

Annex 31

Advanced Modeling and Tools for Analysis of Energy Use in Supermarket Systems

Final Report

Operating Agent: Sweden



2012

Report no. HPP-AN31-1

Published by

IEA Heat Pump Centre
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Production

IEA Heat Pump Centre, Borås, Sweden

ISBN 978-91-87017-52-0

Report No. HPP-AN31-1

Preface

This project was carried out within the Heat Pump Programme, HPP which is an Implementing agreement within the International Energy Agency, IEA.

The IEA

The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of over 40 Implementing Agreements.

The IEA Heat Pump Programme

The Implementing Agreement for a Programme of Research, Development, Demonstration and Promotion of Heat Pumping Technologies (IA) forms the legal basis for the IEA Heat Pump Programme. Signatories of the IA are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the IA collaborative tasks or “Annexes” in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and work plans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex. The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

The IEA Heat Pump Centre

A central role within the IEA Heat Pump Programme is played by the IEA Heat Pump Centre (HPC). Consistent with the overall objective of the IA the HPC seeks to advance and disseminate knowledge about heat pumps, and promote their use wherever appropriate. Activities of the HPC include the production of a quarterly newsletter and the webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the IEA Heat Pump Programme and for inquiries on heat pump issues in general contact the IEA Heat Pump Centre at the following address:

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**KTH Industrial Engineering
and Management**



IEA Heat Pump Program Annex 31

ADVANCED MODELING AND TOOLS FOR ANALYSIS OF ENERGY USE IN SUPERMARKET SYSTEMS

Final Report

**Canada
Germany
Sweden (Operating Agent)
United States**

2006 - 2011

Summary

The main goal of Annex 31 is to provide new knowledge, methods and reasonably accurate simulation tools to assist in the analysis of the energy performance and in the development of energy efficient strategies for supermarkets. Another goal of Annex 31 is to increase the level of understanding of the interaction between the refrigeration system and the indoor climate as well as HVAC system and the building envelope. A third goal is to develop indices for energy use and environmental impact for different countries and systems.

Participating countries are Sweden, Canada, Germany and the United States. Sweden is represented by the Department of Energy Technology at KTH and the Technical Research Institute of Sweden (SP). KTH is acting as the operating agent (OA)

This National final report presents the work being conducted within the IEA Annex 31 by May 2011. The project has been granted extension from the IEA Heat Pump Centre so activities within this international cooperation project will continue until the middle of 2011. This report describes the goals of the project and the methodologies used to achieve them. The project tasks have been discussed and main findings has been summarized. The conclusions of this report are based on the completed task by the date of submission which is mainly related to the experiences, difficulties and qualities of data collection. They are also related to developed figures of performance indices.

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1 Introduction

Supermarkets are the most energy intensive buildings in the commercial sector. It has been estimated that 3-5 % of the total use of electricity stems from supermarkets in industrialized countries. In addition, it is estimated that the annual refrigerant losses are as high as 15 - 30% of the total charge thus making supermarkets the No.2 emission source after mobile air conditioning. The supermarket sector has therefore a significant role to play not only from the point of view of the energy consumed but also from the point of view of the impact of refrigerant leakage¹.

IEA Annex 26 has shown that various new system solutions² such as the adoption of secondary loops both on the hot and cold sides of the refrigeration system as well as the integration of HVAC and refrigeration systems are efficient strategies to drastically reduce the charge and leaks of refrigerant as well as the energy consumption in supermarkets. There is however a strong international debate whether indirect systems are energy efficient enough in comparison with state of the art direct systems and more studies are needed to resolve this issue. Nevertheless, supermarket system design and operation are very complex due to the strong interconnection between the thermodynamic systems³, the building envelope, the outdoor and the indoor climate. For instance, during winter time the refrigeration system can work at low condensing temperatures resulting in lower energy consumption. However, the demand for space heating will be higher and could be met totally or partially by the energy released by the refrigeration system, as long as its condensing temperature is high enough. In cold climates this is an interesting optimization problem with economic and environmental impact minima not necessarily coinciding. Similarly there may be a need for hot and cold storage to help the refrigeration system match the building daily heating and cooling demand as well as to take advantage of cheap time-of-day electricity rates/peak shaving not to mention energy need for defrost.

It is also obvious that development and adoption of energy efficient display cases is one of the effective strategies needed to reduce the supermarket energy consumption but also to improve the quality and lifetime of their products as well as the comfort of their clients. Since the performance of the display cases and the thermal comfort of occupants are strongly influenced by the surrounding environment, their assessment requires also a detailed calculation of indoor air characteristics such as temperature and moisture distribution at different zones, even in the same room of the building. This part of the project should aim at the development of physically transparent⁴ component models able to handle the most common types of display cases used today and in the near future.

The ability to judge the potential benefits of a multitude of possibilities need detailed and reasonably⁵ accurate simulation and design optimization tools that take into account the full

1 1 kg of refrigerant corresponds to a Global Warming Potential i.e. GWP of 0 to 4500 kg of CO₂ equivalent dependant on the choice of refrigerant.

2 Please refer to Final report of Annex 26. Several new types of systems for commercial refrigeration have evolved during the last five to ten years. Secondary loop systems using phase changing fluids such as CO₂ and ice-slurries are examples of the latest. Other strategies to minimize charge, leakage and improve energy efficiency can be found in the report.

3 Refrigeration, HVAC and other systems...

4 to improve understanding...

5 The word reasonable is used to stress that the "support" for the design process and the understanding the interaction of various systems is more important than the ability to exactly mimic the behaviour of a specific supermarket. Someone said: "It is better to approximately right than exactly wrong..."

complexities presented by the interconnection of HVAC&R systems and the building envelope. Such tools must be able to determine, among others, the amount of energy to be stored that provides the lowest building energy consumption, the optimal range for the condensing and evaporating temperatures, the optimal flows and temperatures for the secondary loops and the optimal indoor air temperature and humidity at different zones of the building. These tools could eventually be integrated to dynamic control algorithms. Such integration would allow for a continuous optimization of the total supermarket energy systems. Nevertheless, in order to accomplish it in real time there will be a need for fast – and at the same time accurate enough – building and system simulation tools. Developing accurate and fast building simulation tools could be a challenging task since these two attributes are very often conflicting.

All of the above mentioned strategies are highly appealing to the supermarket sector since they help to reduce operating and maintenance costs and at the same time to increase product sales (since client comfort is improved). However, in order to obtain a widespread adoption of these measures it is essential to increase the awareness of the major players in the supermarket sector.

One way to “reach in” and increase awareness is to use benchmarking as a tool, although not easy to implement. It requires the development of meaningful performance indices like energy consumption and operating costs (per m^2 , or m^3 , per kg etc.), which is quite a complex task. It has to be stressed that benchmarking must be used taking National building standards, climate and other factors into account. For instance the average energy consumption in Canadian supermarkets has been evaluated at $800 \text{ kWh/m}^2/\text{year}$ whereas in Sweden this number is much lower ($350 - 450 \text{ kWh/m}^2$). Hence, there is a need to develop a methodology to assist in the comparison of figures from different countries, and probably regions and systems. Benchmarking without an analysis of underlying causes makes no sense!

The current discussion regarding environmental impact from supermarkets requires a balanced approach where both direct and indirect effect on global warming is taken into account. Two similar measures suggested in the ongoing work for the IPCC/TEAP⁶ Special Report on Safeguarding the Ozone Layer and the Global Climate System is the TEWI and the LCCP-value⁷. The calculation of the TEWI value requires knowledge of refrigerant charge, yearly leakage, energy efficiency and regional energy conversion factor (CO_2/kWh). This data is scarce and only a few reports give enough data for an evaluation. This will be an important part of the benchmarking process.

1.1 Goals

The main goal of Annex 31 is to provide new knowledge, methods and reasonably accurate simulation tools to assist in the analysis of the energy performance and in the development of energy efficient strategies for supermarkets. This has the aims of reducing the global energy consumption, the environmental impact and the life cycle costs of a supermarket within constraints such as the required quality of products, maximized comfort of the occupants and so on.

A second goal is to increase the level of understanding of the interaction between the refrigeration system and the indoor climate as well as HVAC system and the building envelope.

⁶ Intergovernmental Panel On Climate Change/Technical And Economical Assessment Panel

⁷ TEWI = Total Equivalent Warming Impact, LCCP = Life Cycle Climate Performance

A third goal is to develop indices for energy use and environmental impact for different countries and systems.

It should be noted that the methods and algorithms developed in the Annex could also evolve into tools for continuous optimization of the whole building, continuous commissioning and automated diagnostics of the different systems of the building, i.e. fault detection analysis. These tasks could be developed and expanded in future annexes.

1.2 Methodology, task and deliverables.

In order to achieve the above stated goals, the following task-sharing activities have been carried by the participants:

Task 1 - Collection of available data from different supermarkets (benchmarking)
Task leader - Sweden National Team (KTH and SP)

Task 2 – Development of performance indices for supermarkets
Task leader - Sweden National Team (KTH and SP)

Task 3 – Development and validation of a model library for specific supermarket equipment
Task leader - KTH Sweden

Task 4 – Development of whole-building simulation models.
Task leader - KTH Sweden

Task 5 – Comparison of the results obtained with the different whole-building simulation models for selected case studies
Task leader - NRC Canada

Task 6 – Future perspectives and possibilities
Task leader – Sweden National Team (KTH and SP)

Task 7 – Deployment of the knowledge developed (indices, guidelines, papers, fact sheets)
Task leader – Sweden National Team (KTH and SP)

Results from the different tasks are presented in Chapter 2

2 Project Tasks

The most important goal of Annex 31 is to provide new knowledge, methods and reasonably accurate simulation tools to assist in the analysis of the energy performance and in the development of energy efficient strategies for supermarkets. Another goal of Annex 31 is to increase the level of understanding of the interaction between the refrigeration system and the indoor climate as well as HVAC system and the building envelope. A third goal is to develop indices for energy use and environmental impact for different countries and systems.

In order to achieve the above stated goals, the participants in Annex 31 have carried seven different task-sharing activities. Results from these tasks activities are presented in this Chapter

2.1 Task 1: Collection of available data from different supermarkets (benchmarking)

Task leader - Sweden National Team (KTH and SP)

Most large supermarkets are currently fully instrumented and equipped with high performance computerized control systems. A large number of data are available but generally poorly exploited to analyze the energy performance of the HVAC&R equipment and optimize its operation. The objective of this task is to collect enough data in order to establish energy efficiency indices for benchmarking and to validate the models to be developed or improved. The data collected should support a TEWI or LCCP analysis.

The following table has been developed by the Swedish national team and distributed among the participants in order to fill the available supermarkets data.

Table 1 contains many details of the supermarket where the participants were asked to fill few essential points to allow basic analysis of the supermarket. Additional specifications have been added in order to facilitate detailed analysis of the different systems depending on the availability of data.

Table 1: Data collection table.

				Unit	Comments
Mandatory data	Store Specifications				
	Country				
	City				
	Size				
	Area				
	Total			m2	
	Sales			m2	
	Volume			m3	
	Opening hours	Open	Close		
	Mon-Fri	07:00	20:00		
	Sat	Closed			
	Sun	Closed			
Mandatory data	Energy Details				
	Total energy consumption			kWh/year	
	Electricity			kWh/year	
	Price			SEK/kWh	
	District heating			kWh/year	
	Price			SEK/kWh	
	District cooling			kWh/year	
	Price			USD/kWh	
	Gas			m3/year	
	Price			SEK/m3	
	Oil			m3/year	
	Price			SEK/m3	
Priority data	Refrigeration system				
	Refrigeration capacity			kW	
	Medium				
	Low				
	Refrigerant used			kW	
	Medium				
	Low				
	Refrigerant charge			kg	
	Medium				
	Low				
	Leakage rate			kg/year	
	Medium				
	Low				
Priority data	Type of refrigeration system			kg/year	
	Medium				
	Low				
	Other information on cold area (if available)				
	Heat recovery				
	From refrigeration system condenser	Unknown		kW	
	Design capacity				
	From exhaust air (preheating of supply air)	Unknown		kW	
	Design capacity				
	Other information available on items (Climate zone, etc.)				

The wish in the data collection task is to collect the data in the categories presented in the data collection table, however, in practice data collection in supermarkets does not necessarily separate the variables as we would like to have for the required analysis in this project. For example, the electric power consumption measurement could include electric power consumption for heat pumps and for space cooling chillers along with the need for lighting and other uses in the supermarket. Therefore, for most of the cases, energy consumption of the supermarket was used as one unit and it was hard to separate for what that energy was used, except for the consumption of the refrigeration system which is usually measured separately.

The Canadian partners; CANMET Energy Technology Centre - Varennes (CETC-V) and Hydro-Québec Research Institute, Energy Technologies Laboratory (LTE) contributed to this task through the provision of high level (black box) data from several supermarkets and detailed data from five supermarkets. Regarding the detailed supermarket data, LTE and CETC-V have fully instrumented and monitored a number of conventional and advanced supermarket refrigeration/heat recovery systems in the past few years.

For a number of essential parameters as primary refrigerant's pressures and temperatures, power demands and energy consumptions, information is presented in graphic form. Other information is available in references.

The contribution from the USA national team is monitoring data from several supermarkets obtained in previous and ongoing monitoring projects. This data is detailed on refrigeration system performance but generally not so detailed on the building or HVAC systems.

One US supermarket company has provided a summary of energy use and leakage data for 27 stores. In addition similar data were obtained from six other stores. These data will be useful to meet some of the requirements of task 1 but will not be sufficient to generate statistically validated indices nor will it be representative of the US supermarket industry as a whole.

The planned contributions from the Swedish national team to this task are general data from several supermarkets and detailed data from at least ten supermarkets. A questionnaire (appendix 5.1) has been developed by the Swedish national team for the collection of data and development of performance indices for supermarkets in Sweden. The questionnaire has been distributed to the participating countries and to the two biggest supermarkets chain in Sweden.

The first contribution of Germany's national team to the Annex 31 should be a general description of the different actors, markets, developments and trends of the supermarkets in Germany, from convenience stores to hypermarkets.

2.2 Task 2: Development of performance indices for supermarkets

Task leader - Sweden National Team (KTH and SP)

This task will focus on the development of meaningful performance indices for supermarkets, like energy usage, CO₂ – emissions, operating costs (per m², or m³, per m display case, etc.) for different countries and systems. It will be based on the analysis of the data collected in task 1 and an analysis document where performance indices are explained and resolved into categories such as (i) efficient refrigeration technologies, (ii) efficient HVAC integration and control, (iii) efficient buildings (building codes), (iv) climate issues and (v) other issues. One of the primary tools for comparison will be based on the TEWI/LCCP-concept meaning that direct and indirect effect on global warming need to be determined for each supermarket.

The aim with task 2 has been to develop performance indices for supermarkets, like energy usage, CO₂ – emissions and operating costs for different countries and systems. It is based on the analysis of the data collected in task 1 and an analysis document where performance indices are explained and resolved into categories such as (i) efficient refrigeration technologies, (ii) efficient HVAC integration and control, (iii) efficient buildings (building codes), (iv) climate issues and (v) other issues.

Supermarket system design and operation are very complex due to the strong interconnection between the HVAC and Refrigeration systems, the building envelope, the outdoor and the indoor climate.

In order to obtain a widespread adoption of energy efficient solutions in supermarkets it is essential to increase the awareness of the major players in the retail sector. One way to increase awareness is to use benchmarking as a tool, although not easy to implement. It requires the development of meaningful performance indices like energy consumption and operating costs per unit of area or volume, etc. which is quite a complex task. It has to be stressed that benchmarking must be used taking National building standards, climate and other factors into account. The work in this study has been limited to include performance indices related to energy usage. The main reason to this limitation is lack of data for leakage rate, which is necessary for performance indices related environmental impact. Performance indices related to operation cost vary from one country to another caused of national cost for energy. The performance indices expressed as energy could easily be recalculated as operational cost on a national level.

Table 2 presents the energy use and the performance indices expressed as total energy in relation to total area of the supermarket (kWh/m²/year) from 146 supermarkets in Sweden.

Table 2: Energy use expressed as kWh/m²/year from 146 supermarkets in Sweden.

Supermarkets		Average Area	TotEner	TotEner/m2	TotEI/m2
Total Area	Number	m2	kWh	KWh/m2	KWh/m2
0 - 600	21	463	255451	551	527
600 - 1000	51	786	389758	496	475
1001 - 1500	29	1221	560433	459	441
1501 - 3000	31	2066	929026	450	425
3001 - 9000	14	5044	1908686	378	356
	146				

The average energy usage in Canadian supermarkets has been evaluated to 800 kWh/m²/year whereas as Table 2 shows that this number is much lower (350 - 450 kWh/m²/year) in Sweden. On the other hand if the energy usage is related to the installed refrigeration capacity

kWh/m²/kW Refrigeration Capacity, the difference between Canadian and Swedish supermarkets is insignificant. This shows that performance indices of this kind have to be selected carefully.

In an earlier study performed at SP based on field measurement performed in 2 supermarkets during one year another performance indices has been defined. The aim with the performance indices is to compare the energy performance of the refrigeration system for chilled and frozen food. The work included an analysis of energy systems in the supermarkets as well as a more detailed study of the electrical energy usage for chilling and freezing food. For the overall system evaluation it was important to find performance indices that can be used in such comparisons. The size of the two supermarkets differs. It is common to use energy/sales area or energy/total area for this type of comparison. A comparison of the supermarkets using total energy/ total area or sales area indicates that supermarket B uses the energy more efficiently, see Table 3.

Table 3: Comparison of different performance indices for two supermarkets during one year

Performance indices	Supermarket A	Supermarket B
Total Energy / Total area (kWh/m ²)	425	348
Total Energy / Sales area (kWh/m ²)	995	434
Part of the Total Energy used for chilling and freezing food including Electrical Energy to the outdoor dry-coolers (%)	30	46

This is partly true but it is important to know that supermarket A has a more complex energy system with offices, bakery and a greenhouse. One way to decrease the energy consumption and increase the cost effectiveness is to use the surfaces more efficiently. Therefore new performance indices are defined for the comparison of the energy efficiency of the refrigeration systems where the influence of other energy systems in the supermarket can be neglected. Even for a comparison of the refrigeration systems, supermarket B still was the most energy efficient.

$$W_{e,reftot} = W_{e,dry-coolers} + W_{e,ref} + W_{e,fr} \quad (1)$$

$W_{e,reftot}$ = Annual total energy usage, refrigeration system for chilled and frozen food (kWh)

$W_{e,ref}$ = Annual total energy usage, refrigeration system for chilled food (kWh)

$W_{e,ref}$ = Annual total energy usage refrigeration system for frozen food (kWh)

$W_{e,ref}$ = Annual total energy usage dry-coolers (kWh)

$w_{e,reftot}$ = Performance indices refrigeration system for chilled and frozen food, energy related to chilled air volume (kWh/m³)

$w_{e,ref}$ = Performance indices refrigeration system for chilled food, energy related to chilled air volume (kWh/m³)

$w_{e,ref}$ = Performance indices refrigeration system for frozen food, energy related to chilled air volume (kWh/m³)

Table 4: Resulting performance indices for the refrigeration system

Performance indices	Specific Electrical Energy for Refrigeration (kWh/m ³)	Specific Electrical Energy for Chilling Food (kWh/m ³)	Specific Electrical Energy for Freezing Food (kWh/m ³)
	$w_{reftot} = \frac{W_{e,reftot}}{V_{reftot}} \quad (2)$	$w_{ref} = \frac{W_{e,ref}}{V_{ref}} \quad (3)$	$w_{fr} = \frac{W_{e,fr}}{V_{fr}} \quad (4)$
Result Supermarket A	613	499	698
Result Supermarket B	259	169	601

One way to compare the energy efficiency, especially for supermarkets of different size is to use energy performance indices defined as refrigerated electric energy/refrigerated air volume. The

advantage of this method is that supermarkets with different combinations of rooms and cabinets can be compared and the size of the supermarket becomes less important. Also the influence other large energy consumers such as the greenhouse in supermarket A can more or less be neglected in such a comparison.

Figure 1 shows annual total energy consumption versus total area in the supermarket first for Sweden and Figure 2 is the same figure including data for USA and Canada. The figures show that total energy consumption is increasing with total area. In table 1 above is the supermarkets reported in different categories based on the size of the supermarkets. Conclusions from earlier studies performed at KTH and SP indicate that supermarkets should be categorized in different sizes. In a small supermarket stands the energy intensive refrigeration equipment for a relatively larger part of total area in the supermarket. The recommendation is therefore that comparison should be performed with supermarkets from the same category “size”. To make such a comparison on an international level is a challenge the design of supermarkets and opening hours can vary a lot from one country to another.

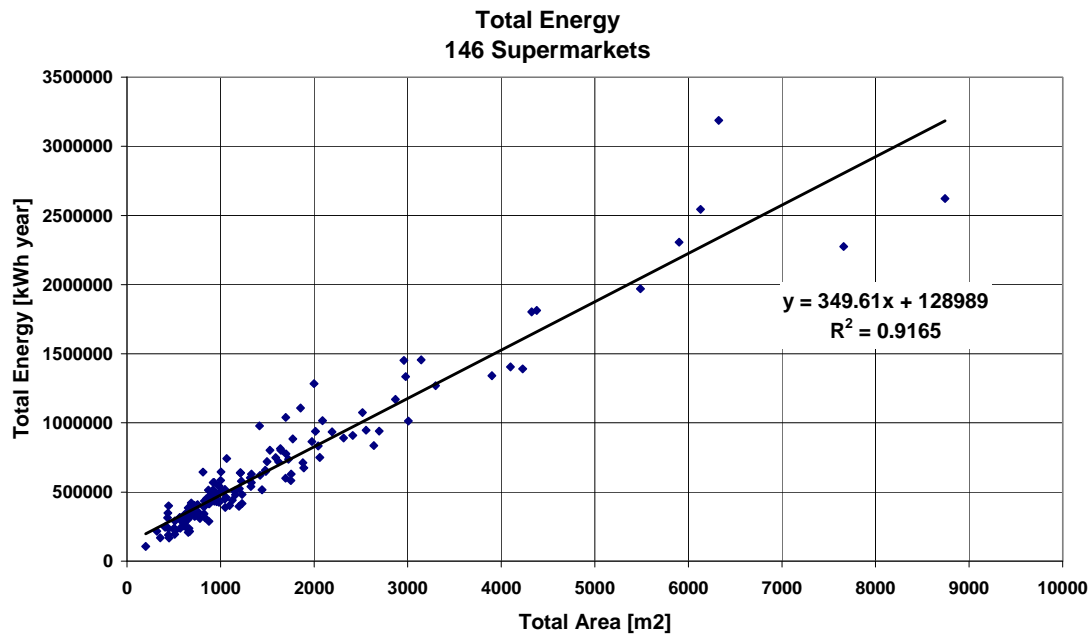


Figure 1: Total energy demand versus total area in Sweden.

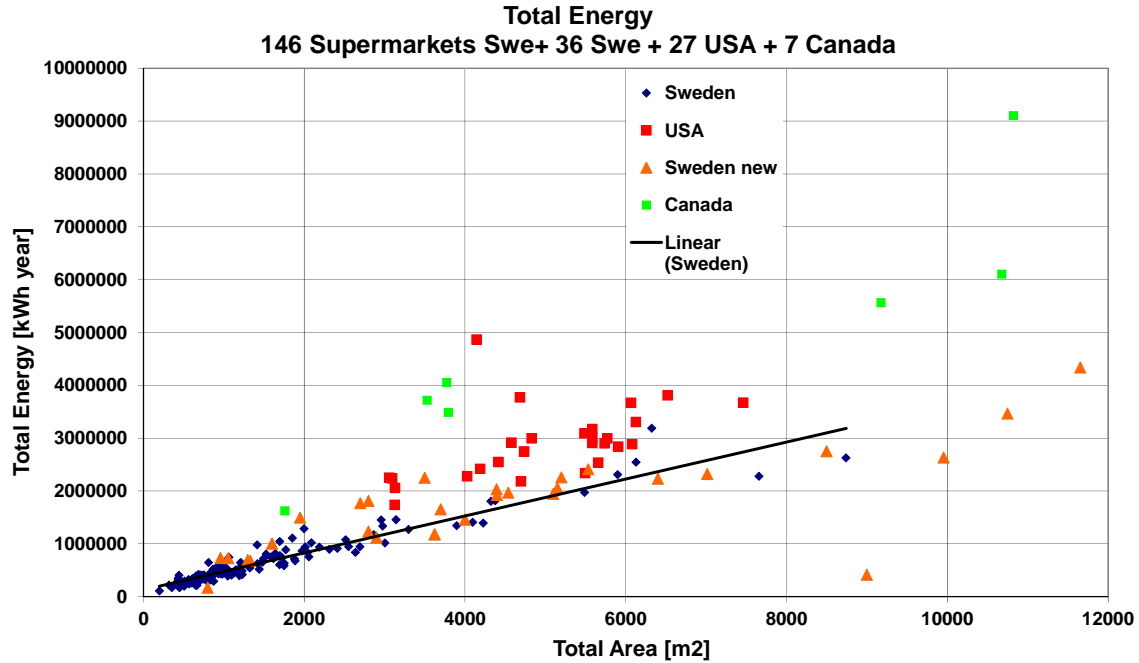


Figure 2: Total energy demand versus total area Sweden, USA, Canada.

Figure 3 shows annual total energy demand per square meter versus total area in the supermarket for Sweden and Figure 4 is the same figure including data for USA and Canada. Using total energy demand per square meter is the most commonly used performance indices in statistic for the building the sector. This performance indices is of interest for comparison of supermarkets with other types of buildings. In addition this could be used for benchmarking of energy performance in supermarkets but it should be performed between supermarkets of the same category. In this study we need further information from the other countries to make such a categorization on an international level.

Using the performance indices kWh/m^2 indicates that the Swedish supermarkets are more energy efficient, see Figure 3 and Figure 4. In addition larger supermarkets are more energy efficient than smaller super markets. One explanation to this outcome is that a relatively larger area in a small supermarket is used for sales of refrigerated goods. The refrigeration system for display of chilled and frozen food is the most energy consuming systems than other systems in the supermarket. It is finally of importance to note that it is a large variation in energy performance between different supermarkets of the same size.

