Computational tools for supermarket planning

Report 5

SUPERSMART

Public report

for the project:

SuperSmart - Expertise hub for a market uptake of energy-efficient supermarkets by awareness raising, knowledge transfer and pre-preparation of an EU Ecolabel

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October 2016

SuperSmart is funded by the European Union, under the Horizon 2020 Innovation Framework Programme, project number 696076.

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The research leading to these results has received funding from the
European Union/EASME H2020 Programme under Grant Agreement No 696076.

EXECUTIVE SUMMARY

This deliverable is a part of the training material developed for the second work package (WP2) in the SuperSmart project and covers the topic of "computational tools in supermarket planning". The term *supermarket planning* in this deliverable specifically refers to the adequate choice of refrigeration equipment in supermarkets. This definition is amongst others described in the introductory chapter, which deals with explanations and definitions for this report.
In general, this report considers the topic of computational tools from three different perspectives:

1. The **tool-oriented perspective**: Chapter 2 gives an overview of relevant characteristics, features and requirements of computational tools in supermarket planning. Moreover, it provides a list of tools that can be used for supermarket planning describing briefly the main characteristics of each tool
2. The **task-oriented perspective**: Chapter 3 describes different tasks that are relevant in supermarket planning. For each task background-information and an explanation are provided, as well as indications which of the previously mentioned tools can used for the specific task
3. The **user-oriented perspective**: The characteristics, features and requirements of the tools can be assigned to different users. The different possible users of the tools are aggregated into three typical users, which are described regarding their interests, applications of the tools as well as need for further information and training. Moreover, the specific non-technological barriers in the field of computational tools are listed as well as measures how to remove them. A summary and conclusion of the user perspective closes the chapter together with an outlook on the scope and limitations of the training sessions.

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1 INTRODUCTION

Efficient solutions for supermarket heating, cooling and refrigeration - such as integrated systems or the use of natural refrigerant-based equipment - are already available in the European market. However, their use is not yet widespread due to remaining non-technological barriers, including lack of knowledge and awareness, social, organizational and political barriers.

The European project SuperSmart aims at removing these barriers and additionally supports the introduction of the EU Ecolabel for food retail stores. The EU Ecolabel can encourage supermarket stakeholders to implement environmentally friendly and energy efficient technologies and thus reduce the environmental impact of food retail stores.

Within the project several activities are carried out to remove the barriers: campaigns to raise the general awareness and spread the information on energy efficient and eco-friendly supermarkets, as well as training activities within the following specific topics:

1. Eco-friendly supermarkets – an overview
2. How to build a new eco-friendly supermarket
3. How to refurbish a supermarket
4. Computational tools for supermarket planning
5. Eco-friendly operation and maintenance of supermarkets
6. EU Ecolabel for food retail stores

For each of the topics a set of training material is developed, which will be used in the training activities. The different kinds of training activities are:

1. Conference related activities
2. Dedicated training sessions
3. Self-learning online activities

Dedicated training sessions are free-of-charge for the different stakeholders in the supermarket sector. This means that highly-qualified experts from the project consortium will carry out a training session on a specific topic at the premises of the stakeholder. If you are interested in receiving such a training regarding any of the above mentioned topics, please contact the project partner via the project website: www.supersmart-supermarket.info.

The present report forms part of the topic "*Computational Tools for Supermarket Planning*". It can be used for self-studying and is freely available. There will be conferences, where this topic is included as a training activity. Information on conferences where members of the SuperSmart-team will be present as well as the planned training activities can be found on the project website.

1.1 Computational tools in supermarket planning

The term "supermarket planning" can be quite ambiguous. Sometimes, it refers to the entire planning process for opening a new supermarket, which includes market studies, feasibility studies, business planning, marketing planning etc. In other cases, it refers to the planning of the store layout [Ohta 2013], which is quite complex. Furthermore, it can be seen from a public authority point of view [Department of the Environment 2012].
This section gives a short introduction to the topic of this report: "Computational tools in supermarket planning". The SuperSmart project focuses on eco-friendly supermarkets. The refrigeration and heating and cooling system are the predominant consumers of energy as well responsible for the emission of greenhouse gases. Therefore, this report centers on the technical aspects and amongst them on the heating and cooling and refrigeration systems of supermarkets. In the following paragraphs some relevant terms that will be used in this report are specified.

Supermarket Planning
Technical equipment is required to maintain comfortable thermal conditions in the salesroom of the supermarket as well as adequate low temperature levels in display cabinets and cold store rooms. This technical equipment refers specifically to the Heating, Ventilation and Air Conditioning (HVAC) systems,

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the refrigeration system and its display cabinets. The lighting can also have a high influence on the thermal indoor conditions. However, it is not further considered in this report, since planning the lighting is more related to illuminating the store, visibility of products, rather than the thermal comfort.
The adequate choice of this equipment depends on many other parts of the supermarket: The building envelope and the thermal boundary conditions - for instance climate or number of customers in the market. **Supermarket planning in this report shall therefore be understood as the selection and dimensioning of the technical equipment that achieves the desired thermal conditions of the supermarket for given boundary conditions, specifically the refrigeration systems.**

Computational tools in this report are software tools that can be used to support the user to carry out the supermarket planning task.

