Even though the fridges at the wards at S:t Görans hospital is not a part of Medirest responsibility regarding food quality, the temperatures in these fridges were noticed. The majority of the fridges kept a temperature of 4 °C. Two of them had temperatures that were higher than 6 °C. This most likely depends on that the fridges have previously been open by the kitchen staff at the wards.However, there is no other obvious indication that the fridges are not working properly and hence it is assumed that these are well-functioning and the meal boxes are handled in an appropriate way.

Another aspect that was briefly investigated during the project were the choice of refrigerant as well as refrigeration system design, which are important factors both for the effectiveness, cost and environmental impact of the system, regarding both the facility and the delivery vehicle at Medirest. An introduction of different refrigerants as well as different refrigerating solutions in transport available at the market has been given. For discussion regarding improvements of the choice of refrigerant and system solution at Medirest, see chapter 7 and 8 above. Since R404a has several drawbacks this refrigerant could be phased out and be exchanged with other HFC R407a or R407f, where the major design of the equipment could be kept. An alternative in the long run, when the system needs to be replaced or major renovated it could be enhanced to one with CO2 and designed as a cascade system.

8.1 Improvements of measurements

The measurements performed in this project have room for improvement. Here follows a few things that could have been improved to achieve a better and more reliable result:

- More tests should have been carried out.
- Measurements of the whole cold chain should have been done, including the frozen state of the chicken.
- The measured prepared meal boxes should have been placed in the main meal preparation room rather than in the small meal preparation room in order to be exposed to the internal loads present by the staff.
- The measurements should have been carried out for a longer period of time, including during the summer time when the food is more exposed to high temperatures.
- Use better and more precise measurement equipment.

9 Conclusions and Future work

In accordance to the set objective of this project mapping and logging of the cold chain at Medirest was performed successfully. The analyse of collected data from the temperature loggers did not indicate any unsatisfactory temperature throughout the cold chain, except during the delivery of the meal boxes to the different wards, as the temperature reached above 8 °C for about 20 minutes. This may indicate that the time of round is too long, or that the transportable mini fridges are unable to maintain appropriate temperatures. Another crucial part of the cold chain was during storage in the cold room at S:t Görans hospital. It turns out that the temporary cold room at S:t Görans hospital was maintaining the meal boxes at a temperature of 6.3 °C. In accordance with Medirest own regulations to maintain temperatures 2 °C below legislated temperature levels, this is one section of the cold chain that might be of interest of improvements. Other exposed parts of the meal boxes were during the preparation of the meal boxes, the transportation to the hospital, as well as fluctuating temperatures in the holding fridge at Medirest. But no inadequate temperatures were reached during these sections of the cold chain.

The measurements were carried out in November, which is a relative cold month. Problems not showed in this study could hence occur during the summer months when the cold chain is exposed to higher loads and higher ambient temperatures. Warmer outside air temperatures causes more heat transmission losses from the cold storages which may not be counteracted by the current refrigeration systems, thus leading to warmer temperatures within the cold rooms and storages. Furthermore, the meal boxes are also more exposed to higher ambient temperatures when moved and transported which requires effective routines and refrigerators. Hence, it would be preferable to repeat the measurements in the summer time when some parts of the cold chain could be more exposed.

This is an interesting topic and there are room for further investigations in the future. Here follows some things that could be of interest to do further research about:

- Extend the investigation to include the entire cold chain of the products, either at reception of the food at Medirest, or even further back in the cold chain.
- How the control system of the fridges and freezers are conducted and operated.
- Investigation of other types of cold chains included in the project *Aktivt åldrande*, such as meal delivery to private households or elderly care.
- The investigation of temperatures of the defrosting of chicken, as presented in this report, was not investigated during enough time. In order to avert any possibility of deficiency in the cold room, measurements should have been conducted to the point where temperature of the defrosting chicken has reached the set point temperature of the room for a longer period of time. This in order to state that the cold room is operating as intended.

- Given the unfortunate time of the year this project was performed, it is safe to say that an investigation of refrigeration would be more rewarding to conduct during the time of the year when refrigeration needed the most. Conducting this investigation during the summer time would have been more suitable due to the influence of the warm outside air temperature.
- In the cold rooms at Medirest there are temperature loggers that often are placed close to the doors. Since the doors are open several times during the day it would be of interest to investigate how the temperatures within these varies in different locations of the fridge and freezer and how the food temperature is affected.
- Since only one tray of chicken was measured within the several refrigerated spaces it would have been more suitable to place temperature loggers at different locations within the cold rooms and freezers. The temperature profiles of the rooms are usually warmer at the ceiling and in close proximity to the doors and colder at floor level. By only measuring one tray of chicken important data indicating warmer temperatures may have been overlooked.
- Another matter worth further investigation is the measurement of the raw salmon. Raw fish is a critical product in the cold chain and it is important to get ensure its integrity throughout the whole meal box production. Unlike the chicken, that comes already cooked and frozen, the salmon arrives raw to the Medirest facility which makes it more vulnerable. Another issue addressed by one of the employees at Medirest regarding the salmon is that higher temperatures of the salmon compared to the temperature in the fridge it is placed in have been recorded. This may be a potential problem since the threshold temperature for keeping the food at a secure temperature for avoiding bacteria can be reached. Why it is possible to achieve higher temperatures than the room is a question for further investigation.
- An investigation of the impact from the dishwasher room located beside the holding fridge on the temperature within the holding fridge.

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