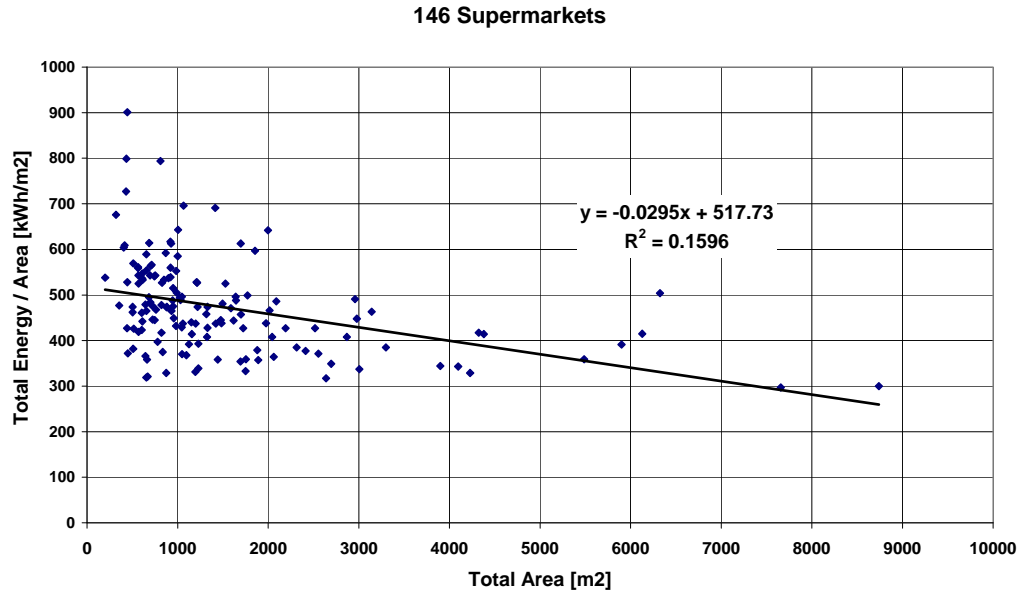


Figure 3 Total energy demand per area versus total area Sweden

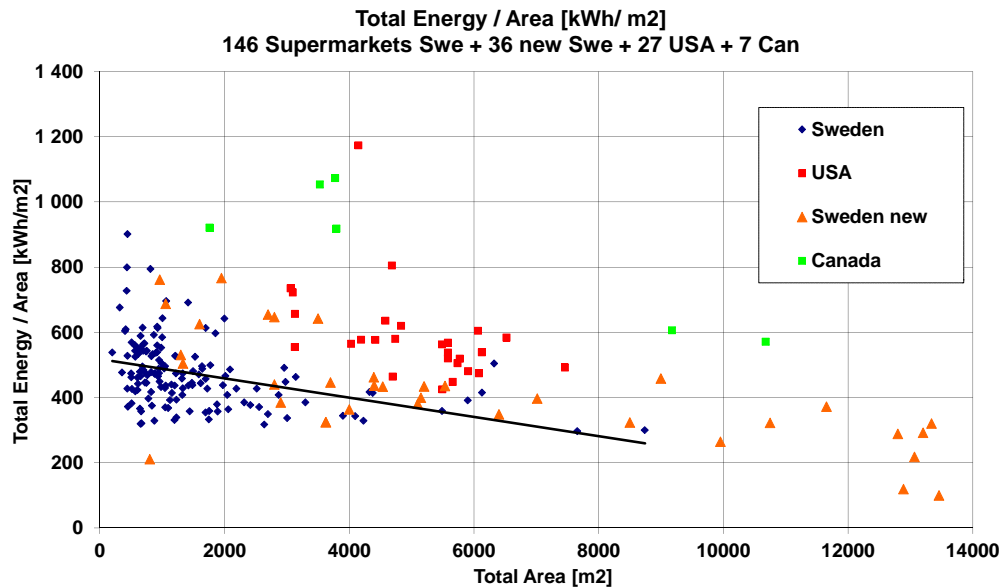


Figure 4: Total energy demand per area versus total area Sweden, USA and Canada

Figure 5 shows annual total energy demand per opening hours versus total area in the supermarket for Sweden and Figure 6 is the same figure including data from USA and new supermarkets from Sweden. With a correction to opening hours a comparison of energy performance between Sweden and USA indicate that the supermarkets from USA are at least as energy efficient as the Swedish supermarkets. The conclusion is that it is necessary to make a correction to the opening hours. It is differences in opening hours between countries and between different categories of supermarkets. The opening hours is probably the single most important factor influencing the total energy usage.

Studies performed at SP in both laboratory and field show that the energy usage from refrigeration system for chilled food can vary as much as 100 % between open and closed

supermarket. This is mainly caused of most of chilled food are displayed in vertical display cabinets. A comparison of the total refrigeration system for chilled and frozen food shows a decrease in energy usage for closed supermarkets with as much as 55 %. The explanation to the lower figures is that main part of the frozen food is displayed in horizontal cabinets. The possible savage with coverage during the closed period is lower in a horizontal cabinet. In addition is the light turned off in a closed supermarket will also significantly influence the energy usage. As a rule of thumb lighting stands for 20 to 25 % of the energy usage in a Swedish supermarket.

146 Supermarkets

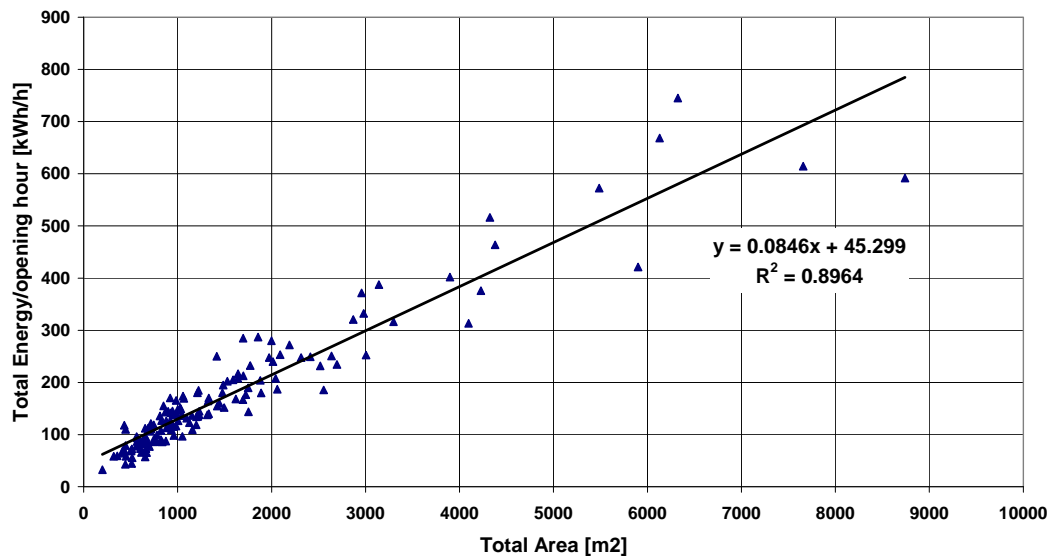


Figure 5: Total energy demand/ opening hours versus total area Sweden.

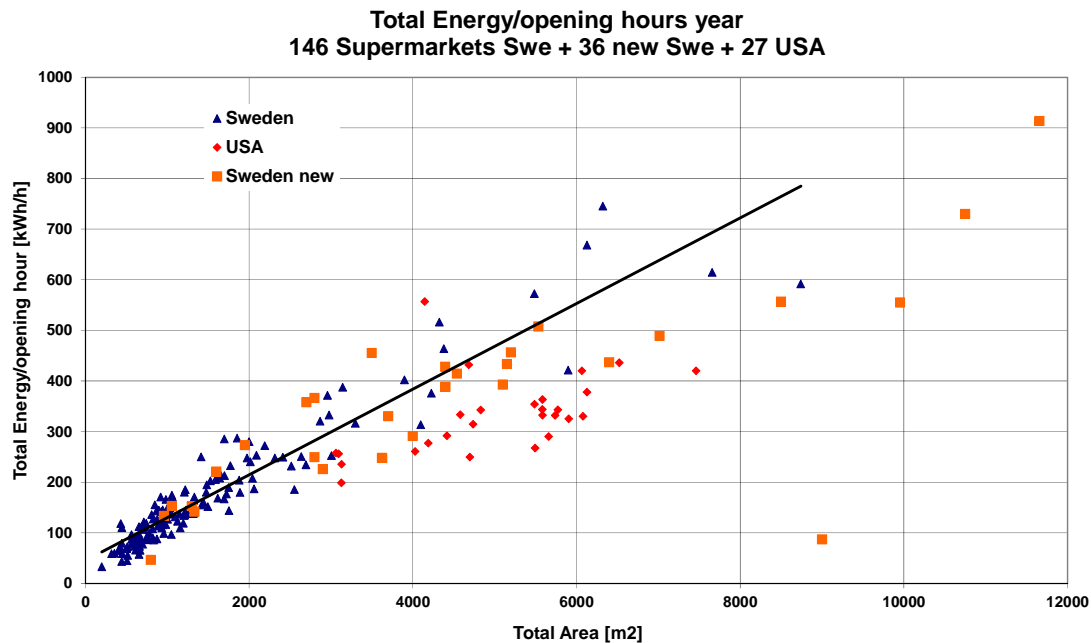


Figure 6: Total energy demand /opening hours versus total area for Sweden and USA.

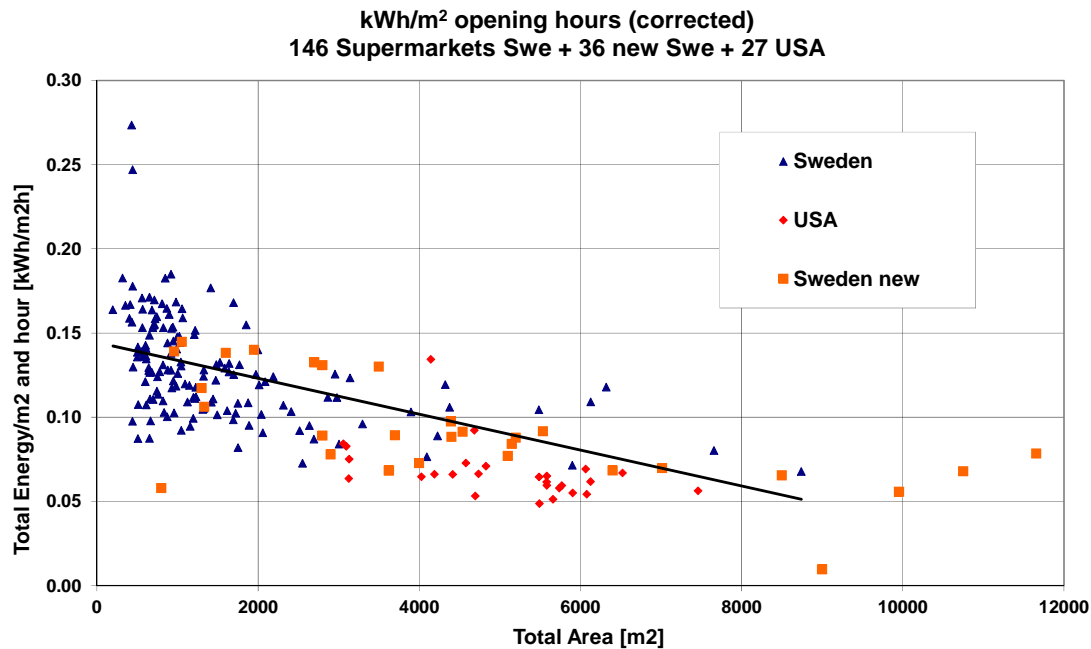


Figure 7: Total energy demand /opening hours and area versus total area for Sweden and USA.

In task 2 a number of different performance indices have been defined and compared national and international. An international comparison shows that performance indices need to be selected carefully. Performance indices have been described both on a global level describing the overall energy performance of the supermarket and performance indices for comparison of the energy performance of the refrigeration system for storage and display of frozen and chilled food.

The recommendation from this work is following:

The input data need to be analyzed in detail and it is necessary to collect annual energy usage because it is a huge variation in energy usage between summer and winter it can vary as much as 100 %.

It is common to relate the energy performance to the size of the building. For such performance indices it is important to have a definition of the area and it is important to be aware of that such definition can vary from one country to another.

For comparison of energy performance of supermarkets with other types of buildings is total energy usage in relation to the area of the building the most suitable. The result shows that the energy performance can vary a lot from one supermarket to another. In addition it also indicates that supermarkets in general use a lot of energy and it is a need for further improvements. If such a performance index should be used for comparison of different supermarkets it is a need for a categorization. In Sweden it is common to make such a comparison for different sizes, see Table 2. In Sweden most of the supermarkets are designed for different concepts with fixed installed refrigeration capacity for chilled and frozen food and also the opening hours are relatively similar. From a national perspective it can be suitable to use a “simple” model for categorization based on the size. A categorization on an international level it is a need to make a more sophisticated categorization taking into account at least the opening hours.

For an international comparison on a global level it is important to use performance indices which make correction to the opening hours like in Figure 6 and 7. There is often a huge difference in opening hours between Sweden and USA. For further international comparison

there is a need for more data from a variety of countries to obtain a statistically valid index. The data available from USA and Canada for this report is limited. The design can vary between different concepts.

For comparison of the refrigeration system for chilled and frozen food, especially for supermarkets of different size is to use energy performance indices defined as refrigerated electric energy/refrigerated air volume the best. The advantage of this method is that supermarkets with different combinations of rooms and cabinets can be compared and the size of the supermarket becomes less important. Also the influence other large energy consumers such as the greenhouse in supermarket A can more or less be neglected in such a comparison. The drawback with such performance indices is that it has been hard to collect the detailed data from the retailers about energy usage for the refrigeration system as well as data for the chilled air volume. The international comparison performed in this work indicate that also for the proposed indices refrigerated electric energy/refrigerated air volume it is necessary to make a correction to the opening hours. This has not been performed in this project because of lack of data from other countries. One way to overcome the need to make a relation to the opening hours would be to define new performance indices and relate the refrigerated electric energy/the number of sold refrigerated goods. Such performance indices have the benefit that it refers to the business in the supermarket.

The aim from the beginning was to also include performance indices describing the environmental impact but lack of data for annual leakage is the main reason to focus the work on energy performance. The effect of a refrigeration system on global warming can be described by the Total Equivalent Warming Impact (TEWI). In order to make such a calculation it is a need to collect detailed information about annual leakage of refrigerants, refrigerant used in the refrigeration system, refrigerant charge and annual energy usage for display of chilled and frozen goods. In addition it is necessary to have reliable and accepted data for the regional conversion factor for electricity. Finally for an international comparison it is a need to either make a comparison with the refrigerated air volume and the opening hours or make a direct comparison to the number of sold refrigerated goods. Even if it has not been possible to evaluate such performance indices within this project it can be used as a recommendation based on the more detailed evaluation on energy performance indices.

The TEWI combines the direct emissions of CO₂ due to refrigerant leakage and refrigerant losses at the end of the system's life and the indirect emissions of CO₂ associated with energy consumption and generation.

The TEWI calculation of a refrigeration system is based on the following relation:

$$TEWI = (M_{\text{losses}} \cdot N + M_{\text{ref}} \cdot (1 - \kappa)) \cdot GWP_{\text{ref}} + RC \cdot E \cdot N$$

Where M_{losses} is the refrigerant leakage, N is the lifetime of the refrigeration system, M_{ref} is the refrigerant charge, κ is the recycling factor, GWP_{ref} is the Global Warming Potential of Refrigerant, RC is the Regional Conversion Factor, which is the emission of CO₂ per unit of energy delivered, and E is the annual energy consumption of the equipment.

Using performance indices as a tool to improve energy efficiency in supermarket is valuable and easy to use but it can be a challenge to collect data. In addition it is recommended to compare supermarkets of the same size/category if total energy related to area and opening hours are used as performance indices. "The best in each size/category" can be used as a goal/good example.

The categories should probably be defined on a national level. An example of categorization is shown in table 2 for Sweden.

2.3 Tasks 3: Development and validation of a model library for specific supermarket equipment

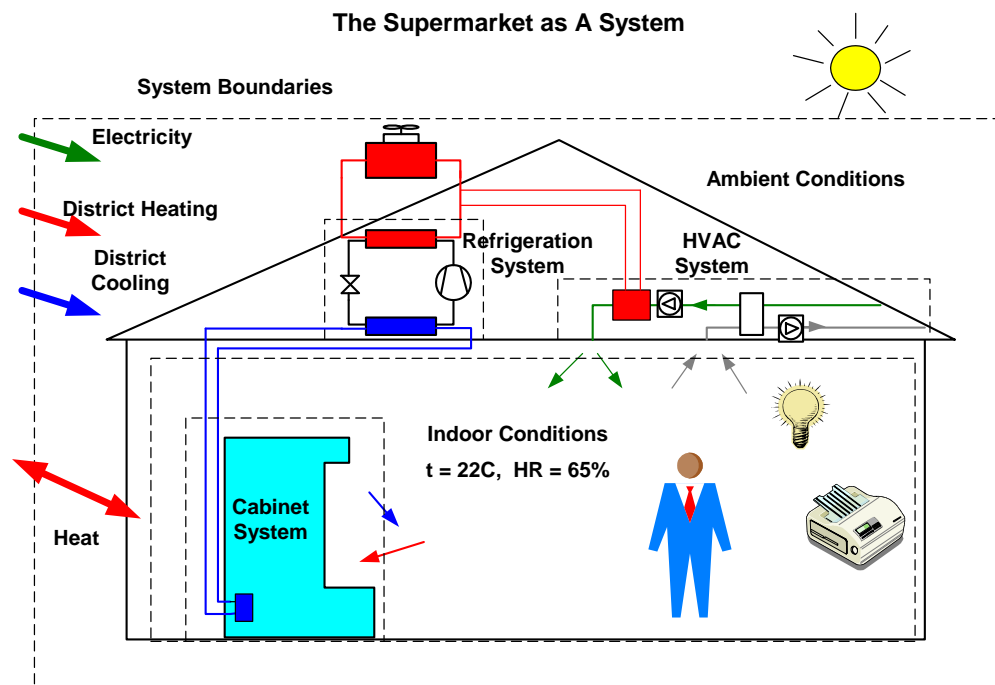
Task leader - KTH Sweden.

Several models for building equipment are currently available in the open literature. The whole-building models that are referred to in the following sections are CyberMart from Sweden, EnergyPlus from USA, Retscreen from Canada, and SuperSim from UK. The developers of the models are participants in Annex 31. Detailed description of the models calculations capabilities, inputs and outputs are discussed in Chapter 2.4.

This task focuses on identifying the main equipment simulation models (subsystems models) necessary for simulating the energy use in supermarkets. The different methods and assumptions used in building the sub-systems models are collected and analyzed.

A supermarket is a complex system where many subsystems interact. A systems approach must therefore be taken in evaluating the impact of energy efficient measures in different subsystems in the supermarket. It is also necessary to implement a comprehensive system (computer) model in order to predict and evaluate the introduction of new concepts and ideas in supermarkets not yet built (or existing ones being refurbished).

The various boundaries of the system “supermarket” are presented in Figure 7. The figure shows different subsystems in supermarket such as the HVAC system, refrigeration system, cabinet system and heating sources. Estimation of the energy requirement in a supermarket is based on the interrelatedness between the different subsystems and their energy demand.



Outdoor climate is an important factor for energy usage in supermarkets. It affects the indoor climate and therefore the performance of the refrigeration system. The outdoor temperature,

relative humidity, solar irradiation and wind speed all influence the loads on the HVAC and refrigeration systems.

The heat or cooling gains through the building envelope, i.e. the walls, floor, roof and windows, depend on the thermal properties of the components. Specific heat capacity, density and thermal conductivity of the walls, floor, roof and windows affect not only the heat transfer but also storage of energy in the building structure.

The ventilation system supplies air from the outside to the inside of the supermarket in order to provide comfort and acceptable indoor air quality. The air supplied to the supermarket is heated or cooled in the HVAC system according to the desired indoor conditions. When the HVAC system maintains the indoor temperature at the control set value the only influence of indoor climate on the refrigeration system capacity is due to the relative humidity in the store, which usually follows the trend of the outdoor relative humidity.

Infiltration is the air leakage from the outside to the inside of supermarket through exterior doors and windows. Infiltration is caused by the temperature difference between indoor and outdoor air and wind velocities.

Many of the sub-systems in the supermarket are directly connected. Figure 8 shows a conceptual schema of the different subsystems in a supermarket and their interconnections.

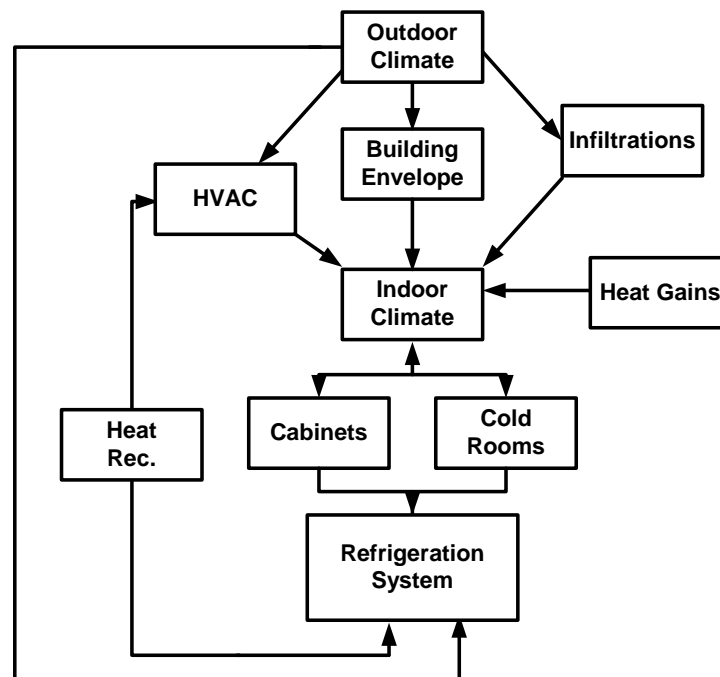


Figure 8: Conceptual Model of the Different Subsystems in a Supermarket

In addition to heating or cooling gains, ventilation and infiltration through the building envelope, the indoor conditions in a supermarket are affected by lighting, equipment, occupants, cabinets and the control system.

Lighting and equipment account for an important part of the total energy performance in supermarkets. Moreover, lighting and equipment emit heat that affects the heating or cooling loads.

People in supermarkets are the customers and employees who give off heat, moisture and carbon dioxide. The heat and moisture emitted by people affect the heating and cooling requirements. The carbon dioxide influences the volume of air from the outside needed to cover the ventilation requirements. The number of occupants varies according to the profile of the supermarket with a daily and weekly pattern.

The cabinets exchange heat and moisture with the indoor air of the store. Cabinets require proper indoor conditions in order to reduce refrigeration loads and to avoid frost on products and coils. The cold air from the cabinets escaping to the surroundings affects heating and cooling requirements in the supermarket.

The control system of the supermarket manages the operating scheme of lighting, equipment, the HVAC system and set point temperatures when the supermarket is either open or closed and when the season is summer or winter.

To estimate the energy requirement in a supermarket it is necessary to evaluate the interrelatedness between the different subsystems and their energy demand. The main subsystems included in computer simulation model for energy use in supermarkets are presented in the following sections.

2.3.1 Building model

There are many principles for calculation of energy requirements in buildings. The complexity of the model varies according to the application and the objectives of the model. There are three fundamentally different types of building energy modelling techniques: steady state, quasi-steady state and dynamic. Steady state models assume that there is no energy storage during the time period or temperature condition under consideration. These models are based on time averaged temperature differences between the indoor and outdoor conditions, and all properties and variables are assumed constant for each calculation condition. The quasi-steady state model takes into consideration transient effects from weather, equipment use, occupancy profile and the storage and release of energy. The calculation period for quasi-steady state models can be any time interval, but one hour or a typical day from each month are often used. Dynamic models are based on time intervals that are less than one hour in order to represent the continuous time variation of the properties of interest in the building (Hunn 1996).

ASHRAE suggests two methods for calculation of cooling and heating loads. The first method is the Heat Balance Method that can be viewed as four different processes. The first process is an outside face heat balance involving solar radiation, convective flux with outside air and conductive flux. The second process is a wall conduction process where two methods, a finite difference procedure and conduction transfer function, have been used widely to model the wall conduction. The third process is the inside heat balance concerning the radiation between different surfaces, the convective flux to zone air and the conductive flux. The fourth process is an air heat balance involving the convective part of surfaces, internal loads and air from infiltration and the HVAC system. The second method to calculate cooling and heating loads suggested is the Radiant Time Series Method (RTS), which is a simplification of the heat balance method. These methods are based on the assumption of steady periodic conditions, i.e. that weather, occupancy and internal loads are identical to those of preceding days. The RTS method is suitable for peak design load calculation, but it should not be used for annual energy calculations (ASHRAE 2001).

The model used to calculate the heating and cooling loads in CyberMart is an adaptation of a model suggested by Tor Helge Dokka (Dokka 2001). The model is based on the heat balances of room air, room surfaces and building structure. The model assumes that the variation in room temperature is negligible, that the temperatures of surfaces are the same and that thermal loads such as outdoor temperature, solar radiation and internal gains are constant during each time interval (1 hour in this case). The walls, floor and roof are modelled as equivalent RC-circuit elements where the construction's internal heat capacity is concentrated in the middle of an accumulating layer in the internal part of the construction in contact with the room air. The sales and office areas in the supermarket were assumed to be one zone for the calculation of heating and cooling loads.

The development of the building model 'SuperSIM' is based on the multizone building module in TRNSYS (TRNSYS 2005). TRNSYS is a transient system simulation program with a modular structure whereby the user specifies the components that constitute the system and the manner in which they are connected. The floor layout of the supermarket is divided into zones according to their function and temperature control requirements. For each zone, description of fabric structure such as wall type, size and category and window details etc. are used together with specification of the infiltration rate, ventilation rate, external and internal heat gains and schedules and temperature and humidity controls for each zone. Local hourly weather data which includes ambient temperature, humidity, wind velocity and direction and solar radiation are also inputs to the model. The schedules include store daily opening and closing time and the number of customers in each time period.

Space heating or cooling is taken into consideration because it influences the relative humidity and the temperature in the supermarket. Therefore, information about the HVAC system is required, such as; equipment type, operating schedule and control information. Usually the indoor temperature is kept constant in the simulation following the input of the different supermarket zones thermostatic settings.

The EnergyPlus program uses similar approach to what explained in this section. Figure 9 shows the program modules that work together to calculate the energy required for heating and cooling a building using a variety of systems and energy sources. It does this by simulating the building and associated energy systems when they are exposed to different environmental and operating conditions.

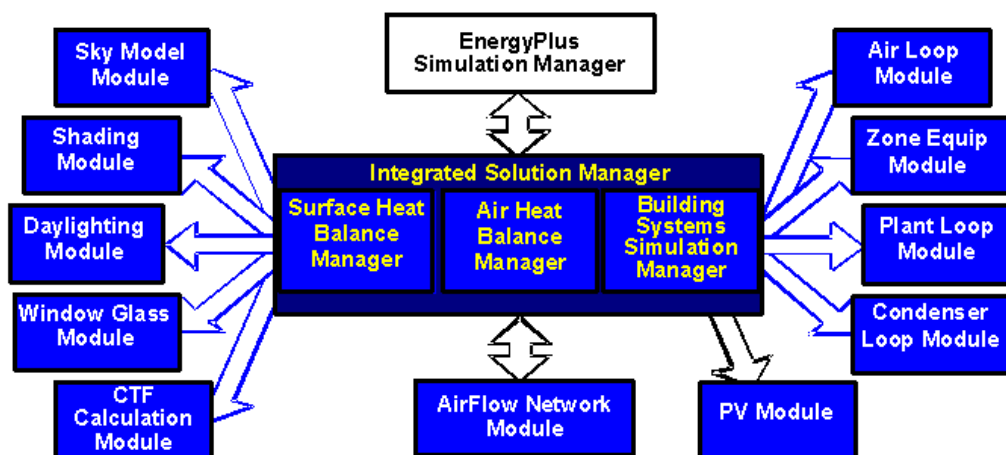


Figure 9: EnergyPlus Program Schematic

EnergyPlus is an integrated simulation. This means that all three of the major parts, building, system, and plant, must be solved simultaneously which will give a physically realistic solution. As can be seen in Figure 9, many program modules constitute the building model where all the elements are integrated and controlled by the Integrated Solution Manager.