Background: Why are computational tools necessary from a technical point of view?
There are several reasons, why computational tools are necessary for efficient supermarket planning from a technical point of view. This does not refer to the general use of software or online applications, but specifically to the abovementioned definition of supermarket planning.

Firstly, there are several tasks in supermarket planning which are very well automatable. For instance, searching for specific components in a catalogue using filter-functions can be easier and faster than searching in paper-catalogues. A basic method for planning of refrigeration systems is refrigeration cycle calculation, which requires the knowledge of thermophysical fluid property data. They are available in tables, but it is easier and faster to use software for calculation. Additionally, by using software which is able to calculate fluid property data, the cycle calculation can be automated, for instance via spread-sheets.

Secondly, supermarkets are complex thermal systems with an important number of interacting subsystems, like display cabinets, refrigeration system, and HVAC systems. They are interacting in many different ways and therefore influencing each other's performance. For instance, adding glass doors to a refrigerated display cabinet has effects on several other systems, as less heat is withdrawn from the sales floor area, less refrigeration capacity is required, but possibly more air conditioning. These mutual dependencies of the relevant thermal systems of a supermarket are impossible to analyse manually, hence computational tools are required.

To gain high overall efficiency in the supermarket, the different subsystems must be adjusted to each other. Only improving the efficiency of a subsystem is not enough. Examples are self-contained display cabinets. Even if they are optimized and highly efficient, they still reject their heat to the sales floor area and thus act as a heat source. Instead of only looking at the self-contained display cabinet, it would be better to check whether the system interactions could be improved, by using a remote refrigeration system. One example of how the interactions between the systems are smartly used, is heat recovery in supermarkets. Part of the waste heat from a remote refrigeration system can be used for space heating in winter, while in summer, when no space heating is needed, the waste heat is rejected to the ambient. Thus, to gain a high overall efficiency in supermarkets, it is mandatory to take into account the entire supermarket and the interaction of all its subsystems. However, these interactions are complex and not easy to estimate. With appropriate computational tools, these interactions can be quantified and thus consequently considered in the planning process. This is reflected by the quote from IEA Annex 31:

„The ability to judge the potential benefits of a multitude of possibilities need detailed and reasonably 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." (p. 6, [KTH 2011]*)*

Why is training required in this area?
As in the whole IT sector, progress of computational tools for supermarket planning is fast and the capabilities of tools are constantly changing. Additionally, many non-technological barriers discussed in other SuperSmart reports [SuperSmart D2.2], [SuperSmart D2.3] are relevant also regarding the computational tools as described in section 4.1.4. The objective of this training material is to start the removal of these non-technological barriers by giving supermarket stakeholders an overview of relevant aspects regarding computational tools in supermarket planning.

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1.2 Outline of this report

This report consists of the following parts:

1. **Overview of existing tools**
   There exist several tools that can be used for supermarket planning. However, they are different in matters of target group, features and requirements. These aspects will be explained and used to categorize the existing tools. Furthermore, a list of tools for supermarket planning with a short description of each tool is given to help the user to get an overview of the features and requirements of the tools.
2. **Overview of tasks**
   The tools have very different scopes, features and applications, which can be overlapping or complementary. For some tasks there exist several alternative tools. Relevant tasks that can be carried out with the tools are listed and described in this part. For each task a short description and relevant background information is given. Additionally, the tools that can be used to carry out these tasks are given as well as indications how to use them for this specific task.
3. **User of the tools**
   In this chapter, the tools are considered from a user-oriented perspective. Based on the described tools and tasks, three typical users are described. Their interests, aims and previous knowledge are described as well as the tools and tasks they might be interested in. Additionally, demand for further tools and functionalities are described as well as the non-technological barriers that can be found regarding computational tools in supermarket planning.
4. **Summary**
   The report closes with a summary.

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2 COMPUTATIONAL TOOLS OVERVIEW

This section gives an overview of existing tools that can be used for supermarket planning and their capabilities. The objective of this section is firstly to show, what kind of tools can be used for supermarket planning and how the tools can be categorized; and secondly to show some commonly used tools and explain their main characteristics.
This overview shall help the reader to get an idea of the possibilities and challenges using computational tools for supermarket planning and additionally as a quick reference of existing tools.