In the simulation model RETscreen, some of the main assumptions made in the building model are:

- The building is considered one conditioned zone;
- Building loads are estimated in steady state operation;
- The model uses monthly climatic data: temperature, humidity and solar radiation;
- Two store temperature set points: one during opening hours and one during closing hours;
- The internal heat gains and loads are: lighting, occupancy, cooking appliances and display cases “cooling effect”.

The main buildings’ loads considered are as follows: infiltration, ventilation, lighting, occupants, display cases, and building envelope.

2.3.2 Outdoor climate

The location of the facility under analysis is critical for the determination of energy consumption, heating/cooling loads, daylighting potential, and a host of other calculations. Important climate parameters are: air temperature, relative humidity, wind speed, beam and diffuse radiation on horizontal surface, height of sun, solar azimuth and cloud cover fraction. METEONORM is software (Remund 2005) that can generate these climate parameters based on average values from the period 1961-1990 obtained from different weather stations according to the World Meteorological Institute (WMO) climate normal. METEONORM generates hourly climate data at any location in the world by using average data of the surrounding locations when direct measurements averages are not available. CyberMart, for instance, uses METEONORM to generate the necessary input data to the calculations.

EnergyPlus uses measured outdoor weather; hourly data files are currently available for more than 2000 international locations. Sub-hourly weather data files can also be used when available. To generate weather data for design day calculations, or to fill in gaps in measured weather data, an alternative method to obtain the climate data is used. These needs are met by calculating the required parameters by the using the “Site Location” as the input object including the parameters; Latitude, Longitude, Elevation, Timezone that allows the calculation of the solar position for any day of the year as well as supply the standard barometric pressure (using elevation). The daily temperature profile calculations are run by using the typical design day input which includes a “high” and a “low” dry-bulb temperature for the day. As these two temperatures are insufficient to represent a full 24 hour period, the program uses a “range multiplier” profile to represent the full day’s temperatures. The multipliers are taken from the (ASHRAE 2009) explicitly, EnergyPlus creates an air temperature for each time step by using the entered maximum dry-bulb temperature in conjunction with the entered daily range and the range multiplier values. Different models are used to calculate/generate the necessary climate data, examples of the some models are; sky radiation model, sky temperature model, sky radiance model, daylight model.

2.3.3 HVAC model

The main objective of the HVAC system in supermarkets is to maintain the desired comfort level and indoor air quality conditions. The traditional HVAC system is a central plant located in the machine room consisting of heating and cooling systems, an air distribution system, fans, a rotary heat exchanger and a re-circulated air system.

The typical heating system consists of an oil boiler, electric boiler, gas boiler or district heating system connected to the HVAC system by a heat exchanger. The cooling system is a chiller or district cooling connected to the HVAC system by a heat exchanger.

Ventilation is the purposeful flow of air from the outdoor environment directly into a thermal zone in order to provide some amount of non-mechanical cooling and to maintain a healthy indoor environment. The air from the inside of the store is sometimes re-circulated to improve the energy performance. The mass flows of the re-circulation and fresh air can be determined from the mass concentration of carbon dioxide in the supermarket. A reasonable limit for CO₂ concentration in the supermarket is 800 ppm, used in CyberMart.

Ventilation in EnergyPlus can be controlled by a schedule and through the specification of minimum, maximum and delta temperatures. The temperatures can be single constant values for the entire simulation or schedules which can vary over time. The actual flow rate of ventilation can be modified by the temperature difference between the inside and outside environment and the wind speed.

Heat recovery from condensers of the refrigeration system for heating the premises or to heat water is one way to increase overall energy efficiency in supermarkets. A rotary heat exchanger is another type of heat recovery system in which the heat contained in the air extracted from the store is reutilised to heat or cool the fresh air supplied to the indoor area.

The ventilation system usually has two fans: one for air supplied and another for air extraction. The energy demand of the fans is due to volume flow of the air and pressure drops in the distribution system. Assuming that the fans are properly selected for the required capacity then the increase in temperature over the fan can be assumed equal to 1°C.

Figure 10 shows a conceptual schema of the different subsystems in the HVAC system and their interconnections.

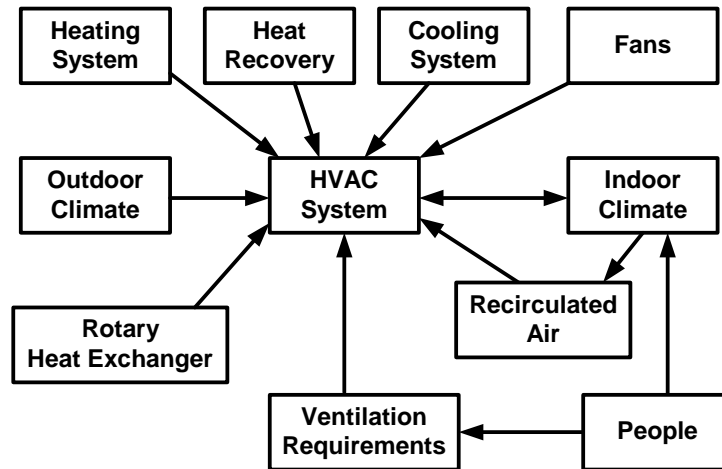


Figure 10: Different subsystems in the HVAC System

A model of a HVAC system in supermarket is shown in Figure 11. The components include in the model are: a rotary heat exchanger, a bypass for re-circulation of return air, a coil for air cooling and two coils for air heating, one for heat recovery from the condenser of the refrigeration system and the other for auxiliary heating.

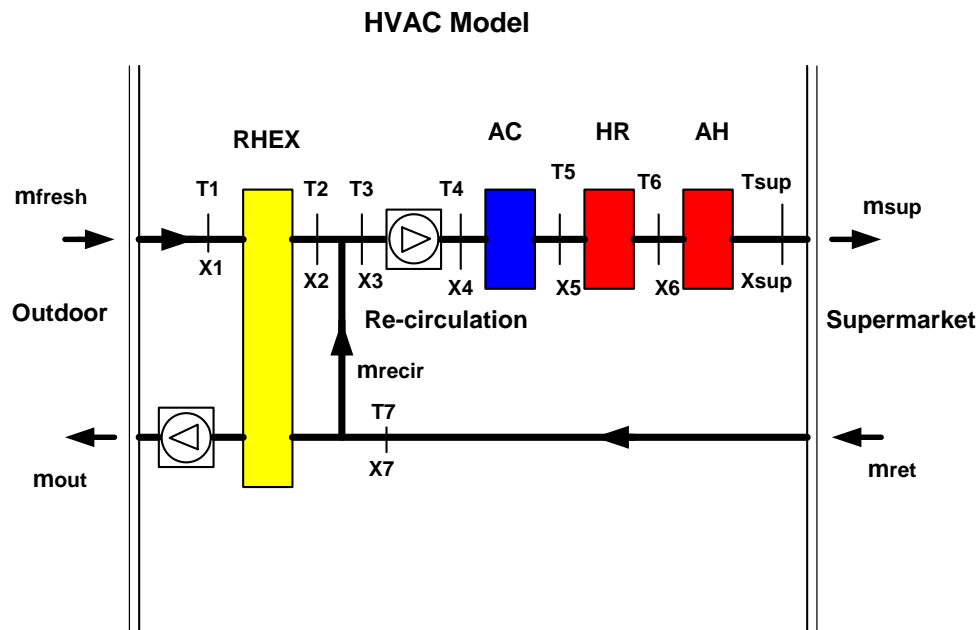


Figure 11: Components of a HVAC system in a supermarket

Any air that enters by way of infiltration can be assumed to be immediately mixed with the zone air. The determination of the amount of infiltration air is quite complicated and subject to significant uncertainty. In the most common procedure, the infiltration quantity is converted from a number of air changes per hour (ACH) and included in the zone air heat balance using the outside temperature at the current hour.

The EnergyPlus model contains three models for infiltration. The first is the “Design Flow Rate” model that was inherited from EnergyPlus’s predecessor programs. It is based on environmental

conditions modifying a design flow rate. The second is the “Effective Leakage Area” model based on Sherman and Grimsrud (Sherman and Grimsrud 1980). The third is the “Flow Coefficient” model based on Walker and Wilson (Walker and Wilson 1998). The model formulations for the Effective Leakage Area and Flow Coefficient models are from the ASHRAE Handbook of Fundamentals (2001 Chapter 26; 2005 Chapter 27) where they are referred to as “Basic” and “Enhanced”, respectively.

The temperature and humidity ratio of the air after the different coils are calculated according to the heating or cooling requirement of the supermarket and the heat from the heat recovery system in the refrigeration system.

The zone air heat balance is the primary mechanism for linking the loads calculation to the system simulation. As such, the zone air temperature becomes the main interface variable. The zone air temperature can be assumed constant which corresponds to the temperature setting/requirements in the different zone.

Simplified assumptions could be used for the calculations. For instance RETScreen software, considers only the sensible heat part of infiltration load, calculated according to the method proposed by ASHRAE (ASHRAE 2005), and the fresh air standard volumetric flow rate for the supermarket is by the user.

2.3.4 Refrigeration system model

Heat gain in the evaporator and rejection in the condenser of the refrigeration circuit may be performed directly to the heat source and sink, respectively, or indirectly by using a loop with heat transfer fluid.

When the heat transfer fluid loop is not used on the heat source side, the refrigeration system is called direct expansion. In this system, racks of compressors in the machine room are connected to the evaporators in the display cases and to the condensers on the roof by long pipes with refrigerant. In an indirect system, the central refrigeration unit cools a fluid that circulates between the evaporator in the machine room and the display cases in the sales area.

Usually cooling at the medium and low temperature levels is provided by at least two independent refrigeration circuits with at least two compressors each, depending on the system capacity. The refrigeration circuits at the low and medium temperature levels have similar components so they are simulated in the same manner.

To evaluate the energy performance of a refrigeration system in the supermarket the simulation model should be capable of predicting the hourly total power consumption for the entire year of compressors, condenser fans and cabinet electric associations. To achieve this target, models of the system components should be developed, a compressor model is required to calculate the compressor power consumption, and air-cooled condenser model is needed to provide a prediction of the fan power and refrigerant head pressure. The total cooling loads need to be calculated at part-load conditions for the cabinets and cold rooms to predict the equivalent cooling capacity supplied from the compressors. The evaporating temperature of the cycle should be the lowest evaporating temperature of all the cabinets and cold rooms.

Control parameters are important inputs for the refrigeration system calculations, such inputs are the internal superheat and the control strategy of the head pressure, which can be fixed or floating with the ambient temperature.

2.3.4.1 Indirect System Modelling

The main components of the indirect system are presented in Figure 12. The most important device in the model is the chiller that is represented by four components: condenser, expansion valve, evaporator and compressor. A model of the chiller is suggested in (Bourdouxhe 1994), which has been applied in CyberMart. The components that directly affect the operating conditions of the condenser and the evaporator are cabinets and dry coolers. The models for the key components are presented in the following sections:

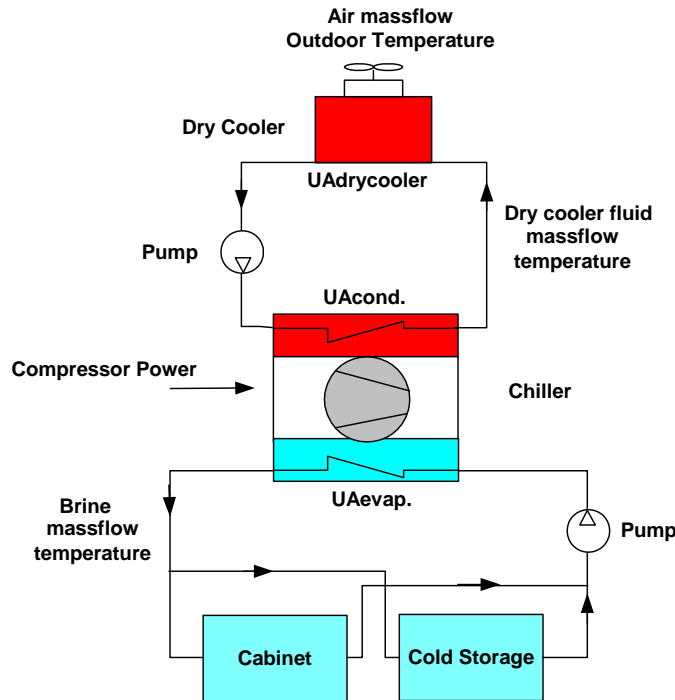


Figure 12: The Basic Model of the Indirect System.

2.3.4.1.1 Medium Temperature Cabinets and Low Temperature (Deep-Freeze) Cabinets

The cooling loads of the display cabinets and cold rooms in the supermarket are generally determined at full-load conditions, although the refrigeration system actually operates at part-load conditions for the majority of time. Therefore, good estimation of the cooling capacity at part load conditions is key factor in determining the performance of the refrigeration system. The refrigeration loads in display cases are dependent on indoor conditions in the supermarket; a higher indoor temperature and relative humidity increase the cooling demand and the energy requirement.

A representative energy balance of an open front, vertical, medium temperature cabinet is shown in Figure 13 where heat losses from infiltration, radiation, conduction, lighting, the fan and heating wires (often called anti-sweat heaters in the US) are presented. Figure 13 also shows the interaction between the indoor conditions in the supermarket and the interior conditions in vertical cabinet. The heat losses dependent on the ambient conditions in supermarkets are from infiltration, radiation and conduction. The losses from infiltration are about 64% of the total refrigeration load at 25°C indoor temperature, including the latent and sensible part of the

infiltration. For the energy balance shown in Figure 13, defrost losses are zero (none or off-cycle defrost method assumed – see section 2.3.4.1.5 below).

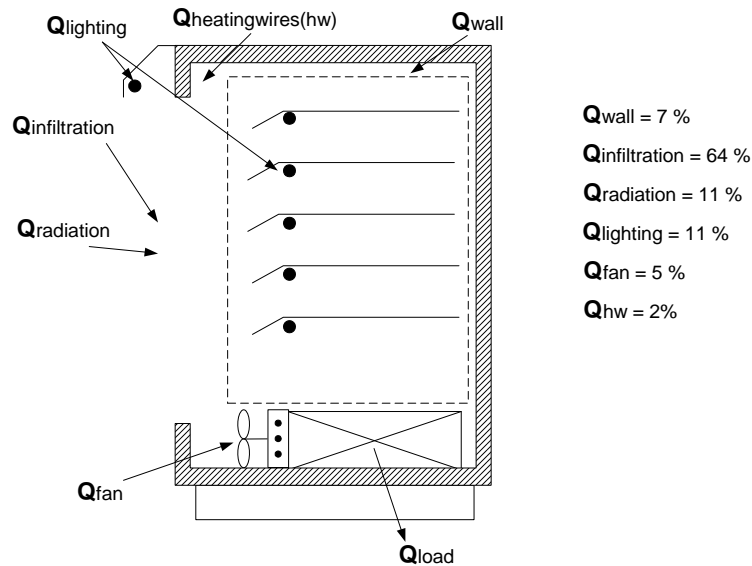


Figure 13: Energy Balance of a representative Open-front Vertical, Medium Temperature Display Case

The effect of indoor temperature on the refrigeration load in vertical display cases is presented in Figure 14. The values in the diagram have been calculated according to the heat balance in Figure 13 at different indoor temperatures (Fahlén 1999).

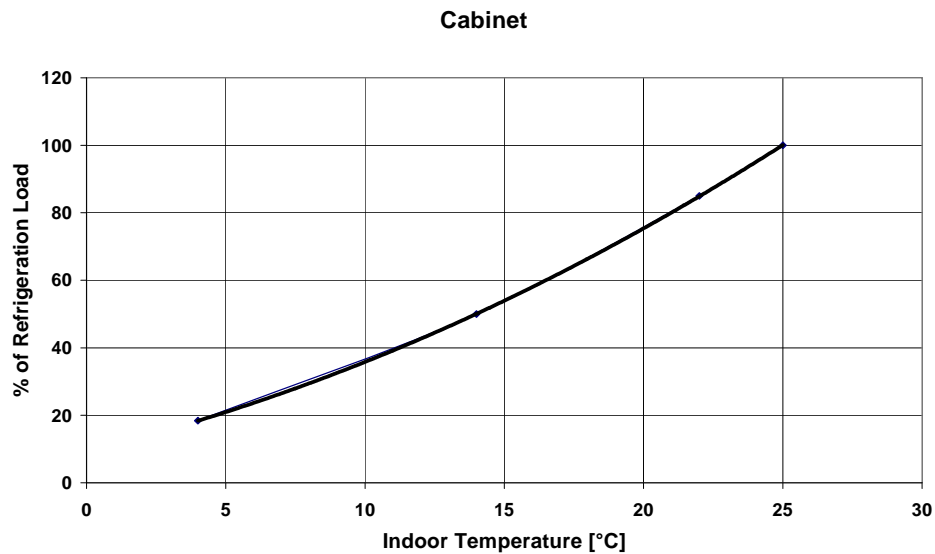


Figure 14: Effect of Indoor Temperature on Refrigeration Load in Vertical Display Cases.

The diagram shows that the refrigeration load will be halved at 14°C. At the same temperature in the cabinet and in the surroundings, the refrigeration load is equivalent to heat from the illumination, heating wires, defrost and fan, which is about 18% of the total refrigeration load at 25°C.

The effect of the indoor temperature on the refrigeration load in a horizontal deep-freeze cabinet can be calculated according to the same reasoning as for vertical display cases.

A representative energy balance of a horizontal, low-temperature cabinet is shown in Figure 15 where heat losses from infiltration, radiation, conduction, lighting, the fan, heating wires (or anti-sweat heaters) and defrost are presented. The heat losses dependent on the ambient conditions in supermarkets are from infiltration, radiation, conduction and defrost. The losses from radiation are about 46% of the total refrigeration load at 25°C indoor temperature.

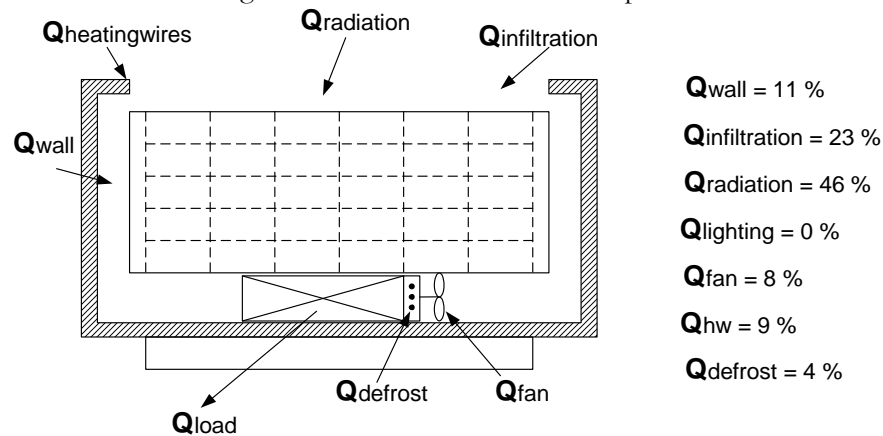


Figure 15: Energy Balance of a representative Open, Horizontal, Low Temperature (frozen food) Display Case

At an indoor temperature of 25°C, the refrigeration load is equivalent to 100%. At the same temperature in the cabinet and the surroundings, the refrigeration load is equivalent to the heat from heating wires, defrost and the fan, which is about 20% of the total refrigeration load at 25°C.

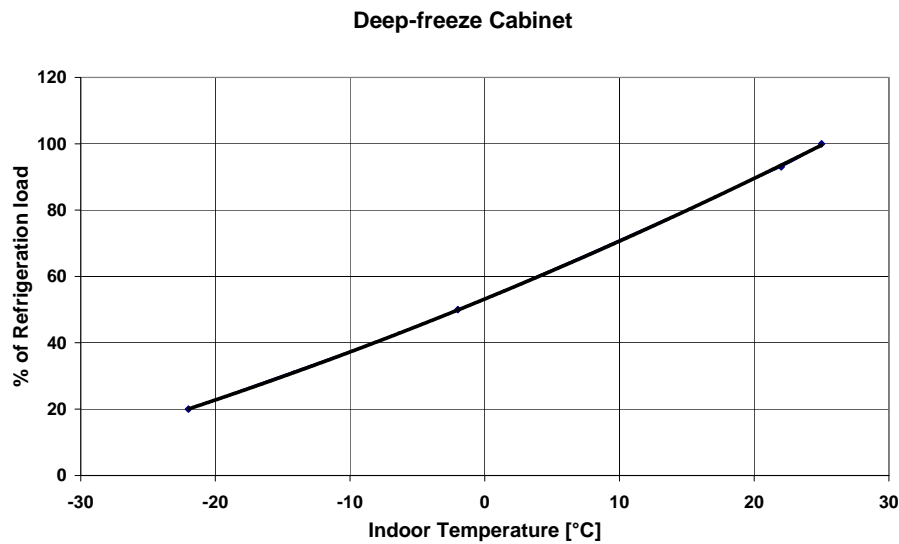


Figure 16: Effect of Indoor Temperature on Refrigeration Load in Horizontal Display Cases

An additional heat loss term which has been disregarded in the above analysis is the sensible load on the refrigerated case due to restocking of products that are at a higher temperature than the case. This has been included in the EnergyPlus refrigeration module.

The influence of indoor relative humidity on the refrigeration load of display cases can be calculated with a correction factor TP according to (Howell 1993). The correction factor TP is a

relation between the refrigeration load at a selected store relative humidity (RH) and the refrigeration load at 55% store relative humidity.

The heat losses in the cabinets that are affected by the relative humidity are the infiltration latent heat, heating wire, and defrost. They increase with increasing the relative humidity in the store. However, when the indoor temperature is controlled at a constant value, which is usually the case, the rest of the heat losses in the cabinets do not change. Then, schedule and control type will be the only parameters that influence the energy consumption of lights, fans, and restocking of products.

The rated cooling capacity at design conditions can be obtained from the performance data of the cabinets and deep-freeze cabinets using the manufacturer data sheets. CyberMart, for instance, creates database from manufacturer data including the average air temperature, inlet and return air temperatures, evaporating temperature, electrical data for fans, heating wires, defrost heaters and light, coil volume, diameter of tubes and refrigeration loads at 22°C – 65% RH and at 25°C – 60% RH for each cabinet. A similar database is under development for EnergyPlus and will be available in 2010.

For certain refrigerated case types, the sensible case credits provided to the zone can create an uncomfortably cold environment in the surrounding area. For this reason, return air ducts are frequently placed behind these cases to draw this cold air under the case and direct it back to the HVAC system. This reduces localized over-cooling and improves occupant comfort.

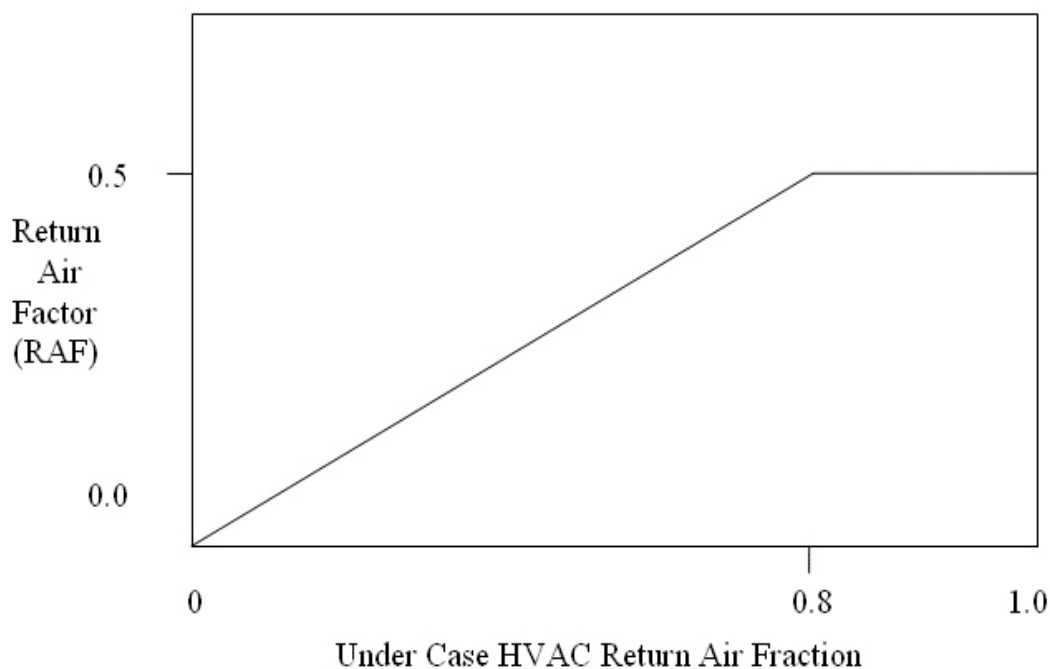


Figure 17: Return Air Factor Versus Under Case HVAC Return Air Fraction

Since under case return ducts reduce the temperature and humidity of the air being recirculated to the HVAC system, this can impact HVAC system performance. Figure 17 shows the relationship that is used by the refrigerated case model in EnergyPlus to determine the fraction of case credits that directly cool and dehumidify the HVAC system return air. This fraction, referred to as the Return Air Factor (RAF), is a function of the fraction of the HVAC system return air

that comes from under the cases. The remaining fraction of the case credits (1-RAF) becomes part of the overall zone air energy balance. If the HVAC system is off for a simulation time step (no return air mass flow), the sensible and latent case credits normally attributed to the HVAC return are set equal to zero (even though they get calculated and reported as non-zero values) and all case credit energy is applied to the zone air heat balance.

2.3.4.1.2 Cold Storage

The capacity demand for cold storage is due to four factors: heat transmission, exchange of air, cooling or freezing of products and internal heat generation (Granryd 2003).

Heat transmission through walls, floor and ceiling is dependent on the overall heat transfer coefficient and the temperature difference between the room and the surroundings. The exchange of air in cold rooms depends on the frequency of door openings and the size of the room. The exchange of air increases the refrigeration load of the room.

Temperatures and the frequency of door openings influence the number of air exchanges. Results from experiments can be found in (Granryd 2003). The refrigerant load required to cool or freeze products is dependent on the mass flow rate and the enthalpy difference of the products.

Reasonable assumptions can be used to calculate the required parameters. In CyberMart software, the enthalpy difference for freezer rooms has been assumed to be 45 [kJ/kg], which is the average between the enthalpies of different products at temperatures -15°C and -18°C. In the same manner, the enthalpy difference for the cold room has been assumed to be 55 [kJ/kg], which is the average between the enthalpies of different products at temperatures 17°C and 1°C. The mass flow has been assumed to be 20 kg/m³ per 24 hours (Bäckström 1970) for cold rooms and 15 kg/m³ per 24 hours for freezer rooms.

Internal heat generation from lighting and people also affects the refrigeration load of the cold room. The heat generated by lighting has been assumed to be 15 W/m² and the heat from people to be 200 W.

The ASHRAE load model (ASHRAE 2006d) can be used as well to simulate the cold storage room, which has been adapted for the EnergyPlus software. The model includes infiltration through door openings and sensible loss through walls/ceilings described by the user for each zone. All equipment loads (fan, light, heaters) are modeled as well. Sensible and latent exchange with multiple adjoining zones is included.

EnergyPlus also uses a master schedule for the door opening operation and additional schedules control the lights, defrost, and heater operation. Sensible heat loads are placed on a cold storage by fans, heaters, and lighting. Unlike refrigerated cabinets, there is no option to allocate any portion of these heat loads on the surrounding zone(s). The general circulation fan is assumed to run at all times. The cooling coil fan is assumed to be off for Hot-Fluid and Electric defrost. Lighting, heating, and restocking are modeled according to the schedule values entered by the user. For lighting and heating, the maximum power is entered along with a scheduled ratio (between 0 and 1) to be applied for any point in time. The heating power includes all heaters except those used for defrost purposes. The heater power should include anti-sweat, door, floor, and drain-pan heaters. For restocking, the total sensible load is scheduled for each point in time (the restocking latent load is assumed to be zero).

2.3.4.1.3 Condenser, Evaporator, and Dry Cooler models.

The condenser and evaporator used in indirect systems are usually plate heat exchangers. The refrigeration side of the evaporator and condenser has been assumed to have a constant temperature. The properties of the secondary refrigerant and the coolant fluid have been taken from (Melinder 1997) and data from manufacturers. The effectiveness model of the condenser and evaporator, relations defined in (Incropera 1996), can be used in the simulation. The values of overall heat transfer coefficient in the evaporators and condensers can be taken from manufacturer performance data sheets and assumed to be constant. The same can be applied to dry coolers and other heat exchangers in the system. This method has been followed in the CyberMart software.

Two evaporative condenser models are included in EnergyPlus. One uses a four-factor curve based upon manufacturers' literature values and the heat rejection temperature and the other a combined compressor/condenser efficiency curve using the outdoor wet-bulb temperature as the effective heat rejection temperature. Water-, air-cooled, and cascade condenser models are also available in EnergyPlus. Condenser fan energy varies according to the type of fan control and the heat rejection load on the condensers. That condenser heat rejection load can be reduced by heat reclaimed for building or water heating or by heat used for hot brine or hot gas defrost systems.

2.3.4.1.4 Compressor Model

Manufacturer's performance data can be used to simulate the compressor performance and calculate the total energy consumption of the compressor. The data can be used in different ways, for instance, CyberMart Software creates has a database of the compressor power and refrigeration capacity as two matrices of three rows and three columns equivalent to condensing temperatures of 30°C, 40°C and 50°C and evaporating temperatures of -15°C, -10°C and -5°C.

The matrix of compressor 2N-5.2Y is shown in Figure 18. The compressor power is dependent on the variation of the indoor and outdoor climate, which directly or indirectly will influence the refrigeration load. The capacity and COP of the refrigeration system is also dependent on the boundary conditions of the condenser. The simulation of the compressor power is done by interpolation and/or extrapolation between the condensing and evaporating temperatures.

Compressor 2N-5.2Y			13,8 kW
	30	40	50
-15	14,8	12,5	9,9
-10	18,5	15,7	12,7
-5	22,7	19,5	15,9

Figure 18: Matrix with Performance Data of Refrigeration Capacity of Compressor 2N-5.2Y

In SuperSIM software, a map-based compressor model is utilized (Fischer and Rice 1983). The compressor types used in supermarket refrigeration systems are mostly semi-hermetic and scroll compressors from different manufactures. The map-based model can be applicable for the performance prediction of different types of compressors supposing the manufacture performance data is available.

The map-based routine uses performance curve fits to compressor power input and cooling capacity as functions of saturated suction temperature and saturated discharge temperature. It is noted that the manufacturer performance curves are typically obtained at specified suction temperature and without liquid subcooling. Some corrections are needed when the operating states in practice are different from the manufacture specifications.

In EnergyPlus, there are two options for calculation of compressor rack electric power. The first uses a simple model based on the total evaporator load (sum of the evaporator loads for all refrigerated cases and cold storage connected to a rack) and the compressor rack operating COP which accounts for the air temperature entering the condenser. Because the COP curve is defined only as a function of the condensing temperature, it is important that this curve definition corresponds to the lowest evaporating temperature served by the compressor rack. The second approach, for the detailed simulation option, uses manufacturer's compressor map data (the ten factor AHRI rating curves for capacity and power consumption) to calculate compressor power based on a bi-quadratic fit to the suction and discharge saturation temperatures. Corrections are made for subcooling and superheating.

2.3.4.1.5 Defrost

Eight refrigerated case defrost strategies can be simulated: none, off-cycle, electric, electric with temperature termination, hot-gas, hot-gas with temperature termination, hot-brine, and hot-brine with temperature termination. Some research has shown that the defrost times for cases defrosted using hot brine can be significantly shorter than defrost times for electric or hot gas (Terrell, Mao et al. 1999). For each of these strategies, the refrigerated case evaporator is turned off for the required time period to allow accumulated frost to melt. Additional time can be scheduled (drip-down) to allow the water to drip from the evaporator and drain from the case.

Refrigerated cases typically require a specific number of defrost cycles per day for a predetermined length of time. Refer to manufacturer's recommendations for proper defrost frequency and duration. For example, a refrigerated case may have a single defrost period each day with defrost scheduled from 7:00 – 7:40 am and defrost drip-down scheduled from 7:00 – 7:55 am. Notice the drip-down schedule and the defrost schedule start at the same time, and the drip-down schedule is longer than the defrost schedule. These schedules should normally repeat for each day of the year.

For electric, hot gas, and hot brine defrost types, energy use by the defrost heater occurs during the scheduled defrost period. For defrost with temperature termination, the energy is also multiplied by the defrost ratio simulating a defrost duration shorter than the defined (maximum) period. For all non-electric defrost types, defrost electric power is set equal to zero. For hot gas and hot brine defrost types in cases served by a detailed system, the condenser heat rejection load is reduced by the amount of heat recovered for use in the defrost system.

Frost accumulation on the case evaporator will vary with the humidity level in the ambient air surrounding the case. Therefore, defrost heater operation can be reduced when ambient air humidity levels are low. Several methods are used to reduce unnecessary defrost heater operation, including terminating heater operation when the measured evaporator temperature indicates that the accumulated frost has been completely melted.

When the evaporator surface temperature is lower than the dew point temperature of the air, the water vapor in the air will condense on surfaces and there will be frost deposited on the surface. The rate of frost deposit on the surface can be defined related to the latent heat of diffusion of

water from liquid to solid ice, the latent heat of vaporization and the latent heat contribution to the total refrigeration capacity. For walk-in coolers, users can also specify what fraction of the total defrost energy is actually used to melt the accumulated ice.

The influence of the indoor relative humidity on defrost in display cases can be calculated with a correction factor DP according to (Howell 1993). The correction factor DP is a relation between the moisture exchange across the air curtain of the cabinet at a selected store relative humidity and moisture exchange across the air curtain of the cabinet at 55% store relative humidity.

2.3.4.2 Direct System Modelling

The traditional refrigeration system design in supermarkets is the direct system (also known as the direct expansion or multiplex direct expansion type of system). The characteristics of the system are long lines of refrigerant between the compressor, evaporator and condenser, which affect the total refrigerant charge in the system and the potential for refrigerant leakage.

Figure 19 presents the components of the direct system that are simulated in CyberMart.

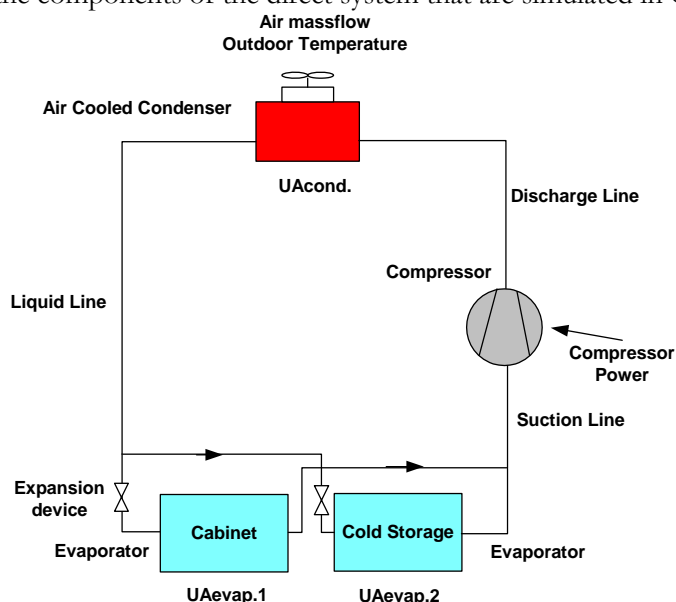


Figure 19: The Basic Model of the Direct System in CyberMart

The main difference in modelling the direct and indirect systems is related to the condenser and evaporator. In direct system, the condensers are of the air-cooled condenser type and the evaporators are the fincoils in cabinets and in the air coolers. The refrigeration side of the evaporator and condenser can be assumed to have constant temperature. CyberMart software uses the effectiveness model to simulate the performance of evaporators and condensers. Overall heat transfer coefficient values are taken from the compressor manufacturer data sheet

In SuperSM software, in order to predict the total fan power consumption of the air cooled condensers and actual head pressure in the system at part-load conditions, a simplified condenser model combined with fan power calculation has been utilized (Chan and Yu 2004). Alternatively, if the geometric details of the actual condensers are available, a detailed condenser model can also be employed so that the effect of different heat exchanger designs with different pipe arrangements on system performance can be investigated (Ge and Cropper 2004). When refrigerant properties (temperature and pressure) at condenser inlet and outlet, refrigerant mass flow rate and ambient air temperature are available at a steady state, the simplified model is able

to predict the required air flow rate, operational fan number and total fan power consumption (Chan and Yu 2004).

Summary and conclusions:

Several models for building equipment are currently available in the open literature. The main equipment simulation models have been identified in this chapter. Different methods and assumptions used in building the equipment models have been collected and discussed.

The whole-building models that were referred to in the chapter are CyberMart from Sweden, Energy Plus from USA, Retscreen from Canada, and SuperSim from UK. The developers of the models are participants in this Annex.

The main sub-models in the whole supermarket energy model are; the building, HVAC, outdoor, and refrigeration system models. A supermarket is a complex system where these main models also consist of models of sub-systems which interact in order to simulate the energy performance of the whole supermarket. The complexity of the model varies according to the application and the objectives of the model which is being reflected in the assumptions discussed in this chapter.

In simulating the building model, two main methods have been suggested for calculation of cooling and heating loads. The first is the heat balance method that can be viewed as four different processes. The second method is the radiant time series, which is a simplification of the first method. The building model can be based on a multi-zone model or a simplified single-zone. The information about the HVAC system is important, such as; equipment type, operating schedule and control information. Usually the indoor temperature is kept constant in the simulation following the input of the different supermarket zones thermostatic settings.

Outdoor climate data can be obtained by separate commercial software and loaded into the supermarket simulation model. Weather data generation software is usually based on averages of actual weather data for certain locations. An alternative method is to use the location coordinates as input to the supermarket model and generate the weather data using, for instance, “range multipliers” to calculate values between the maximum and minimum available data for the specific location.

In an HVAC system, the typical heating system consists of an oil boiler, electric boiler, gas boiler or district heating system connected to the HVAC system by a heat exchanger. The cooling system is a chiller or district cooling connected to the HVAC system by a heat exchanger as well. In the ventilation system, the mass flows of the re-circulation and fresh air can be determined from the mass concentration of carbon dioxide in the supermarket. And it can also be controlled by a schedule and through the specification of minimum, maximum and delta temperatures. Infiltration can be integrated in the HVAC model by using a “design flow rate”, “effective leakage area”, or “flow coefficient” models.

The two main system solutions categories in supermarket refrigeration are the direct and indirect. The key sub-models in the refrigeration system are the models for the cabinets and the compressors. The refrigeration loads in display cases are dependent on indoor conditions in the supermarket; a higher indoor temperature and relative humidity increase the cooling demand and the energy requirement. The indoor temperature is usually assumed constant by the HVAC system. The influence of indoor relative humidity on the refrigeration load of display cases can be calculated with a correction factor, which is a relation between the refrigeration load at a selected store relative humidity and the refrigeration load at a certain store relative humidity.

The compressor power is dependent on the variation of the indoor and outdoor climate, which directly or indirectly will influence the refrigeration load. The compressor power at different evaporation and condensing temperatures is obtained from the manufacturer data by creating a matrix of the compressor power consumption at different evaporating and condensing temperature. A different approach is to use curve fit of the compressor power, or COP, at different evaporating and condensing temperatures.

2.4 Task 4: Development of whole-building simulation models.

Task leader - KTH Sweden

This task will be broken down in the following subtasks:

- Analysis and evaluation of the present simulation tools available/suitable for supermarkets
- Identification of the most suitable simulation environments for the given modeling aims
- Development of whole-building simulation models and integration of the equipment model library (task 3)

2.4.1 Introduction

There are many models available for evaluation of energy efficiency, renewable energy and sustainability of buildings. In the Building Energy Software Tools Directory on the homepage of the U.S. Department of Energy, there is information about 344 building software tools. The directory includes databases, spreadsheets, component and system analyses, and whole-building energy performance simulation programs (U.S. Department of Energy 2009). Few of the whole-building energy performance simulation programs included in this directory evaluate energy efficiency in supermarkets. The majority of the building energy simulation tools are able to model building and HVAC performance but not refrigeration system performance or the interaction between cabinets and the surrounding environment.

Companies and researchers around the world have developed computer programs for calculation of total energy performance in supermarkets such as the Supermarket Simulation Tool (SST) created by EPRI in the United States or Clim Top created by A.M.E.C. in France. Other computer programs focus on the energy performance of the refrigeration system in supermarkets. Two of them are the Supermarket Excel Spreadsheets created by ORNL in the U.S. and Econu Koeling II created by TNO in the Netherlands.

Some of the countries participating in Annex 31 have developed whole-building simulation models for calculation of total energy performance in supermarkets. USA has developed a module connected to the software Energy Plus. Sweden has developed the software CyberMart, Canada has developed a module in the software Retscreen and UK has developed the model SuperSim using TRNSYS.

The various boundaries of the system “supermarket” are presented in Figure 20. The figure shows different subsystems in supermarket such as the HVAC system, refrigeration system, cabinet system and heating sources. Estimation of the energy requirement in a supermarket is based on the interrelatedness between the different subsystems and their energy demand.

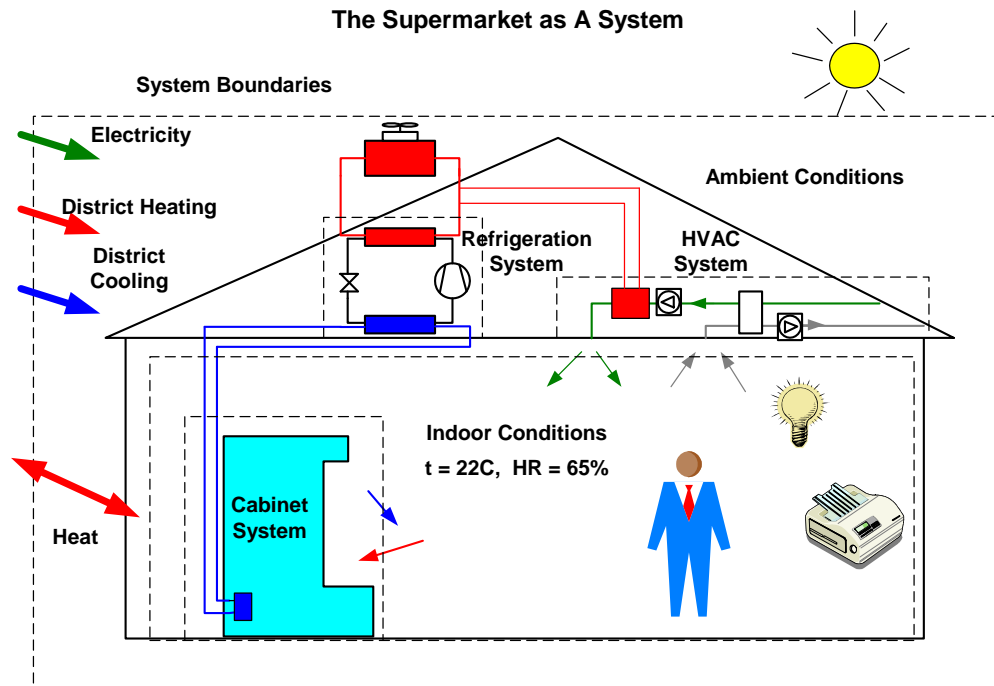


Figure 20: System Boundaries in supermarkets

2.4.2 *EnergyPlus*

The supermarket refrigeration system simulation module of EnergyPlus is one numerous system modules under the Building Systems Simulation Manager of the code. The EnergyPlus program is a collection of many program modules that work together to calculate the energy required for heating and cooling a building using a variety of systems and energy sources. It does this by simulating the building and associated energy systems when they are exposed to different environmental and operating conditions. The core of the simulation is a model of the building that is based on fundamental heat balance principles. Since it is relatively meaningless to state: “based on fundamental heat balance principles”, the model will be described in greater detail in later sections of this document in concert with the FORTRAN code which is used to describe the model. It turns out that the model itself is relatively simple compared with the data organization and control that is needed to simulate the great many combinations of system types, primary energy plant arrangements, schedules, and environments. The next section shows this overall organization in schematic form. Later sections will expand on the details within the blocks of the schematic.

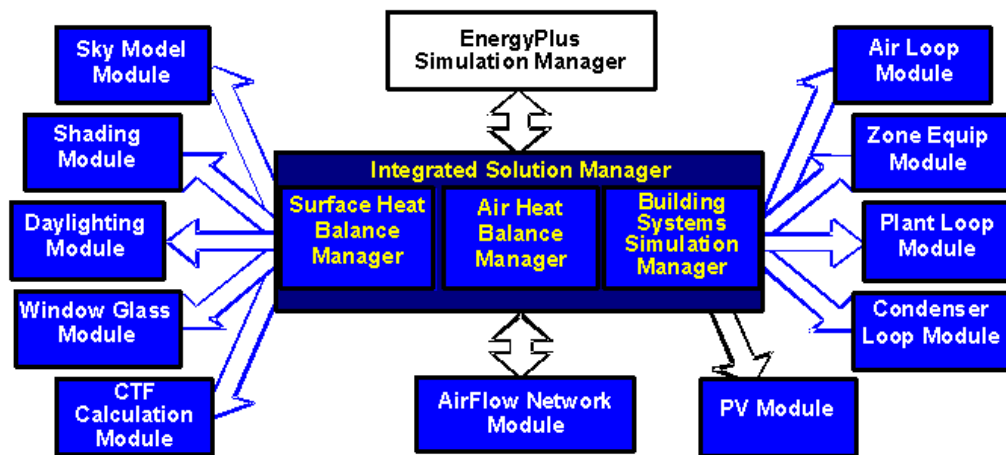


Figure 21: EnergyPlus Program Schematic

EnergyPlus is an integrated simulation which means that all three of the major parts, building, system, and plant, are solved simultaneously. Full details of the building loads, heat balance methodology, and systems simulation approach can be found in the EnergyPlus Engineering Reference Manual (2008).

The supermarket refrigeration system simulation module of EnergyPlus models refrigerated case equipment consisting of a compressor rack, refrigerated case and walk-ins connected to the compressor rack, and an optional heat reclaim air (or water) heating coil. Both direct (DX) and indirect (secondary loops on the chilling and/or heat rejection sides of the system) are available. Liquid overfeed (i.e., low-temperature CO₂) secondary systems can also be modeled. Output variables are available to trace the energy use and heat transfer for every component in the system, including lights, fans, defrost heaters, etc. for each case or walk-in and the heat rejection loads and temperatures at the condensers and subcoolers, and the compressor temperatures, suction pipe heat gains, and energy use on a sub-hourly basis over a selected period of time. The refrigerated case equipment models perform five major functions:

- Calculate the electric consumption of refrigerated cases connected to a compressor rack
- Determine the impact of refrigerated cases on zone cooling and dehumidification loads (i.e., sensible and latent case credits), including the effects of HVAC duct configuration
- Calculate the electric consumption and COP of the compressor rack, and the electric and water (if applicable) consumption related to cooling the compressor rack's condenser.
- Determine the total amount of heat rejected by the compressor rack's condenser and store this information for use by waste heat recovery models (e.g., using Coil:Desuperheater:Heating as an air reheat coil for high humidity control in a supermarket). The term Coil:Desuperheater:Heating is typical of the way system modules, or objects, are designated within EnergyPlus.
- Calculate the energy consumption of all auxiliary refrigeration equipment including fans and pumps.

2.4.3 *CyberMart*

The software *CyberMart* has been developed in Sweden. It predicts building heating and cooling loads, HVAC (heating, ventilation, and air conditioning), and refrigeration system performances of a supermarket. The focus of the model is on energy use, environmental impact (TEWI), and life cycle cost (LCC) of the refrigeration system.

The supermarket is regarded as a system consisting of several subsystems. This means that improved energy efficiency is achievable by a number of measures such as: more efficient display cases, more favorable indoor climate, increasing the COP of the refrigeration system or simply by an overall reduction of chilled or frozen foodstuff etc. Figure 22 shows a conceptual schema of the different modules in the program. *CyberMart* is a simulation program that allows the user to see the variation of different variables such as heating and cooling load, compressor power, refrigeration capacity and temperatures in the supermarket throughout a year.

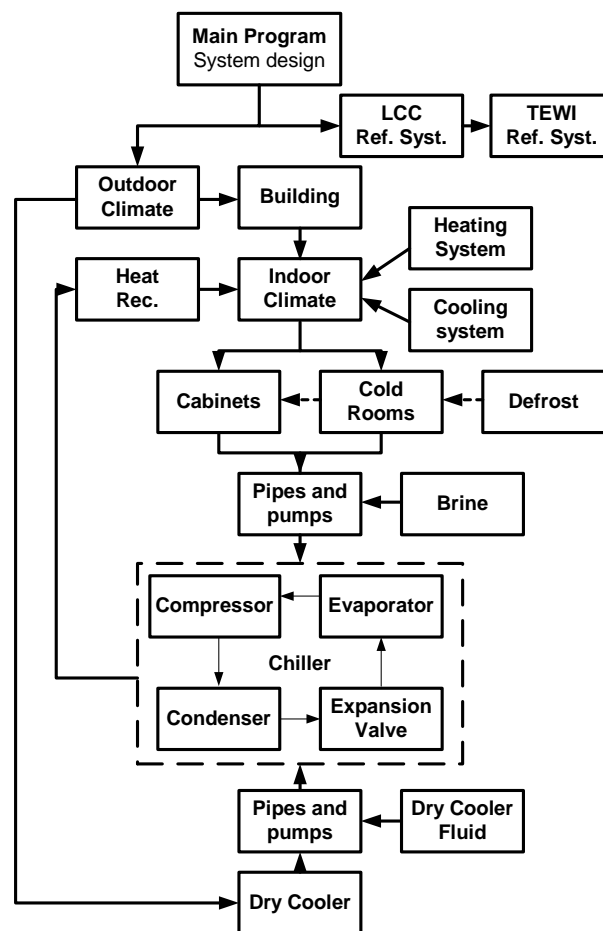


Figure 22: Different modules in software *CyberMart*.

The program calculates indoor conditions, heating and cooling loads from the building, refrigeration loads from cabinets and storages, compressor power and condenser heat from the refrigeration system, energy performance of lighting, equipment, plug-in cabinets, fans and pumps.

The results presented in the program (see Figure 23) are the energy consumption from heating and cooling systems, lighting, rotary heat exchanger, fans, service water heating and the refrigeration system of the first and last systems simulated.

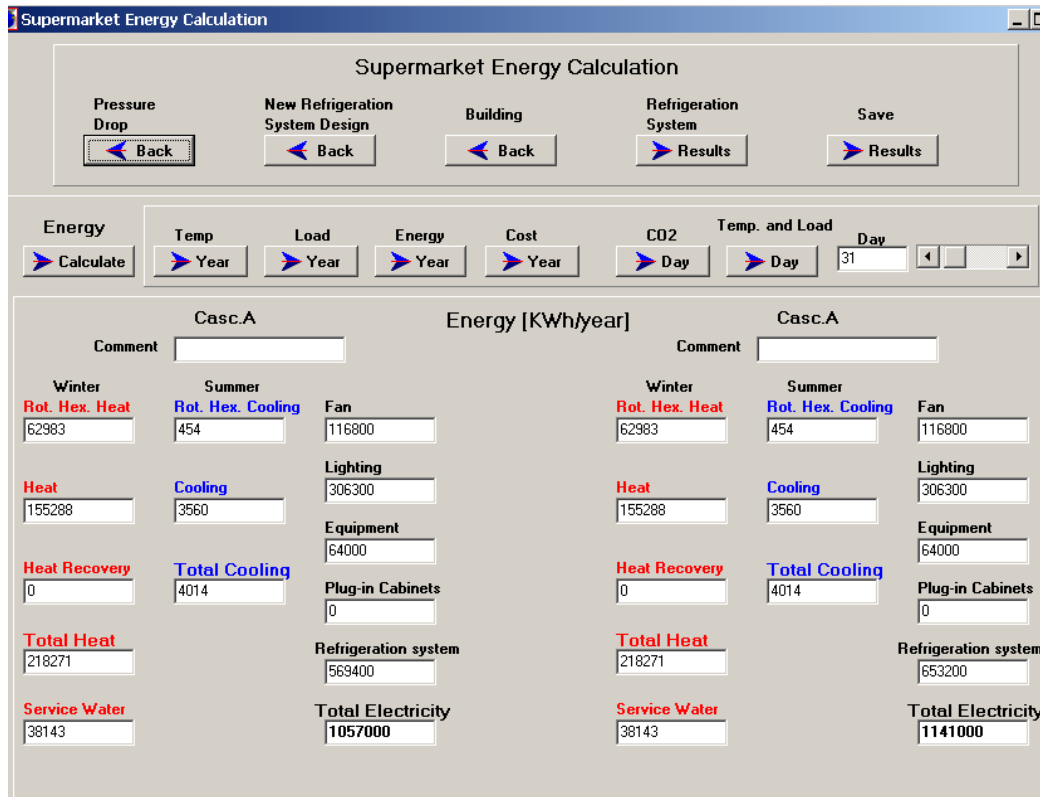


Figure 23: Results from the program CyberMart

2.4.4 RETScreen

The RETScreen Clean Energy Project Analysis Software is a unique decision support tool developed with the contribution of numerous experts from government, industry, and academia. The software, provided free-of-charge, can be used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of Renewable-energy and Energy-efficient Technologies (RETs). The software (available in multiple languages) also includes product, project, hydrology and climate databases, a detailed user manual, and a case study based college/university-level training course, including an engineering e-textbook.

The supermarket refrigeration system simulation module is one of the system modules in RETScreen. The software evaluates energy efficiency measures for residential, commercial and institutional buildings; communities; and industrial facilities and processes. This whole-building energy performance simulation program for supermarkets combines HVAC and refrigeration models, climate data, financial and risk analysis tools to provide a comprehensive evaluation of alternative system solutions. The tool is based on semi-empirical models and takes into account secondary loops as well as the interaction between the HVAC and the refrigeration systems. The semi-empirical models have been developed with the help of the huge amount of detailed data coming from the supermarkets monitored for the past few years. A description of the tool with inputs and outputs is presented in Figure 24.

RETScreen Energy Model - Supermarket project

Facility characteristics		Unit			%
Dimensions					
Total building floor area	m²	6,000			
Ceiling height	m	9.0			
Operating schedule					
Operating hours per day - weekday	h/d	13			
Operating hours per day - weekend	h/d	13			
Peak number of people		500		100.0%	
Average number of people		300		60.0%	

Energy efficiency measures	Unit	Base case	Proposed case	Incremental cost (credit)
		Copy base to proposed	See Energy consumption graph	
Building envelope				
Exterior walls insulation level	m² - °C/W	User-defined	User-defined	\$ <input type="text" value=""/>
RSI-value of exterior walls		2.35	2.35	
Roof insulation level	m² - °C/W	User-defined	User-defined	\$ <input type="text" value=""/>
RSI-value of roof		4.70	4.70	
Building controls & ventilation				
Design fresh airflow rate	L/s - m²	1.50	1.50	
Ventilation operating strategy		24 h/d - full output	24 h/d - full output	\$ <input type="text" value=""/>
Temperature - space heating	°C	19.0	19.0	
Temperature - space cooling	°C	24.0	24.0	
Relative humidity - space cooling	%	60%	60%	\$ <input type="text" value="1,000"/>
Other heating and cooling source				
Heating source - other	kW	11.0	11.0	
Cooling source - other	kW	0.0	0.0	
Domestic hot water				
Hot water use	L/d	5000	5000	
Hot water temperature	°C	65	65	
Supply temperature method		User-defined	User-defined	
Water temperature - minimum	°C	1.0	1.0	
Water temperature - maximum	°C	11.0	11.0	
Lighting				
Store lighting load	kW	306.0	306.0	\$ <input type="text" value=""/>
Store lighting load per unit area	W/m²	51.0	51.0	
Lighting schedule		User-defined	User-defined	\$ <input type="text" value=""/>
Hours of lighting per week	h/w	129.5	129.5	
Display cases				
Medium temperature				
Refrigeration capacity	kW	286.50	286.50	\$ <input type="text" value="1,000"/>
Case air temperature	°C	-1.0	-1.0	
Retail zone temperature - design	°C	21.0		
Retail zone relative humidity - design	%	55.0	55.0	
Air coil type		Secondary fluid	Direct expansion (DX)	
Defrost type		Electrical	Electrical	
Daily defrost energy consumption	KWh	5.0	5.0	
Fan power	kW	16.7	16.7	
Lighting load	kW	7.0	7.0	
Lighting operation		24 h/d	24 h/d	
Anti-sweat heater load	kW	3.0	3.0	
Anti-sweat usage factor	%	0	0	
Low Temperature				
Refrigeration capacity	kW	153.00	153.00	\$ <input type="text" value="1,000"/>
Case air temperature	°C	-21.0	-21.0	
Retail zone temperature - design	°C	21.0	21.0	
Retail zone relative humidity - design	%	55.0	55.0	
Air coil type		Direct expansion (DX)	Direct expansion (DX)	
Defrost type		Electrical	Electrical	
Daily defrost energy consumption	KWh	5.0	5.0	
Fan power	kW	16.1	16.1	
Lighting load	kW	9.4	9.4	
Lighting operation		24 h/d	24 h/d	
Anti-sweat heater load	kW	3.0	3.0	
Anti-sweat usage factor	%	0	0	

Figure 24: RETScreen Energy Model – Supermarket project.

2.4.5 SuperSim

The supermarket simulation model ‘SuperSIM’ developed by the Brunel University involves the integration of building, HVAC and refrigeration system models within the software TRNSYS . For the simulations a simplified condenser model is utilized to predict the variation of the condenser pressure and power consumption of the compressors. The model, in order to reduce simulation time, also employs manufacturers’ design performance data for each component. The HVAC model enables the evaluation of the effect of different design options, such as fresh air flow rates and heat recovery, on the overall system performance.

To obtain a precise prediction of the space air parameters and the actual cooling load at part-load condition, the models of building, HVAC and refrigeration require integration, as shown in Figure 25. In this diagram, each one-direction arrow represents the data input from one block to the other, while each two-direction arrow signifies the interaction between two blocks.

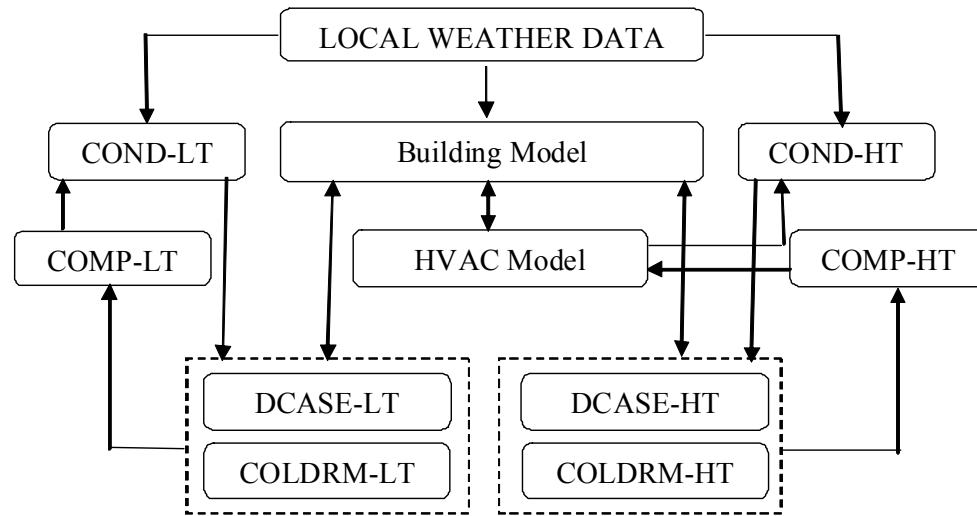


Figure 25: Integration for models of building, HVAC and refrigeration system

It should be noted that the design condition of refrigeration systems indicates the full-load operation, and requires an explicit specification in the model. The design condition assumes a 50 °C refrigerant condensing temperature for each temperature pack, and -10 °C and -32°C evaporating temperatures for high and low temperature packs respectively. The ambient air temperature is specified as 35 °C. For each temperature pack, refrigerant subcooling and superheating are all effected as 5k, with a 2k saturated temperature equivalent pressure drop in the suction line of each pack. Consequently, the design of the total compressor displacement and condenser structure for each temperature pack can be initialized given that the design details about the compressors and condensers are unknown.

2.4.6 . Capabilities of the different whole-building simulation models for supermarkets

There are different ways to evaluate and compare building simulations models as a sensitivity analysis of model predictions, comparison between different software or comparison between results from the computer models and measurements carried in different buildings.

A matrix with specific details of calculations for each whole building simulation model has been developed to evaluate the capabilities of the models to calculate energy use from different systems in supermarkets. The main idea with the Matrix is to provide information to users in the decision of the most appropriate program for general and specific calculation of energy use in supermarkets.

The matrix presents the abilities of the different software to simulate outdoor and indoor condition, building envelope, HVAC system, internal loads as people, lightings or equipments, different refrigeration systems, cabinets, costs, environmental impacts and outputs. The Matrix has been divided in six different groups, Indoor and outdoor conditions, HVAC system, Refrigeration system, Cabinets, Cost and environmental impacts and Outputs.

Table 5 presents information about indoor and outdoor conditions, calculation and units for CyberMart, EnergyPlus, RetScreen and SuperSim.

Table 5: Matrix with information about outdoor and indoor conditions, calculation and units

Software	CyberMart	EnergyPlus	RetScreen	SuperSim
Units	SI	SI (can convert output to archaic American if desired)	SI and IP	SI
Calculations	Hourly values during a year	Variable time step (typical 10 to 15 minutes, although shorter time steps are used for the plant equipment calculations) and reporting intervals (time step, hourly, daily, etc.) over the test period (day to a year)	24 time steps per year. It uses day and night conditions for each month	Hourly values during a year but can be adjustable by user to smaller time step.
Cities				
Cities in software	25 different cities from different countries from Meteonorm	Weather data for more than 2100 locations are now available in EnergyPlus weather format	9643 weather stations in 222 countries.	Selected worldwide stations from Meteonorm .More than 1000 locations

		— 1042 locations in the USA, 71 locations in Canada, and more than 1000 locations in 100 other countries throughout the world. The weather data are arranged by World Meteorological Organization region and Country.		are included, in more than 150 countries
New cities?	Possible as text file with outdoor conditions	Weather data pre-processor provided to translate most formats into format needed.	the user can enter their specific monthly temperature, relative humidity and daily solar heat gain	Possible as text file with required outdoor weather conditions
Outdoor conditions				
Dry bulb temp	Yes	Yes	Yes	Yes
Wet bulb temp.	No	Yes	No	Yes
Relative humidity	Yes	Yes	Yes	Yes
Solar irradiation	Direct and diffuse solar irradiation	Infrared sky temperature, solar radiation (global, normal, diffuse), Illuminance (global, normal, diffuse), sky cover (cloud amount), opaque sky cover	Total daily solar radiation (kWh/m ² -d)	Radiation(global,direct,diffuse), Illuminance(global,direct,diffuse),sky cover(total, opaque)
Wind speed	Yes	Yes and direction	Yes, annual average wind speed	Yes and direction
Indoor conditions		Set point can be varied sub-hourly		Set point is adjustable
Indoor Temperature	Yes	Yes	Yes	Yes

Summer	Yes	Yes	Yes	Yes
Winter	Yes	Yes	Yes	Yes
Day	Yes	Yes	No	Yes
Night	Yes	Yes	No	Yes

As explained in section 2.3.1 (Building model section), there are three main types of building energy modeling techniques: steady state, quasi-steady state and dynamic. CyberMart and Retscreen are quasi-steady state models while EnergyPlus and SuperSim are dynamic models. The calculation period for CyberMart is an hourly time interval during a year. EnergyPlus has typical variable time step of 10 to 15 minutes, although shorter time steps are used for the plant equipment calculations. SuperSim has hourly values during a year as calculation period but can be adjustable by user to smaller time step. Retscreen has calculation period of 24 time steps per year. It uses day and night conditions for each month.

About unit systems the four models use International System units (SI). EnergyPlus and Retscreen can convert units from SI to the United State Customary System units (USCS).

Outdoor climate is an important factor for calculation of energy usage in supermarkets. It affects the indoor climate and the performance of the refrigeration system in several ways. The outdoor temperature, relative humidity, solar irradiation and wind speed all influence the indoor climate through the building envelope, the ventilation system and infiltration.

The climate data of different cities around the world is used in the software. In CyberMart there is climate data from 25 different cities from different countries generated from the software METEONORM (Remund 2005). In EnergyPlus there are weather data for more than 2100 locations; 1042 locations in the USA, 71 locations in Canada, and more than 1000 locations in 100 other countries throughout the world. The weather data in EnergyPlus are arranged by World Meteorological Organization region and Country. In RetScreen there are weather data from 9643 weather stations in 222 countries. In SuperSim there are worldwide stations from Meteonorm (Remund 2005). More than 1000 locations are included, in more than 150 countries.

All four software can include weather data from new cities. In CyberMart new climate data can be include by a text file with dry bulb temperature, relative humidity, direct and diffuse solar irradiation, and wind velocity. In EnergyPlus is possible to include new cities using a weather preprocessor to produce the specific format which include, dry and wet bulb temperatures, relative humidity, infrared sky temperature, solar radiation (global, normal, diffuse), illuminance (global, normal, diffuse), sky cover (cloud amount), opaque sky cover, wind velocity and direction. In RetScreen the users can enter new cities with their specific monthly temperature, relative humidity, daily solar heat gain and annual average wind speed. In SuperSim is possible to include new cities by a text file which include dry and wet bulb temperatures, relative humidity, solar radiation (global, direct, diffuse), illuminance (global, direct, diffuse), sky cover (total, opaque) wind velocity and direction.

EnergyPlus, SuperSim and CyberMart calculate indoor temperature night and day, summer and winter. In EnergyPlus the set point can be varied sub-hourly. In CyberMart the set point is adjustable. RetScreen calculates the indoor temperature winter and summer.

Table 6: Matrix with information about Building envelope and HVAC system in CyberMart, EnergyPlus, RetScreen and SuperSim.

Software	CyberMart	EnergyPlus	RetScreen	SuperSim
Building envelope				
Different U values	No, Heavy, Medium, Light	Yes	Yes	Yes
Area	Yes	Yes	Yes	Yes
Windows area	Yes	area, U-value, SHGC	no	Yes
windows type	Yes	Yes	no	Yes
windows shield	Yes	Yes, shading	no	Yes
Doors	No	Yes	no	Yes
Infiltration	Yes in air changes per hour	Yes	Fixed in air changes per hour	Yes in air change per hour
HVAC system				
CAV or VAV	CAV	Either, wide range of HVAC options	CAV	CAV
Volume flow	Yes m3/hr	Yes	Yes, can be set constant or according to operation schedule/occupation	Yes
Pressure drop	Yes in Pascal	Yes	NO	No
Heat recovery	Rotary heat exchanger	Yes	No	Yes
Recirculation of Air	Amount of fresh air according with the amount of CO ₂ indoor	specified amount or variable	YES, fresh air according to occupancy schedule	Yes, is adjustable according to requirement
Efficiency of heat recovery	Yes	Variable	YES, user input	Yes
Heat recovery from Refrigeration System	Yes	Yes	yes, condenser and desuperheater	Yes
Heating system				
Oil boiler	Yes	Yes	Yes	Yes
Gas boiler	No	Yes	Yes	Yes
Electric boiler	Yes	Yes	Yes	Yes
Heat Pump	No	Yes, air-source, water-source, geothermal	Yes	No
District heating	Yes	Yes	No	Yes

Cooling system				
Chiller	Yes, Possible to define temperatures	Yes - also unitary ACs, heat pumps, room Acs	Yes. For the main refrig. System, the users enters the COP of the system at some reference temperature. This COP is recalculated with varying operation conditions. For air conditioning, constant heat pump COP	Yes, possible to control space temperature
District Cooling	Yes	Yes	No	No
Internal Loads				
Lighting Indoor	day / night	Yes per any schedule	day / night	Yes per schedule
Lighting Outdoor	No	Yes per any schedule	no	No
Equipments	day / night	Yes per any schedule	Yes, constant	Yes per schedule
People	Profile week and day	Yes per any schedule	yes per schedule	Yes per schedule
Plug-in Cabinets	Yes	Yes per any schedule	no	Yes per schedule
Opening hours				
Weekly profile	Yes	Yes per any schedule	Yes, operating hours per day on week and weekend. This defines the 'day' and 'night' conditions	Yes per schedule

Table 6 presents information about Building envelope and HVAC system in CyberMart, EnergyPlus, RetScreen and SuperSim.

In the software EnergyPlus, RetScreen and SuperSim is possible to change the heat transfer coefficients and area of building envelope. CyberMart has three different types of construction modeled in the program, heavy, medium and light. The heavy wall has, from the inside: 120 mm concrete, 150 mm insulation and 80 mm concrete. The medium wall has, from the inside: 10 mm stucco, 200 mm light concrete, 150 mm insulation and 10 mm stucco. The light wall has: 25 mm gypsum, 200 mm cross bars, 150 mm insulation and 120 mm brick.

Three of the software EnergyPlus, SuperSim and CyberMart take into consideration windows area, windows type and windows shield. RetScreen has no choice about windows. EnergyPlus and SuperSim can include data from doors.

All four programs have the possibility to modify infiltrations through building envelope in air changes per hour.

About HVAC system the software RetScreen, SuperSim and CyberMart have Constant Air Volume system (CAV). EnergyPlus has a wide range of HVAC system with constant and variable air volume systems. Air volume flow can be changed in EnergyPlus, SuperSim and CyberMart. In RetScreen the air volume flow can be set constant or according to operation schedule/occupation. Pressure drop of ventilation system is included in EnergyPlus and CyberMart.

All four programs have the option of heat recovery from Refrigeration and HVAC system with possibilities to vary the efficiency. Recirculation of air and amount of fresh air according with occupancy schedule and requirements are other options in the four software.

Regarding heating systems, oil and electric boilers are alternative in all the programs. EnergyPlus, RetScreen and SuperSim have the option of gas boiler. Heat pumps are a choice in EnergyPlus and RetScreen while District heating is a possibility in CyberMart, EnergyPlus and SuperSim.

Concerning cooling system in CyberMart there are options for District cooling and chillers. In EnergyPlus the users can select central chillers, unitary ACs, heat pumps, room ACs and District cooling. In RetScreen the AC System is defined by COP of the system at some reference temperature. This COP is recalculated with varying operation conditions. In SuperSim the option is a chiller.

The opening hours and internal loads as lighting, equipments and people are choices in all four programs with different schedules. Plug-in cabinets are an option in CyberMart, EnergyPlus and SuperSim. Lighting outdoor is a choice in EnergyPlus.

Table 7: Matrix with information about Refrigeration system in CyberMart, EnergyPlus, RetScreen and SuperSim.

Software	CyberMart	EnergyPlus	RetScreen	SuperSim
Refrigeration System				
DX	Yes	Yes, detailed and simple modules available	yes	Yes, with detailed and simple models
Completely Indirect system	medium and low temp level	indirect condensing available; glycol/brine (medium temp) and liquid overfeed (low temp) loops to cases available	yes	Medium temperature level
Partially Indirect	in low temp level	indirect condensing available; glycol/brine	yes	in medium temperature level

		(medium temp) and liquid overfeed (low temp) loops to cases available		
Booster (cascade)	Yes	Yes	no	Yes, for CO ₂ booster system
Mechanical subcooling freezer	Yes	Yes, models interactions between refrigeration systems and reports energy transfer	yes. Independent compressor for mechanical subcooling, or use of medium temperature system to subcool low temperature system	Yes
District cooling to cool condensers	medium and low temp level	You can specify any source/temperature for the water-cooled condenser option	no	No
Condensing conditions				
Fixed Cond.Temp or Floating Cond.Temp	Fixed and floating Cond temp	Fixed and floating	User can choose fixed or floating for low and med. temp. System	Fixed and floating
Capacity fans	In database	fan power (and pump power for cooling tower) as function of condenser/tower air temp; dry air-cooled and evaporative condenser options	No	fan power calculated
Subcooling	Fixed	Liquid suction and mechanical subcoolers calculated in detailed DX module	options: mechanical subcooling with external compressor, use of med. temp. to subcool low temp. system, or use of free cooling with heat exchanger	user definable
Evaporating conditions				
Evaporating temp	Per Rack	Per Rack	per rack	per rack
Superheat	Fixed 5°C	Fixed 4°C	Fixed and not user definable	Fixed
Compressor				
Number of Racks	Unlimited	Unlimited	Only two racks: low temp and med. temp.	Unlimited

Predefined Compressor	Bitzer and Copeland	Library with Carlyle and Copeland; input AHRI map data for others with detailed DX module ; modeled as capacity and COP vs. fTemp for simple module	generic compressor based on a typical semi-hermetic compressor performance curve	Correlations for various types of compressors
Add user compressor	No	Yes	yes, user supplies COP at an evaporation/condensing temperature. COP recalculated using standard curve at different operation conditions	Yes
Suction line pressure or temp.	Calculated	Calculated in detailed DX module	no, nominal COP should include this effect	Fixed and user definable
Fluids				
HFC Refrigerants	R404A	library of most commonly used refrigerants in supermarkets; refrigerant data taken from REFPROP software as distributed by the US National Institute of Standards and Technology (NIST)	50 refrigerants, Only used for GHG calculation, and for estimating the amount of superheat heating power available	Any refrigerant from REFPROP software
Natural Refrigerants	Can be added to database	can be added to library	Yes, Only used for GHG calculation, and for estimating the amount of superheat heating power available	Yes, including CO ₂ and NH ₃ etc.
Secondary refrigerant medium	12 fluids	User can input properties for any glycol or brine. Several glycol concentrations already available	Yes. 5 fluids with variable concentration plus user defined density and specific heat	12 fluids
Secondary refrigerant low	6 fluids and CO ₂	User can input brine properties. CO ₂ as fluid in secondary loop system module	Yes. 5 fluids with variable concentration plus user defined density and specific heat	6 fluids and CO ₂
Coolant fluid	12 fluids	water-cooled	Fluid irrelevant, a TD	12 fluids

		condenser option can use water or glycol	between coolant fluid and refrigerant evaporation temperature is used.	
Walk-in Coolers facing multiple zones		Yes	Added 2009	

Table 7 presents information about Refrigeration system in CyberMart, EnergyPlus, RetScreen and SuperSim.

All four programs have the possibilities to simulate direct expansion (DX) refrigeration system. EnergyPlus and SuperSim have detailed and simple modules available.

Indirect refrigeration systems are also options in the four software. In CyberMart completely indirect system is included in medium and low temperature level while partially indirect system is a choice for low temperature level. In EnergyPlus indirect systems are available as indirect condensing and glycol/brine or liquid-overfeed secondary refrigerant loops to display cases. RetScreen has the possibility to calculate completely and partially indirect system in medium and low temperature levels. SuperSim can simulate completely and partially indirect system in medium temperature level. Booster indirect system is available in CyberMart and EnergyPlus. SuperSim has a booster system for CO₂ system

Mechanical subcooling is also an option in the four programs. RetScreen has the choice of independent compressor for mechanical subcooling, or use of medium temperature system to subcool low temperature system.

District cooling to cold condensers is an alternative in CyberMart and EnergyPlus. In CyberMart the district cooling choice is available for the medium and low temperature systems. In EnergyPlus is possible to specify any source/temperature for the water-cooled condenser option. Condensing conditions are dependent on outdoor conditions and heat recovery from condensers. Heat recovery is a good possibility to decrease the heating cost in supermarkets in cold climates. The obvious drawback is the high condensation temperature necessary to cover the heating requirements of the supermarkets. In floating condensing systems the condensing temperature is changing with the ambient temperature. All four programs have the possibilities to simulate fixed and floating condensing temperatures for medium and low temperature systems.

The electrical power of fans in condensers and dry coolers are calculated in different ways in all the programs. In CyberMart the fan power is calculated from the ambient conditions and the nominal capacity of the fans in a database. In EnergyPlus the fan power (and pump power for cooling tower) is calculated as function of condenser/tower air temp and heat rejection load; dry air-cooled and evaporative condenser options. In SuperSim the fan power is calculated.

Subcooling of the refrigerant is an option in three of the programs. In EnergyPlus liquid suction and mechanical subcoolers are calculated in the detailed DX module. RetScreen has the options of mechanical subcooling with external compressor, or use of free cooling with heat exchanger. In SuperSim the subcooling is definable by the user. In CyberMart the Subcooling of the refrigerant is fixed and it cannot be specified by users.

All four programs calculated evaporation temperatures per rack of compressor and the superheat is fixed. The number of compressor rack is unlimited in CyberMart, EnergyPlus and SuperSim.

RetScreen has the option to use two racks of compressors in the medium and low temperature level.

There are different kinds of compressors in the software. CyberMart has a database with Bitzer and Copeland compressors and the users cannot add new compressors. EnergyPlus has a library with Carlyle and Copeland compressors, and the users can input AHRI map data for other compressors. RetScreen uses a generic compressor based on a typical semi-hermetic compressor performance curve. The users can add new compressors. They supply COP at evaporation and condensing temperature. COP recalculated using standard curve at different operation conditions. SuperSim has correlations for various types of compressors and the users can add new compressors.

The suction line pressure or temperature is calculated in CyberMart and EnergyPlus. In RETScreen the suction line temperature is not calculated but the nominal COP should include this effect. In SuperSim the suction line pressure is fixed and user definable.

About refrigerants the software have different options. CyberMart has R404A as the only HFC refrigerant. Natural refrigerants can be added to a database. EnergyPlus has a library with the most commonly used refrigerants in supermarkets. Natural refrigerants can be added to the library. In RetScreen there are available 50 refrigerants (HFC and natural refrigerants). These refrigerants are only used for greenhouse gas calculation, and for estimating the amount of superheat heating power available. In SuperSim are options to any refrigerant from REFPROP software.

Indirect refrigeration systems are options in the four software. There are different choices for secondary refrigerants and coolants fluids. In CyberMart and SuperSim there are 12 secondary refrigerants for the medium temperature level and 6 (include CO₂) for the low temperature level. These software have also 12 coolant fluids. In EnergyPlus the user can input properties for any glycol or brine. Several glycol concentrations are already available. CO₂ as fluid in secondary loop system module has been added. RetScreen has 5 fluids with variable concentration. The user can define density and specific heat. Walk-in Coolers facing multiple zones was added in EnergyPlus and RetScreen during 2009.

Table 8: Matrix with information about Cabinets in CyberMart, EnergyPlus, RetScreen and SuperSim.

Software	CyberMart	EnergyPlus	RetScreen	SuperSim
Cabinets				
Predefined cabinets	180 Swedish Cabinets	Library of cases to be added in 2010.	no specific cabinets	no specific cabinets
Add user cabinets	Possible as text file	Standard now and will still be possible when case library is finished	The user has to supply total capacity and operation conditions for all cabinets in one rack	some manufacture data for each cabinet is needed such as cooling capacity, evaporating temperature and case temperature.
Nightcovers	All medium and low temp cabinets	Yes according to schedules	no	Yes per schedule

Doors	As a new cabinet with a text file	doored and open cases will be included in library	no	Calculated and scheduled
Information Cabinets as text file				
Refrigeration Capacity at 22°C and 65% RH:	Yes	Most rated at 24 °C and 55% RH. Capacity calculated at other operating conditions.	yes, can supply any design conditions in the interface. An empirical performance curve is adjusted to this conditions. Only one condition necessary.	Yes, to be used to calculate cooling load at part-load condition
Refrigeration Capacity at 25°C and 60% RH:	Yes		yes, can supply any design conditions in the interface. An empirical performance curve is adjusted to this conditions. Only one condition necessary.	
Length:	Yes	Yes	no	no
Power of Fans:	Yes	Yes	yes	Yes
Power of Light:	Yes	Yes	yes	Yes
Power of Heating Wires:	Yes	Yes	Yes, user must enter antisweat capacity	no
Power of Defrost Heater:	Yes	Yes	yes, in term of daily electrical defrost energy consumption	Yes
Air Temperature at the Inlet of the Cabinet:	Yes	No	no	no
Air Temperature at the Outlet of the Cabinet:	Yes	no	no	no
Air Temperature in	Yes	Yes	yes	Yes

the Cabinet:				
Evaporation Temperature:	Yes	Yes	yes in case of DX system	Yes
Supplied Brine Temperature:	Yes	Yes	yes in case of secondary loop system	Yes
Return Brine Temperature:	Yes	Yes	no, software uses TD between return brine and evaporating temp.	no
Pressure Drop for Propylene Glycol:	Yes	Yes	no	no

Table 8 presents information about Refrigeration system in CyberMart, EnergyPlus, RetScreen and SuperSim.

All four software have the capability to simulate the interaction between cabinets and indoor conditions. Information about display cases has been added to the programs in different ways. In CyberMart there is a database with 180 cabinets from two brands. In EnergyPlus the cabinets are standard, a library with display cases will be added. The cabinets in RetScreen and SuperSim are also standard.

Additional display cases can be added in all the four programs. In CyberMart the user can include new case as text file. In EnergyPlus it will be possible to add new cabinets when the case library is finished. In RetScreen the user can supply total capacity and operation conditions for all cabinets in one rack. In SuperSim some manufacture data for each cabinet is needed such as cooling capacity, evaporating temperature and case temperature.

The option of night cover on cabinets is possible in three software. CyberMart has the choice of night cover of cases in the medium and low temperature levels. EnergyPlus and SuperSim have night cover on cabinets according with schedules.

The alternative of Cabinets with doors is a possibility in some of the software. In CyberMart display cases with doors can be added as text file. In EnergyPlus doors and open cases will be included in the case library. In SuperSim cabinets with doors are calculated and scheduled.

The information require in the software to calculate energy performance of cabinets is almost the same in the four programs. The data necessary is refrigeration capacity at 22°C and 65% RH and 25°C and 60% RH, power of fans, lighting, heating wires and defrost heater, air temperature in the cabinets, evaporation temperature and supplied brine temperature. CyberMart and EnergyPlus require some additional information as length, air temperature at the inlet and outlet of the cabinets, return brine temperature and pressure drop for propylene glycol:

Table 9: Matrix with information about cost and environmental impacts in CyberMart, EnergyPlus, RetScreen and SuperSim.

Software	CyberMart	EnergyPlus	RetScreen	SuperSim
LCC		life cycle cost will be added		
Supermarket	No	no	No, but a complete set of financial indicators, cash flow graph/table and sensitivity and risk analysis tool	no
Refrigeration system	Yes	no	No, but a complete set of financial indicators, cash flow graph/table and sensitivity and risk analysis tool	no
TEWI/LCCP				
Refrigeration system	Yes/No	Independent environmental outputs for each pollutant and energy use	No/No, but a sheet with complete report on GHG emissions	Yes/No
Air condition system	No/No	Independent environmental outputs for each pollutant and energy use	No/No, but a sheet with complete report on GHG emissions	No/No

Table 9 presents information about cost and environmental impacts in CyberMart, EnergyPlus, RetScreen and SuperSim.

There are different methods to analyze investment and energy costs. Life Cycle Cost (LCC) is a method that evaluates present and future costs from the investments in and operation and maintenance of a project over its entire life cycle. To calculate the LCC, it is necessary to compute the present value of all costs occurring during the period of study.

None of the four computer programs have the options of LCC calculation for the supermarket as a system. CyberMart has the choice of LCC calculation for the refrigeration system. EnergyPlus will add LCC calculation. RetScreen has a complete set of financial indicators, cash flow graph/table and sensitivity and risk analysis tool

Global environmental impacts due to greenhouse gas emissions to the atmosphere have been associated with refrigeration systems during recent years. Refrigerants HCFC and HFC are

recognized as greenhouses gases. The concept of Total Equivalent Warming Impact (TEWI) is a useful tool when studying the influence of a refrigeration system on global warming. The TEWI combines the direct emissions of CO₂ due to refrigerant leakage and refrigerant losses at the end of the system's life and the indirect emissions of CO₂ associated with energy consumption and generation. Life Cycle Climate Performance (LCCP) is a concept that takes into consideration the effect of production of the refrigerant in the system in addition to the direct impact of leakage and indirect impact of energy used.

CyberMart and SuperSim have the capability to calculate TEWI of the refrigeration system. EnergyPlus has independent environmental outputs for each pollutant and energy use, but does not report refrigerant leakage. RetScreen has a complete report on greenhouse gas emissions. None of the software have the options of LCCP calculation.

Table 10: Matrix with information about outputs in CyberMart, EnergyPlus, RetScreen and SuperSim.

Software	CyberMart	EnergyPlus	RetScreen	SuperSim
Outputs				
Yearly Energy	Total energy use, Total electricity, total heat, energy refrigeration system, lightings, equipments, plug-in cabinets, ventilation	User-selected. Available for all energy uses and many operating parameters on component, system, and building levels.	yes: compressors, case lights, case fans, case electrical defrost, heat pump, heating equipment (electricity, gas, oil or other units), domestic water heating, air conditioning, store lighting and misc. electrical usage	Yes, compressors, condenser fans, lighting, heating, heat recovery
Monthly Energy	Total energy use, Total electricity, total heat, energy refrigeration system, lightings, equipments, plug-in cabinets, ventilation	User-selected. Available for all energy uses and many operating parameters on component, system, and building levels.	no, monthly results calculated internally but not shown	Yes, compressors, condenser fans, lighting, heating, heat recovery
Daily	Indoor temp, RH, Total energy use, Total electricity, total heat, energy refrigeration system,	User-selected. Available for all energy uses and many operating parameters on component, system, and building levels.	no	Yes, compressors, condenser fans, lighting, heating, heat recovery

	compressor, lightings, equipments, plug-in cabinets, ventilation			
Hourly	Indoor temp, RH, Total energy use, Total electricity, total heat, energy refrigeration system, compressor, lightings, equipments, plug-in cabinets, ventilation	User-selected. Available for all energy uses and many operating parameters on component, system, and building levels.	no	Yes, indoor temp, RH ,compressors, condenser fans, lighting, heating, heat recovery
Sub-hourly Time Step	no	User-selected. Available for all energy uses and many operating parameters on component, system, and building levels.	no	Yes, compressors, condenser fans, lighting, heating, heat recovery

Table 10 presents information about outputs in CyberMart, EnergyPlus, RetScreen and SuperSim.

All four software report results yearly. CyberMart presents results of total energy use, total electricity, total heat and energy used by the refrigeration system, lightings, equipments, plug-in cabinets and fans from ventilation system. In EnergyPlus the user can select for all energy uses and many operating parameters. RetScreen has annually report of compressors, case lights, case fans, case electrical defrost, heat pump, heating equipment (electricity, gas, oil or other units), domestic water heating, air conditioning, store lighting and misc. electrical usage. SuperSim has reports of compressors, condenser fans, lighting, heating, heat recovery, etc.

Monthly, daily and hourly reports are possible in three programs. CyberMart has monthly, daily and hourly report of indoor temperature and RH, total energy use, total electricity, total heat and energy used by refrigeration system, compressor, lightings, equipments, plug-in cabinets, and fans from ventilation system. In EnergyPlus the user can select for all energy uses and many operating parameters. SuperSim has yearly and monthly reports of compressors, condenser fans, lighting, heating, heat recovery, etc. Sub-hourly time step reports are possible in EnergyPlus and SuperSim

2.4.7 *Summary.*

An overview of four different models that calculate energy performance in supermarkets and developed by the countries participating in Annex 31 has been presented in this task. All four software are able to model building, HVAC and refrigeration system performance and the interaction between cabinets and the surrounding environment.

Outdoor climate is an important factor for calculation of energy usage in supermarkets. The four models have the possibility to choose and include weather data from new cities from different countries.

The calculation periods of the software are different. The calculation period for CyberMart is an hourly time interval during a year. EnergyPlus has typical variable time step of 10 to 15 minutes, although shorter time steps are used for the plant equipment calculations. SuperSim has hourly values during a year as calculation period but can be adjustable by user to smaller time step. RetScreen has calculation period of 24 time steps per year. It uses day and night conditions for each month.

About HVAC system the software RetScreen, SuperSim and CyberMart have Constant Air Volume system (CAV). EnergyPlus has a wide range of HVAC system with constant and variable air volume systems. Air volume flow can be changed in EnergyPlus, SuperSim and CyberMart. In RetScreen the air volume flow can be set constant or according to operation schedule/occupation. Pressure drop of ventilation system is included in EnergyPlus and CyberMart. All four programs have the option of heat recovery from Refrigeration and HVAC system with possibilities to vary the efficiency. Recirculation of air and amount of fresh air according with occupancy schedule and requirements are other options in the four software.

Direct and indirect refrigeration systems are options in the four programs. In CyberMart completely indirect system is included in medium and low temperature level while partially indirect system is a choice for low temperature level. In EnergyPlus indirect systems are available as indirect condensing and glycol/brine or secondary refrigerant liquid overfeed loop to display cases. RetScreen has the possibility to calculate completely and partially indirect system in medium and low temperature levels. SuperSim can simulate completely and partially indirect system in medium temperature level. Booster indirect system is available in CyberMart and EnergyPlus. SuperSim has a booster system for CO₂ system

About refrigerants the software have different options. CyberMart has R404A as the only HFC refrigerant. Natural refrigerants can be added to a database. EnergyPlus has a library with the most common used refrigerants in supermarkets. Natural refrigerants can be added to the library. In RetScreen there are available 50 refrigerants (HFC and natural refrigerants). These refrigerants are only used for greenhouse gas calculation, and for estimating the amount of superheat heating power available. In SuperSim are options to any refrigerant from REFPROP software.

All four software have the capability to simulate the interaction between cabinets and indoor conditions. Information about display cases has been added to the programs in different ways. In CyberMart there is a database with 180 cabinets from two brands. In EnergyPlus the cabinets are standard, a library with display cases will be added. The cabinets in RetScreen and SuperSim are also standard. Additional display cases can be added in all the four programs. In CyberMart the user can include new case as text file. In EnergyPlus it will be possible to add new cabinets when the case library is finished. In RetScreen the user can supply total capacity and operation

conditions for all cabinets in one rack. In SuperSim some manufacture data for each cabinet is needed such as cooling capacity, evaporating temperature and case temperature.

About Life Cycle Cost (LCC), none of the four computer programs have the options of LCC calculation for the supermarket as a system. CyberMart has the choice of LCC calculation for the refrigeration system. EnergyPlus will add LCC calculation and RetScreen has a complete set of financial indicators, cash flow graph/table and sensitivity and risk analysis tool

About environmental impact CyberMart and SuperSim have the capability to calculate Total Equivalent Warming Impact (TEWI) of the refrigeration system. EnergyPlus has independent environmental outputs for each pollutant and energy use. RetScreen has a complete report on greenhouse gas emissions. None of the software have the options of Life Cycle Climate Performance (LCCP) calculation.

2.5 Task 5 Comparison of the results obtained with the different whole-building simulation models for selected case studies

Task leader – CanmetENERGY - Natural Resources Canada

Object of this task

This study was performed with the intent of assessing the differences in results obtained with the use of three different modeling software designed to estimate the whole-building energy consumption of a supermarket.

The software are:

1. **RETScreen**[®] developed by CanmetENERGY, Natural Resources Canada
2. **EnergyPlus** developed by the US Department of Energy, USA
3. **CyberMart** developed by KTH, Sweden

At first, EnergyPlus and CyberMart were used with a set of input data that were specific to each country with the features of the supermarket selected by the user. Differences in the results of the two simulations can be explained either by the differences in the input data, the weather data or the algorithms used within the software.

To further assist in analyzing these differences, the input data of each supermarket used in EnergyPlus and CyberMart were entered in RETScreen. In the later, the weather data was selected for the same region as the one used in the original model. There are minor differences between the various sets of weather data because they originate from different sources but when compared to one another, the differences are not significant.

Results of these simulations are further analyzed and commented in this task. The input data are shown in Tables 11 to 15 and the modeling results summarized in Tables 16 to 18.

2.5.1 Comparing input data

Table 11 Building Description

Description	Units	Linköping, Sweden	Miami, FL USA
Sales Floor Area	m ²	800	1,881
Height of the building	m	4.00	4.27
Lighting	W/m ²	23	28
Thermal resistance of external walls	m ² .K/W	2.40	2.32
Ceiling Thermal Resistance	m ² .K/W	4.80	3.33
Other heat sources (restaurant, kitchen and others)	W	7,500	9,980
Fresh Air flow rate requirements for the store	m ³ /s	3.33	1.40
Operating hours per week	h	88.0	77.5

The sales floor area of the Miami supermarket is more than twice larger than the Linköping one and the lighting intensity (W/m²) is 22% larger.

Table 12 Low Temperature Display Cases

Description	Units	Linköping, Sweden	Miami, FL USA
System type		Secondary Fluid	DX
Refrigeration load at design conditions	W	15,584	18,472
Display cases Lights, fans and anti-sweat power	W	1,424	6,408
Defrost mode.	-	Electric	Hot gas
Display Case air Temperature	°C	-25.0	-20.0
Display Case coolant supply temperature (brine or refrigerant)	°C	-34.0	-23.5

The refrigeration load of the display cases excludes the fan and internal lighting loads. The display cases refrigeration load for Linköping is high for the supermarket area probably because of a lower temperature set point.

Table 13 Low Temperature Compressor Rack (at design conditions)

Description	Units	Linköping, Sweden	Miami, FL USA
Compressors COP	-	1.29	2.00
Evaporating Temperature	°C	-35.0	-24.5
Condensing temperature	°C	40.0	35.0

The Miami DX compressor rack works at 10°C higher evaporating temperature than the Linköping secondary fluid rack and consequently achieves a much better compressor rack COP, 2.0 vs. 1.29. In addition, a lower design condensing temperature in Miami (35 vs. 40 °C) increases the COP.

Table 14 Medium Temperature Display Cases

Description	Units	Linköping, Sweden	Miami, FL USA
System type		Secondary Fluid	Secondary Fluid
Refrigeration load at design conditions	W	46,070	38,878
Display cases Lights, fans and anti-sweat power	W	2,264	11,443
Display Case air Temperature	°C	3.0	-1.5
Display Case coolant supply temperature (brine or refrigerant)	°C	-7.7	-8.5

Both, Linköping and Miami, use the same type of system, but the Display case lights and fans of the Miami store have a much higher power requirement than in the Linköping store. On the other hand, the total refrigeration loads are almost the same.

Table 15 Medium Temperature Compressor Rack (at design conditions)

Description	Units	Linköping, Sweden	Miami, FL USA
Compressors COP	-	2.29	2.86
Evaporating Temperature	°C	-12.0	-12.6
Condensing temperature	°C	40.0	35.0

The medium temperature compressors rack has been designed for comparable evaporating temperature conditions. Again, the lower design condensing temperature in Miami increases the COP.

2.5.2 Comparing modeling results

RETScreen versus CyberMart

The same input information used for CyberMart was also used for RETScreen. The output results for both simulations are compared in Table 16

Table 16 Comparing simulation results for the same Swedish supermarket – RETScreen versus CyberMart.

Equipment	RETScreen with CyberMat inputs	CyberMat	RETScreen <u>minus</u> CyberMat	Delta
Units	kWh	kWh	kWh	%
Refrigeration Loads				
Low Temperature Display Cases	124,644	116,346	8,298	7%
Medium Temperature display cases	333,277	311,440	21,837	7%
Energy Consumption				
Low Temperature Compressors Rack	67,020	68,692	-1,672	-2%
Medium Temperature Compressor Racks	96,327	113,534	-17,207	-15%
Low and Medium Temperature Display Cases	33,560	93,315	-59,755	-64%
Total Energy Consumption	196,907	275,541	-78,634	-29%
COP				
COP Low Temperature	1.9	1.7		-10%
COP Medium Temperature	3.5	2.7		-26%

Comments:

1. The most significant difference is on the energy consumptions for Low and Medium Temperature Display Cases. The 59,757 kWh difference correspond to the energy consumption of the secondary fluid pumps. It seems that RETScreen does not include this portion of the energy consumption. This should be adjusted in RETScreen.
2. The second most important difference is with Medium Temperature Compressor Racks. RETScreen reports lower energy consumptions and higher refrigeration loads than CyberMart. Consequently, this means that the compressors model also estimates a higher COP for RETScreen. Results need further investigation to determine the source of these discrepancies and eventually improve simulation accuracy.
3. Although the total energy consumptions show a 29% difference, by adding the secondary pumps energy consumption in RETScreen, the delta would drops to a low 7%, which is acceptable.

RETScreen versus EnergyPlus

The same input information used for EnergyPlus is also used for RETScreen. The output results for both simulations are compared in **Table 17**

Table 17 Comparing simulation results for the same US supermarket – RETScreen versus EnergyPlus.

Equipment	RETScreen with EnergyPlus inputs	EnergyPlus	RETScreen minus EnergyPlus	Delta
	kWh	kWh	kWh	%
Refrigeration Loads				
Low Temperature display cases Refrigeration Load	177,969	85,000	92,969	109%
Medium Temperature display cases Refrigeration Load	377,069	185,778	191,291	103%
Energy Consumption				
Low Temperature Compressor consumption	74,549	68,333	6,216	9%
Medium Temperature Compressor consumption	106,823	63,611	43,212	68%
Low Temperature display cases consumption	39,065	41,667	-2,602	-6%
Medium Temperature display cases consumption	61,251	58,333	2,917	5%
Total Energy Consumption	281,688	231,944	49,744	21%
COP				
COP Low Temperature	2.4	1.2		-92%
COP Medium Temperature	3.5	2.9		-21%

Comments:

1. The Refrigeration Loads are significantly different between the two models while these differences appear on components considered to be the core of the model i.e. refrigeration components. For the same reasons as mentioned previously, this should be investigated more in depth considering that the base model will serve as reference to evaluate various improvements to individual components or systems in the facility.
2. Like in the CyberMart comparisons, the RETScreen Compressor model indicates a higher COP. Again, algorithms need to be analyzed more in-depth to eliminate potential errors in decision making.
3. The Energy consumption for Displays Cases shows a difference of 5%. In this case, the energy consumption for the secondary fluid pump in medium temperature does not affect the results significantly.

CyberMart versus EnergyPlus

The output results for both simulations are presented in Table 18. The purpose of this table is not to compare the simulation algorithm of CyberMart and EnergyPlus. The purpose is to compare the two supermarket cases (inputs and outputs). Differences in the results presented in Table 18 depend on the differences in the input data (two different supermarkets in each country) and the weather data.

Table 18 Comparing simulation results of CyberMart versus EnergyPlus

Simulation software	CyberMat	EnergyPlus	EnergyPlus minus CyberMat	Delta%
Location	Linköping, Sweden	Miami, FL USA		
Sales Floor Area m2	800	1,881	1,081	57%
Refrigeration Loads				
Low Temperature display cases Refrigeration Load	116,346	85,000	-31,346	-37%
Medium Temperature display cases Refrigeration Load	311,440	185,778	-125,662	-68%
Energy Consumption				
Low Temperature Compressor consumption	68,692	68,333	-359	-1%
Medium Temperature Compressor consumption	113,534	63,611	-49,923	-78%
Low and Medium Temperature display cases consumption	93,315	100,000	6,685	7%
Total consumption	275,541	231,944	-43,596	-19%
COP				
Yearly COP Low Temperature	1.7	1.2		-36%
Design COP Low Temperature	1.3	1.7		24%
Yearly COP Medium Temperature	2.7	2.9		6%
Design COP Medium Temperature	2.3	2.3		0%

Comments:

1. The Refrigeration Loads are more important in the smaller Swedish supermarket even though the store is smaller and the climate colder.
2. The Yearly COP on Low Temperature calculated by EnergyPlus is lower than the design COP. Normally, the Yearly COP should be higher as shown by the CyberMart results.

2.5.3 Summary

The main objective of this chapter was to compare results obtained with the different whole-building simulation models for selected case studies. Two supermarkets were simulated. The first supermarket was simulated in CyberMart and the input data were entered in RETScreen. Results from the simulation show that RETScreen does not include the energy usage from secondary refrigerant pumps. Another is with Medium Temperature Compressor Racks. RETScreen reports lower energy consumptions and higher refrigeration loads than

CyberMart. Consequently, this means that the compressors model also estimates a higher COP for RETScreen.

The second supermarket was simulated in EnergyPlus and the input data were entered in RETScreen. The difference in Refrigeration Loads are significantly between the two models while these differences appear on components considered to be the core of the model i.e. refrigeration components. This should be investigated more in depth considering that the base model will serve as reference to evaluate various improvements to individual components or systems in the facility. Like in the CyberMart comparisons, the RETScreen Compressor model indicates a higher COP. Again, algorithms need to be analyzed more in-depth to eliminate potential errors in decision making.

This task has proven its value in revealing the necessity of improving the models or to better qualify their limitations to avoid major errors in the decision process where costly investments are made on energy improvements.

2.6 Task 6 – Future perspectives and possibilities

Task leader - Sweden National Team (KTH and SP)

Best available technology in supermarkets is moving forwards and the situation in the fall 2009 is not the same as when the Annex started a few years ago. Today there is an even stronger pressure on supermarket chains to considering energy efficiency and energy use from both environmental and cost perspectives. The development in refrigeration technology are moving forward addressing challenges such as refrigerant charge minimization, system tightness and alternative working fluids. Several new system solutions has been introduced, notable here are systems in colder climates recovering the heat from the refrigeration system for heating purposes with or without the aid of a dedicated heat pump installed. Some examples from Germany and Sweden are mentioned here.

The previous Annex 26 focused on new system solutions in supermarket and the scope of Annex 31 is more on energy use, indices for energy efficiency and computer models for calculations of supermarket performance. This means that the focus of this report is not primarily on new types of systems. Several supermarket chains are however driving hard to seek new concepts for low-energy stores and the new systems must be mentioned. One recent example in Germany is Tengelmann Climamarkt (<http://www.tengelmann-klimamarkt.de/>). The store uses several innovative technologies. The goal set is ambitious with 50% less energy than a conventional store of similar size. Notable here are the combination of several technologies and measures, not altogether new, but in a combination - a new concept! The roof is for instance entirely covered with solar PV collectors, a ground source heat pump system is used for heat and the ground coupling is used to lower condensation temperatures for the refrigeration machinery. LED light is used to a large extent combined with several other innovative concepts. Similar trends can be seen in other countries as well. Notable here are the ambition by US supermarket chain Wal-Mart with several new concept stores. One example is the newly opened store in Youngstown, Ohio. The design goal here is 25% less energy than a normal store (whatever that is) (Walmartstores, 2009) . (<http://walmartstores.com/FactsNews/NewsRoom/9333.aspx>).

The new store implements the latest “phase” of technologies used in the previous stores, referred to as HE.2 stores, again including a water-source heating, cooling and refrigeration system, where water is used to heat and cool the building, a secondary refrigeration loop that is expected to reduce the initial refrigerant charge by 90 percent and an active dehumidification system

In addition to the innovative features for the refrigeration and HVAC systems the new store includes other energy efficient technologies such as:

- Light-emitting diodes (LEDs) in refrigerated and freezer cases
- Daylight harvesting technology
- Reflective white membrane roof to lower AC demand
- Sensor-activated low-flow bathroom faucets and high efficiency urinals and toilets
- Recycled construction materials such as fly-ash, slag, integrally coloured concrete floors, and plastic baseboards and chair rails

Another important recent contribution to the literature with a very good overview is a German report entitled “Comparative Assessment of the Climate Relevance of Supermarket Refrigeration Systems” (Rhiemeier, J. M. et.al., 2009). The first part of the report contains a market survey of supermarket refrigeration systems that are completely or partially operated with HFC free refrigerants, including information on their actual market penetration in the EU. Beside the

respective relevance of the technology in the market, it is also displayed to what extent appropriate operational experiences exist. In a detailed data compilation, the so-called technology data sheets, 30 main characteristics for decentralized plug-in units, condensing units and for central multiplex systems are given. These characteristics provide information on equipment data, refrigerant losses, energy consumption, life cycle costs, market share, operational experiences, and suppliers. Furthermore, all currently relevant refrigerants are described with regard to their physical properties, with an in depth look at their cost effectiveness and climate relevance for the food retail sector. The data compilation is based on an extensive literature research of scientific technical literature as well as on numerous interviews with manufacturers, suppliers and retail representatives.

Beside the description of the equipment technology itself the market survey also offers an overview of the relevant store categories in which the respective technology is used, substantial details on energy saving measures, a compilation of leakage rates of supermarket refrigeration systems, as well as examples of already existing F-Gas regulations in selected European countries. The report also gives an overview of emissions from refrigeration systems used in supermarkets and indicates abatement costs which arise by conversion of conventional systems to new systems with natural refrigerants.

The report gives a long list of ideas for energy saving measures that are applicable in nearly any Store. The following opportunities for energy savings are described:

- Use glass lids / glass doors on vertical display cases and gondolas
- Fan motors outside the units
- Improved evaporator-fan and/or -fan motor
- Improved airstream in open refrigerated shelves (if necessary)
- Infrared reflecting shades or baldachins
- Edge heating / dew point control
- Siphons in defrosting drain of the refrigeration unit
- Hot gas defrosting
- Variable speed control of compressors, pumps, fans
- Two-stage compression with intermediate cooling
- Improved expansion valves
- Expansion machines to recover lost work in the refrigeration cycle (especially for CO₂ systems)
- Improved evaporators, for example flooded evaporators
- Defrost on demand instead of scheduled defrost
- Improved lighting (LED etc.)
- Reduction of condenser temperature (floating condensation)
- Evaporative cooling of the condenser or ground coupling to further reduce condensation temperatures
- Subcooler or internal heat exchange
- Free cooling (AC)
- Heat recovery for heating of premises (with or without the aid of heat pumps)
- Cold storage system (for load shifting)
- Intelligent system control
- Controlled Air humidity in the sales room
- Better cleaning of evaporator and condenser, and so on.

The German report also adds material to the list of examples on recent progressive initiatives taken by supermarket chains. Aldi Süd is here claimed to have played a prevailing role in the development and market launch of plug-in low temperature chest freezers with glass slide lids, variable speed-controlled compressors, and R290 as refrigerant. By means of the replacement of the condenser fan which was triggered by Aldi Süd the energy consumption of the LT freezer was further reduced. To date, Aldi Süd has also installed 8 transcritical R744 MT refrigeration systems in different discount stores and entered a cooperation and development agreement with Carrier/Linde related to R744 refrigeration systems. The refrigerated shelves of Aldi Süd are equipped with energy saving fans and an energy saving lighting for which Aldi Süd is holding a patent (!) and which introduces less heat into the refrigerated area. Condensers of the refrigeration systems are designed with larger heat exchanger surfaces in order to reduce the energy consumption. More information about energy saving measures employed can be provided from Aldi Süd directly.

(http://www.kovv.nl/uploads/press_release_athen_aldi_english_tk_report.pdf.)

Also the supermarket chain Lidl is reported to use heat pump technologies for heating and cooling in several of the stores. In a market opened on 8th October 2007 it was possible to completely avoid a natural gas connection (for heating) due to the installation of a composite geothermal energy system. Six geothermic ground probes 100 m below the ground serve as source for cooling/heating. The adjustment of room temperature (heating and cooling) relies upon a “thermoactive” concrete core system. Further, ground coupling is used for subcooling of the refrigerant.

It is clear that the trend points towards a multitude of new technologies and measures together enabling a substantial decrease in energy usage. This trend seems to be generic but there are regional differences and foci dependent on environmental legislation and current policies, or on local climate factors (For example: is heat recovery for heating purposes a good idea or not?). Below follows short local reports from US, Sweden and Canada adding further perspectives.

2.6.1 Some Refrigerant and Supermarket System Technology Trends - US

With increasing focus on climate change and growing regulatory pressure on high global warming refrigerants, the supermarket industry in the US has felt increased environmental scrutiny. Standard supermarket direct expansion (DX) systems have large refrigerant charge sizes, long lines with many joints, and therefore, larger leak rates than self-contained systems. They also use HFC-404A and HFC-507 in some medium temperature and most low temperature systems. Though these refrigerants are an excellent match for R-502, (the CFC replaced in the ozone transition), they also have high global warming potential. The 100 year GWP of HFC-404A is 3922 and for HFC-507 is 3985 (AR4, 2007). Therefore, the need to reduce charge size, controls emissions and investigate low GWP options for HFC-404A has intensified in recent years.

A significant amount of research effort has been focused on alternative system designs that have potential to significantly reduce refrigerant charge and emissions. One option is to use distributed direct expansion systems where the large compressor/equipment rack in the machine room is eliminated and separate smaller split systems are placed around the store. This results in reduced charge and reduced leaks by eliminating long line runs. However, it also increases the number of components (compressors, condensers, etc.). These kind of systems are described in the previous Annex 26 (editors remark)

Another option is a secondary coolant or secondary loop system. In this case, the equipment rack and primary refrigerant is in a machine room and a secondary fluid loop is connected to it via a heat exchanger. The secondary fluid then circulates from the machine room into the store to cool the display cases usually without phase change. These are most effective in medium temperature systems where the secondary fluid such as propylene glycol has good viscosity properties and can be easily pumped. At low temperature conditions, potassium based salt solutions are primarily used to maintain low viscosity at freezer conditions. However, some materials compatibility and corrosion issues have been encountered. Secondary loop systems can significantly reduce refrigerant charge size by isolating the primary refrigerant in the machine room. However, they may also reduce energy efficiency from the additional heat exchange step. About 500 secondary loop systems have been installed in the US since their introduction in 1996, but the majority of systems being installed continue to be standard HFC-404A DX designs.

Carbon dioxide systems have more recently been proposed with a variety of potential configurations under investigation. Carbon dioxide with 100 yr. GWP of 1 appears to have the greatest potential in low temperature refrigeration where the cycle can remain subcritical. Some options under study or in prototype testing are (1) CO₂ DX for low temp; separate R404A or R-134a DX for medium temp (2) CO₂ DX for low temp; separate R-404A or R-134a with a secondary coolant for medium temp (3) CO₂ DX for low temp; separate CO₂ DX with secondary loop for medium temp (4) CO₂ DX low temp cascading to an HFC-404A or HFC-134a DX medium temp, or with secondary loop (5) CO₂ DX low temp cascading to CO₂ DX medium temp, or with secondary loop. There has also been some investigation using CO₂ itself as a secondary coolant, with or without phase change. To date, there has not been significant penetration in the US of CO₂ systems, but interest is growing. Some challenges for CO₂ systems include first cost compared to traditional DX systems and lower efficiency at higher ambient temperatures.

There has also been research for other alternative refrigerants with low GWP. Hydrofluoroolefins (HFOs) have recently been identified as a new class of molecules that have low global warming potential and no ozone depletion potential. HFO-1234yf (CF₃CF=CH₂) was recently developed to replace HFC-134a in automotive applications. It has a 100 year GWP of 4 and low toxicity. It is mildly flammable, but comprehensive industry risk assessments have shown it safe to use in automotive air conditioning. HFO-1234yf has the potential to be used in stationary refrigeration applications, in pure form or in blends, but similar risk assessments will be required to understand the safety implications.

Supermarket System Modeling Needs - US

Two types of system modeling capability are of interest in the US. One involves a screening type tool that can quickly compare different refrigeration system options at design stage. This could be as simple as the spreadsheet-based tool developed under IEA Annex 26 and described in the US country report for that Annex. Tools of this type are useful for early stage screening of things like refrigerant choices and system types (direct expansion or secondary loop, etc.) but might not capture effects like refrigerated case/store environment interactions. The second general need is for more detailed energy analyses (benchmarking studies, etc.) that require a whole building simulation tool. Specialized versions for the second type could serve as a foundation for application to FDA or continuous commissioning applications by coupling the tool together with the energy management systems routinely installed with new supermarket systems

2.6.2 Refrigerant and Supermarket System Technology Trends – Sweden

Several new system solutions have been implemented in Sweden in order to reduce energy cost and environmental impact. System solution such as heat recovery with or without heat pumps, floating head condensing and evaporating pressure, defrost control, energy efficient lighting, high efficiency motors, efficient control system and energy efficient display cases with glass doors have been installed in several supermarkets in Sweden to decrease energy usage.

Utilization of heat rejected from condensers to heat service water or the premises in cold climates is a good measure to improve energy usage in supermarkets. Heat recovery leads to a reduction in costs and in the usage of fossil fuels for heating. A drawback with heat reclaiming is the higher condensing temperature that increases energy consumption from refrigeration systems.

The floating condensing system has been implemented in some supermarkets to reduce energy usage by refrigeration systems. The introduction of electronic expansion valves operating over a wide range of pressure drops allows for a low condensing temperature at low ambient temperatures. A reduction of condensing temperatures increases the coefficient of performance of refrigeration systems.

Illumination accounts for about 25% of total electricity used in supermarkets. Cost savings between 25-35% of the electricity consumed for lighting are possible by using the most energy efficient lamp and control system and maximizing the use of daylight.

Display cases commonly carry large refrigeration loads, especially vertical open display cabinets. The reason is that this kind of cabinet displays a large amount of food on a small surface in the store with a large open front area. Infiltration causes about 60-70% of the cooling load for a typical open vertical display cabinet. Installing glass doors in display cases reduces the infiltration and energy consumption of cabinets.

New refrigeration system design with indirect system or CO₂ systems have been also installed in supermarkets in Sweden to decrease environmental impact from refrigerants. R22 and R12 were the most commonly used refrigerants in commercial refrigeration in Sweden prior to the enforced phase-out of HCFCs and CFCs. The use of CFC refrigerants was stopped by the year 2000 and by 2002 the refill of HCFC refrigerants was banned. Thereafter, the number of plants running with R22 and R12 decreased dramatically. The HFC refrigerants R134a and R404A have been used as replacements for R12 and R22. R134a has some drawbacks, such as a relatively low vapor density, so the compressor displacement required for a certain refrigeration capacity is high, necessitating a larger and more expensive compressor (Stoecker 1998). R134a compressors have to run at relatively high pressure ratios, which may compromise compressor reliability and result in low volumetric efficiency. Moreover, for evaporating temperatures lower than -26°C, the saturation pressure of R134a will be sub-atmospheric, resulting in reliability concerns with regard to air leaking into the system. Such drawbacks do not exist in R404A, so by 2005, according to Arias (2005), it became the dominant refrigerant in supermarkets comprising up to 70% of refrigerants used in 371 stores.

The first CO₂ indirect system plant was implemented in Sweden in 1995 with financial support from the government through the Swedish State Department of Environment Protection; it was useful in testing the technology since no consumer would risk the investment. The successful operation of the first plant encouraged the owners to adopt the new technology, which was relatively harmless in environmental terms. By the year 2007, more than 100 plants were running with capacities ranging from 10 to 280 kW.

In early installations of CO₂ indirect, the refrigerants most commonly used in the machine room are NH₃, R404A, and Care50 (a mixture of ethane and propane). Some of the plants were converted from old systems running with artificial refrigerants. The machine room was completely altered due to the change of the working fluid. Owing to the simplicity of the installed systems, there was no problem in finding refrigeration technicians and engineers to run the systems and carry out maintenance in a proper and safe manner.

In cases where NH₃ was used as the refrigerant in the machine room, the installation was more expensive when compared with other systems using relatively safe refrigerants (Rolfman 1996); this is due to the safety devices required for NH₃ usage. The special safety equipment required varies from one case to another, depending on the place where the plant is installed and its surroundings.

A Swedish example of a CO₂ indirect system installation is the City Gross shop in Rosengård, Malmö. The area of the supermarket is 14000 m² and the CO₂ charge is about 450 kg. The primary refrigerant is R404A with a cooling capacity of 3x55 kW on the freezer's side (Nihlen 2004).

The last few years have witnessed the start of the application of CO₂ cascade systems in Sweden. This step has followed the implementation of this technology in countries like Denmark and Luxembourg (Heinbokel 2001). The use of single phase secondary working fluid instead of CO₂ at the medium temperature level has generally been preferred due to the relatively high working pressure of CO₂ in the secondary circuit. As is usually the case in medium size supermarkets, at the low temperature levels direct expansion evaporators are used. Flooded evaporators improve the heat transfer coefficient and have better cooling performance from a temperature point of view but the high installation cost limits their usage.

The first cascade system installed in Sweden was in the town of Kristinehamn. NH₃ is the primary refrigerant and freezing cabinets are specially designed for CO₂ with thicker pipes and electronic expansion valves that are also used as magnetic valves during defrosting, which is performed three times a day. The system is reported to be more expensive than a traditional one but savings in running costs are expected to reduce the total cost. The freezing capacity is 50 kW and the pressure on the high side of the CO₂ cascade system is 30-34 bars (-5-0°C), and at the low temperature side the pressure is 11 bars (-37°C) (StayCool 2002).

Another example of an installation is in Linköping, where the system has a cooling capacity of 130 kW at the medium temperature level and a freezing capacity of 20 kW. NH₃ is used in the high stage with 38% propylene glycol as secondary working fluid at the medium temperature level. The CO₂ and NH₃ compressors used are from Bitzer and the charge of CO₂ is 50 kg, whereas that of NH₃ is 30 kg. A small cooling unit is used to cool the system and reduce its pressure in the event of downtime (Dahlberg 2003).

Systems that solely use CO₂ as the working fluid are suggested by Girotto (2004) to be a competitive solution in cold climates, for instance under the weather conditions of Stockholm. Such systems may be efficient when working in sub-critical conditions, at ambient temperatures below about 20°C, and in that way it will be competitive with conventional systems such as DX R404A (Girotto 2004). Average ambient temperatures in the majority of Sweden suggest that the boundaries of the system will allow it to operate in sub-critical conditions for long periods of the year during both the cold winter and the temperate summer.

The first trans-critical installation in Scandinavia was installed in Odense/Denmark in 2003 (Rehnby 2004). Nowadays, there are at least 20 trans-critical installations in Sweden. ICA

Kvantum in the town of Varberg is the first installation of its kind in Sweden, with capacities of 2x25 kW on the freezer side and 2x55 kW on the medium temperature side (Tesab 2004). This installation is an application of the system presented by Girotto et al. (2003) where two parallel DX circuits are used to provide the cooling capacities at the low and medium temperature levels. The CO₂ charge of this plant is around 50 kg which is lower than the amount an CO₂ indirect system would absorb (Ekenberg 2004). This can be attributed to the absence of an accumulation tank in the DX system, whereas it must be installed in CO₂ indirect systems. Another system in Luleå has been in operation since September 2004, the capacity of which is 50 kW on the freezer side and 150 kW at the medium temperature level which serves the units display cases in a 3000 m² shop (StayCool 2004).

2.6.3 Refrigerant and Supermarket System Technology Trends - Canada

The Canadian Supermarket sector is aware of the impact of their operation on greenhouse gas (GHG) emissions. The two important GHG emission sources are synthetic refrigerant leaks and energy consumption. Most supermarket refrigeration systems in Canada are direct expansion (DX) systems. They look very similar to US supermarket refrigeration systems since most are supplied by US equipment manufacturers. Typically, a supermarket's synthetic refrigerant charge (HCFCs or HFCs) ranges from 1,000 to 1,500 kg. This refrigerant circulates under pressure from the mechanical room to the refrigerated display cases through kilometers of piping with hundreds of brazed joints. An estimated 10% to 30% of this refrigerant charge leaks into the atmosphere annually. Synthetic refrigerants are powerful GHGs - 1,500 to 4,000 times more potent than an equivalent mass of carbon dioxide (CO₂).

During the past few years, demonstration projects have showed many approaches to reduce the impact of supermarket GHG emissions. Examples of projects are: secondary fluids on low side and heat rejection side of refrigeration system, CO₂ as secondary fluid, CO₂ as primary refrigerant in a transcritical cycle, CO₂ as primary refrigerant in a cascade system with R-507a and finally integrated HVAC&R refrigeration system.

Integrated HVAC&R System

In Canadian supermarkets, space heating corresponds to 20 to 25% of the total energy consumption. In many cases, it is possible to meet practically all space and water heating requirements by recovering the heat rejected by refrigeration systems. Today, most of the new supermarket installations recover the heat rejected by the refrigeration system for space heating. This practice is quite different from the traditional approach, which consists in using independent equipment to meet both heating and cooling requirements. This approach requires engineers responsible for HVAC systems in buildings to work closely with refrigeration contractors. Many installations use secondary fluids on the high side to facilitate the controllability and the flexibility of the heat recovery process and at the same time minimizing the synthetic refrigerant charge and leaks in the system.

Secondary Loop Systems as an Alternative to DX Systems

Secondary loop systems allow an 85% reduction in synthetic refrigerant charges in comparison to conventional DX systems. Hence, secondary loop systems offer a very promising alternative for the reduction of GHG emissions. During the past ten years, secondary loops using propylene glycol have gained acceptance in supermarket refrigeration systems. Such secondary loop systems are now present in many new stores. They are usually employed not only for the benefits of refrigerant charge reduction, but also for enhanced product quality and decreased system maintenance.

Floating Head Pressure and Liquid Sub-cooling

Strange as it may seem, the majority of refrigeration systems do not take advantage of the local cold weather to reduce their energy consumption. In using ambient air to satisfy refrigeration requirements (principle of free cooling) or in operating at the lowest condensing pressure possible (result of floating head pressure strategy), significant reductions in the energy consumption of refrigeration systems can occur. Whenever local weather does not allow the refrigeration equipment to benefit from these energy efficiency strategies, mechanical sub-cooling becomes an interesting alternative.

The new generation of semi-hermetic compressors is capable to reduce the condensing temperature to 10 °C for medium temperature and 5 °C for low temperature systems. Some Canadian manufacturers offer compressors racks with dedicated compressors for intensive floating head and others dedicated to heat recovery. This provides an opportunity where an efficient refrigeration system and heat recovery is on the same compressors rack.

Status of CO₂

The use of secondary loop systems for frozen products has been hindered by the lack of a suitable heat transfer fluid. Heat transfer fluids at -28°C are either very viscous, very expensive or corrosive. Since the year 2000, dozens of low temperature systems using brine solutions as secondary fluids have been installed. These solutions have good heat transfer properties but result in premature aging of the surrounding materials, and consequently in an increase of maintenance costs. CO₂ appears to be an excellent heat transfer fluid for secondary loops for frozen products.

Since 2008, carbon dioxide is becoming increasingly popular in Canada. Major supermarkets chains are now considering CO₂ as a good option to reduce the use of synthetic refrigerants. Today, only few CO₂ installations (less than 10) exist, but they are very different: transcritical, cascade, secondary fluid, cascade and secondary fluid. It is difficult to predict the future implementation rate of CO₂ systems but the enthusiasm level of the supermarket sector is high.

2.7 Task 7 – Deployment of the knowledge developed

Task leader - Sweden National Team (KTH and SP)

The objective set out at the beginning of this Annex was to develop “reasonably accurate” simulation tools to assist in the analysis of the energy performance and in the development of energy efficient strategies for supermarkets. These tools should help to reduce the global energy consumption, the environmental impact and the life cycle costs of supermarkets within constraints such as the required quality of products, maximized comfort of the occupants and so on.

In order to meet the ambitious goal four different tools, in Sweden, UK, USA and Canada has been developed or refined during the project. The term “reasonably accurate simulation tools” refers to the classical statement “...it is better to be approximately right than absolutely wrong...” meaning that the software’s developed must be able to handle a wide array of different types of supermarkets, buildings, climates and so on. If not so, a very specific model developed for a specific case is likely to be used to predict the performance of supermarkets of a totally different kind in another part of the world. This would not be a desirable procedure. Another problem with “too high accuracy” would be that such a model needs to be very detailed. This leads to several problems; it will be very time consuming but we believe the largest problem is the impossibility to find the necessary input data, thus leading to informed guessing at the best.

We are also happy to see that the development and adoption of energy efficient display cases and other effective measures such as super-efficient LED lights is adapted during recent years. There are however many different energy efficiency improvements needed to reduce the supermarket energy consumption but also to improve the quality and lifetime of their products as well as the comfort of their clients. However, since the performance of the display cases and the thermal comfort of occupants are strongly influenced by the surrounding environment, their assessment requires also a detailed calculation of indoor air characteristics such as temperature and moisture distribution at different zones, even in the same room of the building. These findings has, during the project period, lead to new development efforts aiming at the development of physically transparent component models able to handle the most common types of display cases used today and in the near future.

Our conclusion is that the current development towards more energy efficient supermarket with a higher level of system integration (heat recovery, for example) leads to an increased need for tools that can facilitate quantitative comparisons and potential benefits of a multitude of possibilities within supermarket energy systems. The new tools need to take into account not only the refrigeration system but also the full complexities presented by the interconnection of HVAC&R systems and the building envelope as well as other energy saving techniques. The new tools must be able to determine, among others, the optimal range for the condensing and evaporating temperatures, the optimal flows and temperatures for the secondary loops and the optimal indoor air temperature and humidity at different zones of the building.

We also foresee an interest from the market to further develop these tools to be integrated to dynamic control algorithms for so called fault detection analysis (FDA). This means that any malfunction in the system can be automatically detected by comparing the actual performance with the predicted in real time. Such integration would allow for a continuous optimization of the total supermarket energy systems. Nevertheless, in order to accomplish it in real time there will be a need for fast – and at the same time accurate enough – building and system simulation tools.

Developing accurate and fast building simulation tools will be a challenging task since these two attributes are very often conflicting. This is one important and very promising area for the future.

One way to increase the “energy awareness” among supermarket owners and operators is to use benchmarking more widely as a strategic tool, although not easy to implement as we have seen in the project. It requires further development and validation of the proposed performance indices like energy consumption and operating costs (per m², or m³, per kg etc.). It has to be stressed that benchmarking must be used taking national building standards, climate and other factors into account as well.

The current discussion regarding environmental impact from supermarkets requires a balanced approach where both direct and indirect effect on global warming is taken into account. Two similar measures suggested by IPCC/TEAP in the Special Report on Safeguarding the Ozone Layer and the Global Climate System is the TEWI and the LCCP– value. The calculation of the TEWI value requires knowledge of refrigerant charge, yearly leakage, energy efficiency and regional energy conversion factor (CO₂/kWh). This data is scarce and only a few reports give enough data for an evaluation. This will be an important part of the benchmarking process and this should be further improved in an internationally standardized way.

We are noting that most large supermarkets today are fully instrumented and equipped with high performance computerized control systems. A large number of data are thus available but still generally poorly exploited for the analysis of the energy performance of the supermarket. In fact, large amount of data are often collected and stored without any analysis at all.

Therefore one of the outputs of the international project will be a guideline for field evaluation of supermarket. Which data to collect? How often? How can these data be connected to the various performance criteria proposed in the project?

In fact, three guidelines were planned as part of the dissemination of knowledge from the international project as a whole:

- Guideline for field evaluation of supermarkets
- Guideline for validation of supermarket simulation models
- Guideline for developing and using performance indices in order to improve energy efficiency in supermarkets

This report can be seen as a not-so-compact guideline answering all these issues. However, dissemination in a more compact form is planned for upcoming issues of the IEA Heat pump Newsletter.

The third guideline is connected to the first one. In order to evaluate the performance of any system a set of suitable criteria must be set up. In this project we call these *performance indices* and a great deal of the work has dealt with this far from trivial problem. One conclusion from the project is that we can differentiate between design and operation related indices. Design related can be referred to throughout the design process to facilitate early decisions about design and technology. More operation related indices can give feedback throughout the technical lifetime of the systems – if effective, they may lead to improved operation of the existing supermarket.

Taking the current progressive strategies of several supermarket chains the above mentioned strategies should be highly appealing to the supermarket sector as a whole since they help to reduce operating and maintenance costs and at the same time increase product sales (since client

comfort is improved). However, in order to obtain a widespread adoption of these measures it is essential to increase the awareness of the major players in the supermarket sector.

Although several supermarket chains today provide us with new “low-energy” pilot stores we must not forget the old Swedish proverb “A lonely fly does not mean that the summer is here”. All these promising technologies need to be mainstreamed and the standard solutions of tomorrow’s supermarkets.

3 Conclusions

The work has showed that supermarkets are among the most energy intensive commercial buildings, but also that there is large potential for improvement. It has also showed that the potential improvements are numerous and very different and that they can be found in the building, the refrigeration system, in the display cases and so on. The international component of the work has also showed that international comparisons of energy systems are difficult to perform for several reasons such as climate, differences in concept, opening hours etc. However, a few of these differences have been resolved in the project. One example here is the typical number of operating hours over the year. The impact of differences in climate on supermarket energy performance is further discussed in the international project and the validation of the three different supermarket models, in different climates, will add to this.

It is clear that existing supermarket show a large variation in energy performance and a full understanding of all the factors influencing the performance is not achieved in the project due to the somewhat disappointing collection of empirical data that was collected during the project. However, the experiences from this project, the three guidelines mentioned above, will hopefully simplify this process in the future.

A family of new performance indices for supermarkets has been defined in the project but only a relatively small number have been fully evaluated due to the somewhat limited amount of data collected. These performance indices (PI's) can be divided into design and operational PI's. This will be extremely useful for both design and commissioning of new supermarkets as well as for operation and improvement of existing systems

Three full supermarket simulation models are evaluated in the project and compared and the full comparison will be included in the final international report from Annex 31 from the IEA. The comparisons show similarities but also major differences on level of detail, input and output data and so on.

During recent year several new ideas and measures to improve supermarket energy efficiency has been introduced in Sweden, and in other countries. Examples here are:

- Energy efficiency display cases with doors
- Heat recovery using heat pumps
- Energy efficiency lightning including smart control (timers)
- New efficient system solutions with natural refrigerants (mainly CO₂)
- Efficient secondary coolant systems utilizing so-called laminar flow heat exchangers
- Etc.

A clear trend is that more advanced monitoring systems are installed in stores. However, this does not necessarily mean that these data are collection with a future evaluation in mind. Measurements are taken and stored but not necessarily evaluated – this takes time and competence. The main purpose is typically to secure and validate food quality which of-course is important too. However, these aspects should be possible to combine in the future, if, good performance indices are developed.

Taken together there is reason to believe that the energy efficiency in the supermarket sector is improving even though the rationality for improved energy efficiency is based on economic considerations rather than energy conservation and mitigation of carbon dioxide emissions.

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5 Appendices

5.1 *Appendix 1: Questionnaire*

ENERGY EFFICIENCY IN SUPERMARKETS QUESTIONNAIRE

Background:

This questionnaire is part of an international cooperation project within IEA, International Energy Agency/Heat Pump Program. The project is a co-operation between Sweden, Canada and Germany. The overall project is coordinated by Sweden, Royal Institute of Technology, Stockholm but the national survey in xxxxx-land is co-ordinated by yyyy-organisation. The long term goal is to provide supermarket owners and chain with better tools to design the supermarkets for tomorrows.

Purpose of this enquiry:

The purpose of this particular enquiry is to map energy usage in supermarkets with regards to differences in climate, size of supermarket, system types etc. Another aim is to develop meaningful indices to help supermarkets owners and chains to benchmark towards better energy efficiency and thereby better environmental performance.

Information disclosure policy:

The results will be handled anonymously and no information or results containing specific Store or Chain names will be disclosed.

Feedback

For those who fill out the questionnaire we will send out results and feedback in two forms: Firstly your organisation will be able to see how your specific supermarket performs in comparison with a large population. Secondly we will put together a set of general recommendations how to improve the energy efficiency, i.e. energy management advice for supermarkets.

FAQ's:

Why should we participate in this enquiry?

Because we believe that the energy efficiency in supermarkets can be significantly improved. This will inevitable lead to cost reductions and reduced environmental impact. Some of the potential improvements may appear costly but our aim with this project is guide supermarket chains and owners to the best investments that addresses energy cost reductions and improved environmental performance.

Will the name and chain of any particular supermarket appear in reports?

No - information or results containing Store or Chain names will not be disclosed whatsoever!

Previous work in this area has shown no significant difference between different chains. The differences within one chain, on the contrary, can be huge, at least a factor 2.

How can we use the data from the project?

The project will collect data from many supermarkets in Sweden, Canada, USA and Germany. These stores are all placed in different climates. This means that we can identify which solution that gives the best performance in a given climate and for a certain type of store. The project will

also show if your particular supermarket is an energy efficient one or perhaps the opposite. That information is however up to you to use!

Can we find more information about the project? Yes, please visit our web site <http://www.energy.kth.se/Annex31> or contact us in person on telephone or via email. Here you can see who is who in the international project and find projects.

Where should we send the questionnaire?

Sweden: address

QUESTIONNAIRE

GENERAL INFORMATION

Mandatory data:

City: _____
Country: _____
Year for data: _____
Store profile⁸: _____

Voluntary data^{*)}:

Store Name: _____
Chain: _____
Store Manager: _____
Address: _____
Tel: _____
E-mail: _____
Web: _____
Annual turnover: _____

Have you undergone an energy efficiency program? Yes/No

Are your or some other organisation monitoring the
System performance? Yes/No

Are you interested to participate in a more elaborate energy audit with a more explicit questionnaire where more data will be collected and also compared with computer modelling of your supermarket?

Yes/No

^{*)} This information will only be used for reference and will not be used for any written or oral communication through seminars, reports or other publications unless agreed upon mutually.

⁸ Hypermarket, Supermarket, Traffic and service store etc

KEY DATA

1 ENERGY

1.1 Energy consumption:

1.1.1 Electricity (kWh/year) _____
1.1.2 District Heating (kWh/year) _____
1.1.3 Gas (m³/year alt ft³/year) _____
Oil (m³) _____
Other (.....)*) _____

District Cooling (kWh/Year) _____
*) Specify

Energy Prices

Electricity (Currency/kWh) _____
District Heating (Currency /kWh) _____
Gas (Currency /m³) _____
Oil (Currency /m³) _____
Other (.....)*) _____
District Cooling (Currency /kWh) _____

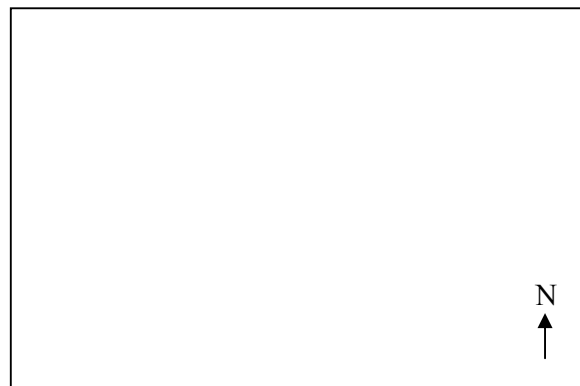
Is heating included in rent Yes/no
Is air conditioning included in rent Yes/no

2. STORE CHARACTERISTICS

Total Area (m²) _____
Sales Area (m²) _____
Ceiling height _____
Building year _____
Lighting W/m² in sales area _____

Stand alone building? Yes/No

Please draw building footprint and orientation in box below:



Opening hours

Mon

Tue _____

Wed

Thu _____

Fri _____

Sat _____

Sun _____

The questions on next page deals with the technical details for the refrigeration system that we believe are significant. Try to fill out as many as possible. If in doubt please consult your service organisation. It is better to fill out something than nothing at all!

Please turn.

3. REFRIGERATION SYSTEM

3.1 System type (check appropriate)

Direct expansion ☐

Indirect expansion (secondary loops) ☐

Please specify if more detailed information is readily available (see example at the end of this document, short but precise in refrigeration expert language☺, but any “language” will do).

— _____

3.2 Capacities

Nominal capacity (medium temp) _____

Nominal capacity (low temp) _____

Charge (medium temp) _____

Charge (low temp) _____

Refrigerant (medium temp) _____

Refrigerant (low temp) _____

Typical annual leakage in % (medium temp) _____

Typical annual leakage in % (low temp) _____

3.3 Display cases

Total length display cases medium temp _____

% with doors _____

% of open display cases with night lids or curtains _____

Total length display cases low temp _____

% with doors _____

% of open display cases with night lids or curtains _____

3.4 Cold storage/cold rooms (including walk in coolers)

Medium temp, total area _____

Low temp, total area _____

4. HVAC

Heat recovery from refrigeration system (condensers) Yes/No

Heat recovery from exhaust air (preheating of air supply) Yes/No

Example for 3.1 (more than this is not necessary):

Ex 1: Distributed system low temp and medium temp, direct expansion, indirect on condenser side (heat rejection side)

Ex 2: Completely indirect system in medium temperature level and partially indirect on low temp with direct expansion in freezer display cases

-----Thank you for filling out the survey!-----

5.2 *Appendix 2: Working Meetings*

1. The kick-off meeting of Annex 31 was held the 20th of January 2006 in Chicago in conjunction with ASHRAE Winter Meeting. The discussion was principally focussed on Task 1 and 2 of the Annex. Per Lundqvist and Jaime Arias from KTH and Monica Axell from SP participated in the meeting.
2. The group also decided to use the internet meeting tool, “Centra”, for meeting purposes. Three Centra meetings were held during February and March 2006. The discussion of the Centra meetings was focussed on a list with data to be collected and performance indices for five different levels for task one and two.
3. The following working meeting of Annex 31 was held in Germany in conjunction with the IKK fair. The goal of the meeting was mainly to discuss the contribution of Germany to the Annex. Per Lundqvist and Jaime Arias from KTH and Monica Axell from SP participated in the meeting.
4. The next meeting of Annex 31 was held in January 2007 in Dallas in conjunction with ASHRAE Winter Meeting. The goal of the meeting was mainly to discuss the contribution of USA to the Annex. Per Lundqvist participated in the meeting by telephone.
5. The next activity of Annex 31 was a workshop in August 2007 in China in conjunction with the 22nd IIR Congress in Beijing. The program of the workshop in Beijing is presented in Appendix 6.3. Per Lundqvist and Jaime Arias from KTH and Monica Axell from SP participated in the workshop.
6. The next activity of Annex 31 was a workshop in May 2008 in Switzerland in conjunction with the 9th Heat Pump Conference in Zurich. The program of the workshop in Zurich is presented in Appendix 6.3. Per Lundqvist and Jaime Arias from KTH and Monica Axell from SP participated in the workshop.
7. Three Centra meetings were held during October and December 2008. The discussion of the Centra meetings was focussed on the different tasks activities.
8. The next meeting of Annex 31 was held in January 2009 in Chicago in conjunction with ASHRAE Winter Meeting. The discussion was principally focussed on Task 3, 4 and 5 of the Annex. Per Lundqvist and Jaime Arias from KTH and Roger Nordman from SP participated in the meeting.

5.3 *Appendix 3: List of conferences and workshops*

5.3.1 *Program Workshop in Beijing*

Program Workshop Annex 31 in Beijing Saturday 25th of August 2007.

Chair: Professor Per Lundqvist, Royal Institute of Technology, Sweden

8:30 Introduction (15 min) Professor Per Lundqvist, Royal Institute of Technology, Sweden

8:45 Energy use in supermarkets (Task 1- Collection of available data from different supermarkets and Task 2 - Development of performance indices for supermarkets)

Country presentation (15 min)

Canada: Dr. Vasile Minea, Scientist Researcher, Hydro-Quebec Research Institute Canada

Germany: Dr. Rainer Jakobs, IZW, Information Centre on Heat Pumps and Refrigeration, Germany.

USA: Dr. Deepak Perti, Senior Research, Dupont, USA.

UK: Professor Savas Tassou, Head of School of Engineering and Design, Brunel University.

Sweden: Dr. Monica Axell, Research, Technical Research Institute of Sweden and Manager, IEA Heat Pump Centre.

10:00 Coffee

10:20 Introduction to Task 3: Development and validation of a model library for specific supermarket equipment and Task 4: Development of whole-building simulation models.

5 Invited lectures (15 min)

Canada: Mr. Daniel Giguère, Project Manager, Natural Resources Canada.

Germany: Dr. Rainer Jakobs, IZW, Information Centre on Heat Pumps and Refrigeration

USA: Dr. Deepak Perti, Senior Research, Dupont, USA.

UK: Dr Yunting Ge, Lecturer, Brunel University

Sweden: Dr. Jaime Arias, Research, Royal Institute of Technology

12:00 Panel and discussion (25 min)

End

5.3.2 Program Workshop in Zurich

Annex 31 – workshop Monday, May 19, 2008

13:30 -13:45 Per Lundqvist, Welcoming address + perspectives on energy use in supermarkets

Energy efficient Supermarket in four countries – a comparison

13.45 – 14.00 Van Baxter, US Natl. Team Activities

14.00 – 14.15 Monica Axell, Sweden Natl. Team Activities

14.15 – 14.30 Rainer Jacobs Germany Natl. Team Activities

14.30 -- 14.45 Daniel Giugere, Canada Natl. Team Activities

14:45 – 15:00 Panel discussion

15:00-15.30 Coffea break

Modelling and Simulation tools for supermarkets – do they exist?

15:30 – 15:45 Daniel Giguere, Canada - New supermarket module in RetScreen software

15:45 – 16:00 Yunting Gee, UK – Experiences from modelling supermarkets in TRNSYS

16:00 – 16:15 Jaime Arias, Sweden – How to use simulation tools to improve supermarket design and operation

16:15 – 16:30 Van Baxter, US – New supermarket modules for the Energy+ software

Heat recovery and other new concepts

16:30 – 16:45 Jaime Arias, Sweden, Heat recovery by Heat pumps in supermarket refrigeration systems

16:45 – 17:00 Rainer Jacobs, Germany + n.n. New concepts and ideas in Germany for improved energy efficiency in supermarkets

17:00 – 17:15 Discussion

5.4 *Appendix 5: Legal text IEA Annex 31*

LEGAL TEXT ANNEX 31

ADVANCED MODELING AND TOOLS FOR ANALYSIS OF ENERGY USE IN SUPERMARKET SYSTEMS

Performance Analysis, System Optimization and Tool Development

Objectives

The objective of this Annex is to develop reasonably accurate simulation tools to assist in the analysis of the energy performance and in the development of energy efficient strategies for supermarkets. The aim is to minimise the impact of supermarkets on the global environment.

BACKGROUND

Supermarkets are the most energy intensive buildings in the commercial sector. It has been estimated that 3-5 % of the total use of electricity stems from supermarkets in industrialized countries. In addition, it is estimated that the annual refrigerant losses are as high as 15 - 30% of the total charge thus making supermarkets to the no2 emission source after mobile air conditioning. The supermarket sector has therefore a significant role to play not only from the point of view of the energy consumed but also from the point of view of the impact of refrigerant leakage⁹.

IEA Annex 26 has showed that various new system solutions¹⁰ such as the adoption of secondary loops both on the hot and cold sides of the refrigeration system as well as the integration of HVAC and refrigeration systems are efficient strategies to drastically reduce the charge and leaks of refrigerant as well as the energy consumption in supermarkets. There is however a strong international debate whether indirect systems are energy efficient enough in comparison with state of the art direct systems and more studies are needed to resolve this issue. Nevertheless, supermarket system design and operation are very complex due to the strong interconnection between the thermodynamic systems¹¹, the building envelope, the outdoor and the indoor climate. For instance, during winter time the refrigeration system can work at low condensing temperatures resulting in lower energy consumption. However, the demand for space heating will be higher and could be met totally or partially by the energy released by the refrigeration system, as long as its condensing temperature is high enough. In cold climates this is an interesting optimization problem with economic and environmental impact minima not necessarily coinciding. Similarly there may be a need for hot and cold storage to help the refrigeration system match the building daily heating and cooling demand as well as to take advantage of cheap time-of-day electricity rates/peak shaving not to mention energy need for defrost.

It is also obvious that development and adoption of energy efficient display cases is one of the effective strategies needed to reduce the supermarket energy consumption but also to improve the quality and lifetime of their products as well as the comfort of their clients. Since the performance of the display cases and the thermal comfort of occupants are strongly influenced by the surrounding environment, their assessment requires also a detailed calculation of indoor air characteristics such as temperature and moisture distribution at different zones, even in the same room of the building. This part of the project should aim at the development of physically transparent¹² component models able to handle the most common types of display cases used today and in the near future.

⁹ 1 kg of refrigerant corresponds to a Global Warming Potential i.e. GWP of 0 to 4500 kg of CO₂ equivalent dependant on the choice of refrigerant.

¹⁰ Please refer to Final report of Annex 26. Several new types of systems for commercial refrigeration have evolved during the last five to ten years. Secondary loop systems using phase changing fluids such as CO₂ and ice-slurries are examples of the latest. Other strategies to minimize charge, leakage and improve energy efficiency can be found in the report.

¹¹ Refrigeration, HVAC and other systems...

¹² to improve understanding...

The ability to judge the potential benefits of a multitude of possibilities need detailed and reasonably¹³ accurate simulation and design optimization tools that take into account the full complexities presented by the interconnection of HVAC&R systems and the building envelope. Such tools must be able to determine, among others, the amount of energy to be stored that provides the lowest building energy consumption, the optimal range for the condensing and evaporating temperatures, the optimal flows and temperatures for the secondary loops and the optimal indoor air temperature and humidity at different zones of the building. These tools could eventually be integrated to dynamic control algorithms. Such integration would allow for a continuous optimization of the total supermarket energy systems. Nevertheless, in order to accomplish it in real time there will be a need for fast – and at the same time accurate enough – building and system simulation tools. Developing accurate and fast building simulation tools could be a challenging task since these two attributes are very often conflicting.

All of the above mentioned strategies are highly appealing to the supermarket sector since they help to reduce operating and maintenance costs and at the same time to increase product sales (since client comfort is improved). However, in order to obtain a widespread adoption of these measures it is essential to increase the awareness of the major players in the supermarket sector.

One way to “reach in” and increase awareness is to use benchmarking as a tool, although not easy to implement. It requires the development of meaningful performance indices like energy consumption and operating costs (per m², or m³, per kg etc.), which is quite a complex task. It has to be stressed that benchmarking must be used taking National building standards, climate and other factors into account. For instance the average energy consumption in Canadian supermarkets has been evaluated at 800 kWh/m²/year whereas in Sweden this number is much lower (350 - 450 kWh/m²). Hence, there is a need to develop a methodology to assist in the comparison of figures from different countries, and probably regions and systems. Benchmarking without an analysis of underlying causes makes no sense!

The current discussion regarding environmental impact from supermarkets requires a balanced approach where both direct and indirect effect on global warming is taken into account. Two similar measures suggested in the ongoing work for the IPCC/TEAP14 Special Report on Safeguarding the Ozone Layer and the Global Climate System is the TEWI and the LCCP– value¹⁵. The calculation of the TEWI value requires knowledge of refrigerant charge, yearly leakage, energy efficiency and regional energy conversion factor (CO₂/kWh). This data is scarce and only a few reports give enough data for an evaluation. This will be an important part of the benchmarking process.

GOALS

The main goal of the proposed Annex is to provide new knowledge, methods and reasonably accurate simulation tools to assist in the analysis of the energy performance and in the development of energy efficient strategies for supermarkets. This has the aims of reducing the global energy consumption, the environmental impact and the life cycle costs of a supermarket within constraints such as the required quality of products, maximized comfort of the occupants and so on.

A second goal is to increase the level of understanding of the interaction between the refrigeration system and the indoor climate as well as HVAC system and the building envelope.

A third goal is to develop indices for energy use and environmental impact for different countries and systems.

It should be noted that the methods and algorithms developed in the Annex could also evolve into tools for continuous optimization of the whole building, continuous commissioning and automated diagnostics

¹³ The word reasonable is used to stress that the “support” for the design process and the understanding the interaction of various systems is more important than the ability to exactly mimic the behaviour of a specific supermarket. Someone said: “It is better to approximately right than exactly wrong...”

¹⁴ Intergovernmental Panel On Climate Change/Technical And Economical Assessment Panel

¹⁵ TEWI = Total Equivalent Warming Impact, LCCP = Life Cycle Climate Performance

of the different systems of the building, i.e. fault detection analysis. These tasks could be developed and expanded in future annexes.

METHODOLOGY, TASKS AND DELIVERABLES

In order to achieve the above stated goals, the following task-sharing activities should be carried by the participants:

Task 1 - Collection of available data from different supermarkets (benchmarking)

Task leader - Sweden National Team (KTH and SP)

Most large supermarkets are currently fully instrumented and equipped with high performance computerized control systems. A large number of data are available but generally poorly exploited to analyze the energy performance of the HVAC&R equipment and optimize its operation. The objective of this task is to collect enough data in order to establish energy efficiency indices for benchmarking and to validate the models to be developed or improved. The data collected should support a TEWI or LCCP analysis.

Deliverables: Each participant produces a national report (working material)

Task 2 – Development of performance indices for supermarkets

Task leader - Sweden National Team (KTH and SP)

This task will focus on the development of meaningful performance indices for supermarkets, like energy usage, CO₂ – emissions, operating costs (per m², or m³, per m display case, etc.) for different countries and systems. It will be based on the analysis of the data collected in task 1 and an analysis document where performance indices are explained and resolved into categories such as (i) efficient refrigeration technologies, (ii) efficient HVAC integration and control, (iii) efficient buildings (building codes), (iv) climate issues and (v) other issues. One of the primary tools for comparison will be based on the TEWI/LCCP-concept meaning that direct and indirect effect on global warming need to be determined for each supermarket.

Deliverables:

Voluntary national report on suggested performance indices,

External intermediate report summarizing results and conclusions from Task 1 and 2.

Open workshop in conjunction with IIR BEIJING 2007 (task 1 and 2)

Task 3 – Development and validation of a model library for specific supermarket equipment

Task leader (KTH, Dr Jaime Arias)

Several models for building equipment are available currently. This task will focus on the selection, adaptation and validation of the equipment models that are specific for supermarkets. Some models for equipment like display cases will be developed or improved. The subtasks will be organized for the different sub-systems such as Display cases, refrigeration system, HVAC etc.

- Grouping of sub-systems and selection of sub-task leaders.
- Identification and collection of existing specific equipment simulation models suitable for modelling of supermarkets
- Analysis and evaluation of selected models
- Selection of models to be included in a “Recommended models library”
- Development of specific simulation models to complement the model library if needed

Deliverables:

Subtask leaders report to OA months 16

Working meeting in conjunction with workshop (task 1 and 2)

Task 4 – Development of whole-building simulation models.

Task leader: preliminary professor Savvas Tassou UK/Brunel with KTH as alternative

This task will be broken down in the following subtasks:

- Analysis and evaluation of the present simulation tools available/suitable for supermarkets
- Identification of the most suitable simulation environments for the given modelling aims
- Development of whole-building simulation models and integration of the equipment model library (task 3)

Deliverable:

National report on existing models and models under development (voluntary)

Task 5 – Comparison of the results obtained with the different whole-building simulation models for selected case studies

Task leader NRC Canada – Roberto Sunye

- Validation of the model(s) using the data collected in task 1 and 2 and/or from field measurements

Deliverable:

Results to be included in final report

Working meeting for task 5-7 in conjunction with workshop part 3-4

Task 6 – Future perspectives and possibilities

Task leader – Sweden KTH and SP

- Identification of the possibilities to implement advanced control strategies in supermarkets
- Identification of possibilities to use modelling and simulation for fault detection analysis (FDA)

Deliverable: to be included in final report

Task 7 – Deployment of the knowledge developed (indices, guidelines, papers, fact sheets)

Task leader - Sweden KTH and SP

Deliverables:

Working meeting 4 - planning for final report

Final report on CD including national reports and intermediate reports produced in tasks 1-6.

Workshop in connection with IEA HPP conference in 2008,

Extended executive summary for a broad audience, printed

Results

The results of this Annex will be:

- A “Recommended models library” for supermarkets
- Whole-building simulation models for supermarkets validated
- Workshops
- Contributions to seminars and conferences
- A final Report on CD, containing data and recommendations

TIME SCHEDULE

This Annex shall enter into force on 1 January 2006 and shall continue for a period of 36 months. The work schedule is as follows:

Meetings:

January 2006: Startup meeting in conjunction with ASHRAE WM 2006 (USA)

October 2006: Annex meeting 2a in conjunction with IKK 2006 (Germany)

January 2007: Annex meeting 2b in conjunction with ASHRAE WAM 2007 (USA)

August 2007: Annex meeting 3 with open workshop in conjunction with IIR congress in Beijing (China)
December 2007: Annex meeting 4
May 2008: Annex meeting 5 with open workshop in conjunction with IEA HP Conference in Zurich (Switzerland)

Deliverables:

September 2007: 18-month report
February 2008: 24-month report
December 2008: Final report of the Annex

Further to this:

An Annex Website (or information on the annex on the HPC website)

Progress reports to the HPC four times annually for publication in the Newsletter

Report to the HPP Annual report

SPECIFIC OBLIGATIONS AND RESPONSIBILITIES OF THE PARTICIPANTS

Each participating country shall:

- Nominate a representative to participate in the work under this Annex;
- Carry out the equivalent of total 4 – 12 person-months of task-sharing work during the programme period unless otherwise agreed by the Participants;
- Conduct its own Task work;
- Submit interim country report as specified in section 3;
- Contribute to the organization of expert meetings and the workshop by identification of speakers and Participants.

Additionally, each Participant shall make a direct financial contribution to the Operating Agent to cover coordination and report preparation expenses and other Annex-related (e.g., Workshop) costs.

SPECIFIC OBLIGATIONS AND RESPONSIBILITIES OF THE OPERATING AGENT

The Operating Agent shall:

- Develop, in co-operation with the Participants, a detailed programme of work, a framework for the Country Report and a budget, including methodology and time schedule;
- Perform the Tasks and deliver the results as described in Section 4;
- Provide semi-annually, periodic reports to the Executive Committee on the progress and the results of the work performed;
- Provide to the IEA HPP Executive Committee, within six months after completion of all work under the Task, with a Final Report for its approval and transmittal to the IEA Heat Pump Center;
- In co-ordination with the Participants, use its best efforts to avoid duplication with activities of other related programs and projects implemented by or under the auspices of the Agency or by other competent bodies;
- Provide the Participants with necessary guidelines for the work they carry out, assuring minimum duplication of effort;
- Co-ordinate the efforts of all Participants and ensure the information flow within the Task;
- Organize workshop(s) in order to review the progress and to coordinate the activities with the assistance of the IEA Heat Pump Centre.

The IEA Heat Pump Centre will be responsible for assistance in having the Annex established, and in organising the workshops and issuing proceedings, as well as the Final Report.

FUNDING

Working Meetings. The working meetings shall be hosted in turn by the several Participants. The costs of organizing and hosting meetings shall be borne by the host Participant.

Publications: The cost of publishing the Final Report and summary assessments described in Section 6 above shall be met by the Participants.

Individual Financial Obligations. Each Participant shall bear all the costs incurring in carrying out the Task activities, including reporting and travel expenses. Additionally, each Participant shall make a direct financial contribution to the Operating Agent to cover coordination and report preparation expenses and other Annex-related (e.g. Workshop) costs.

Table 1 shows the fees per Participant, based upon varying numbers of Participants.

Table 1 Participant fee each year for varying numbers of Participants (or participating country).

<i>No of participants</i>	<i>Participants' fees, (€) - EUROS</i>
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	<i>2006/7</i>	<i>2007/8</i>	<i>2008/9</i>
<i>3</i>	<i>4 000</i>	<i>4 000</i>	<i>4 000</i>
<i>4</i>	<i>3 333</i>	<i>3 333</i>	<i>3 333</i>
<i>>4</i>	<i>3000</i>	<i>3000</i>	<i>3000</i>

Each Participant's fee shall be paid in 3 annual installments, (the first invoices being sent out within one month of signing the agreement), as shown in the table 1 above.

Task-Sharing Requirements. Each Participant shall carry out the equivalent of a minimum of 4-person months of Task-sharing work during the programme period unless otherwise agreed by the Participants.

OPERATING AGENT

The Royal Institute of Technology (KTH), Dept. of Energy Technology, SE 100 44 Stockholm, Sweden, as represented by Professor Per Lundqvist, is designated as Operating Agent.

The Vice-Operating Agent is Natural Resources Canada, CANMET Energy Technology Centre-Varenes (CETC-Varenes) Department of Energy Technology, 1615 Blvd. Lionel-Boulet, C.P. 4800, Varennes, J3X 1S6 Québec, Canada, as represented by Dr Roberto Sunyé.

INFORMATION AND INTELLECTUAL PROPERTY

Executive Committee's Powers.

The publication, distribution, handling, protection and ownership of information and intellectual property arising from this Annex shall be determined by the Executive Committee, acting by unanimity, in conformity with this Annex.

Right to Publish.

The Participants shall have the right to publish all information provided to or arising from their Task, except proprietary information, as defined below.

Proprietary Information.

The Participants and the Operating Agent shall take all necessary measures in accordance with this paragraph, the laws of their respective countries and international law to protect the proprietary information provided to or arising from this Task.

For the purposes of this Annex, proprietary information shall mean information of a confidential nature such as trade secrets and know-how (computer models, design procedures and techniques, chemical compositions of materials, testing procedures or manufacturing methods, processes or treatments) which is appropriately marked provided that such information:

- Is not generally known or publicly available from other sources;
- Has not previously been made available by its owner(s) to others without obligation concerning its confidentiality; and
- Is not already in the possession of the recipient Participant(s) without obligation concerning its confidentiality.

It shall be the responsibility of each Participant supplying proprietary information, and of the Operating Agent, to identify such information as proprietary and to ensure that it is appropriately marked.

Production of Relevant Information by Governments.

The Operating Agent should encourage the governments of all Agency Participating Countries to make available or identify to the Operating Agent all published or otherwise freely available information known to them that is relevant to the Task.

Production of Relevant Information by Participants.

Each participant agrees to provide to the Operating Agent all previously existing information, and information developed independently of the Task, which can assist or is needed by the Operating Agent to carry out its functions in this Task, which is freely at the disposal of the Participants, and the transmission of which is not subject to any contractual and/or legal limitations, under the following conditions:

- If no substantial cost is incurred by the Participant in making such information available, at no cost to the Task therefore;
- If substantial costs must be incurred by the Participant to make such information available, at such charges to the Task as shall be agreed between the Operating Agent and the Participants with the approval of the Executive Committee.

Use of Confidential Information.

If a Participant has access to confidential information which would be useful to the Operating Agent in carrying out the studies, assessments, analysis or evaluations called for in this Task, such information may be communicated to the Operating Agent but shall not become part of any report or other form of documentation issued as part of this Task, nor shall it be communicated to the other Participants, except as may be agreed between the Operating Agent and the Participant who supplies such information.

Acquisition of Information for the Task.

Each Participant shall inform the Operating Agent of the existence of information that can be of value to the Task, but which is not freely available, and each Participant shall endeavor to make such information available to the Task under reasonable conditions, in which event the Executive Committee may, acting unanimously, decide to acquire each information.

Reports on Work Performed under the Task.

The Operating Agent shall provide reports on all work performed under the Task and the result thereof, including studies, assessments, analysis, evaluations and other documentation, but excluding proprietary information, in accordance with paragraph 10(c) above.

Copyrights.

The Operating Agent, or each Participant for its own results, may take appropriate measures necessary to protect copyrightable material generated under this Task. Copyright obtained shall be the property of the Operating Agent, for the benefit of the Participants provided, however, that Participants may reproduce and distribute such material, but shall not publish it with a view to profit, except as otherwise provided by the Executive Committee.

The Contracting Parties understand and agree that the name, acronym and emblem of the IEA has been notified to the World Intellectual Property Organisation (WIPO) Secretariat according to Article 6 of the Paris Convention for the Protection of Industrial Property, as amended on 28 September 1979. The Contracting Parties further understand and agree that the OECD/IEA shall retain the copyright to all IEA deliverables, materials or publications published or to be published by the IEA or jointly by the IEA and a third party to this Annex. Should the Contracting Parties use any such deliverables, materials or publications they shall give full acknowledgement to the OECD/IEA as being the source of the material with a copyright notice in the following form: © OECD/IEA, (year of publication).

Authors.

Each Participant shall, without prejudice to any rights of authors under its national laws, take necessary steps to provide the co-operation from its authors required to carry out the provisions in this paragraph. Each Participant shall assume the responsibility to pay awards or compensation required to be paid to its employees according to the laws of its country.

5.5 *Appendix 6: Participants*

Research organisations in Annex 31

Sweden

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Report no. HPP-AN31-1