2.1 General information on the tools

The tools that can be used for planning of heating and cooling systems in supermarkets can be categorized in different ways. This subsection gives an overview of the criteria to distinguish them. The tools can be distinguished and assessed by different means:

1. Type of license: Some tools are free of charge and other software has to be paid for. Other tools can be used free-of-charge for non-commercial-usage and other tools are free, but require additional, commercial libraries or AddIns to effectively use them for supermarket planning.
2. Type of software and how it is used: As an online application, accessible via Internet or software that can be used offline on a personal computer.
3. Target group, required input data and required previous knowledge: The target group may be very different from one tool to another. Some tools address researcher, others planning engineers or other stakeholders. The distinction via the target group is closely related to the required knowledge and required input data of the tools. Some tools aim at a quick estimation of energy consumption, based on only a few input parameters, while other tools aim at a detailed simulation, which naturally will require more input data.
4. The scope of the tool: As previously described, supermarkets are complex energy systems, which consists of many subsystems which all interact with each other. Few tools are able to represent the entire supermarket and all relevant subsystems (building, HVAC-system, display cabinets, refrigeration system etc.), while other tools focus on individual sub-systems.
5. Features and flexibility: An important feature is a component library. It can be distinguished between a library of models, which still need to be parametrized and models which are already parametrized and represent, for instance, commercially available components (as the compressor library in PackCalculationPro, section 2.2.9). Another aspect is the flexibility of the tools. Many tools have some predefined models, but no further models can be added or used. This is closely connected to the freedom to adapt the tool. Another aspect, which provides highest flexibility, is the utilization of the programming and modelling paradigm of object orientation. Object orientation allows reusing simulation models, loading external libraries and building own systems. Thus, it provides high flexibility, but also requires some additional knowledge to efficiently use it. A further aspect is the distinction between steady state and dynamic simulations. Steady state models are based on the assumption that the system is in a steady state operation mode in each moment, while dynamic models consider also time-dependent behaviour. Often, the time-dependent behaviours can be approximated by quasi-steady-state operation. Modelica based models and TRNSYS are examples for tools that are able to run dynamic simulations.
6. Fluid property library: One main aspect of supermarket planning is the planning of refrigeration systems. In order to be able to calculate/simulate refrigeration systems, thermophysical fluid property data are required. Some tools come along with included fluid property data (as for instance EES, section 2.2.5). There are several program libraries available that can be used with several programming tools. Some of them are commercial tools and some of them are free. Some examples of fluid property program libraries are:
   - CoolProp [CoolProp 2016],
   - FluidProp [Asimptote 2016],
   - Reflib [ILK 2014],
   - Refprop [Refprop 2013],
   - TILMedia [TILMedia 2016].

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Based on the previous considerations, the tools can be categorized in the following groups:

1. Tools to estimate the energy consumption of the entire supermarket,
2. Calculation tools for subsystems,
3. Modelling and simulation platform,
4. Other (component selection; online benchmark).

The distinction between the different categories of tools is sometimes not easy, since many of the previously described features can be found in several tools of different categories. Tools from the modelling and simulation platform category can be used to create a model, which is able to estimate the energy consumption of the entire supermarket and thus could belong to the first category. However, the first category refers to tools, which have been developed specifically for this purpose. Thus, the end user of the tool can directly simulate and calculate supermarkets with these tools. This implies less work for the end user. Tools from the third category are meant to be general and powerful tools, which can be used by the end user to develop own simulation models and are able to simulate an entire supermarket. This, however, implies much work and requires knowledge from the end-user.

For instance, TRNSYS can be seen as a modelling and simulation platform, but also as a tool to simulate an entire supermarket. Other tools do not fit in well in the previously established categories, because they are somehow different, but still considered relevant for this report (for instance VDMA Quickcheck, section 2.2.13).

There are further publications that deal with tools for supermarket simulation and calculation [KTH 2011], [Fidorra 2013]. The Annex 31 [KTH 2011] analysed in detail the tools of the first category, "Tool to estimate the energy consumption of the entire supermarket". In [Fidorra 2013] some tools for estimating the total energy consumption of supermarkets are analysed and categorized. Based on this analysis some ideas are proposed for a new energy benchmark tool for supermarkets, also named "SuperSmart-Tool"[1].

2.2 List of tools

This section presents tools which can be used for supermarket planning. For each tool, the main characteristics will be described, specifically referring to the aspects discussed in the previous section.

2.2.1 CoolPack

CoolPack [CoolPack 2016] is a "collection of simulation programs that can be used for designing, dimensioning, analysing and optimizing refrigeration systems" and thus belongs to the category of "Calculation tools for subsystems". It is a freeware and based on the simulation environment Engineering Equation Solver [EES 2016]. It was developed in the late 1990s and initially financed by the Danish Energy Agency and since 2000 by the Department of Mechanical Engineering at the Technical University of Denmark (DTU) and the program developers. The tool deals with vapour compression refrigeration systems. Thus, it is not specifically designed for supermarkets, but can be used for the calculation of some subsystems. The scope of the program has 6 categories: 1) Refrigeration Utilities, 2) CoolTool: Cycles Analysis, 3) Design, 4) Evaluation, 5) Auxiliary and 6) Dynamic.

In the "CoolTool" module it is possible to analyse different refrigeration cycles, amongst others one- and two-stage cycles or transcritical R744 ones. Figure 1 and Figure 2 show the cycle specification and cycle analysis user interface for a two-stage cycle. The design-module supports the user with the design of a one-stage cycle. Additionally, the "auxiliary" category offers help with different tasks, as for instance calculation of the cooling demand of a display cabinet, the comparison of refrigerants or the calculation of life cycle costs (LCC).

The tool is available in English, in addition, Spanish and German translations are partly downloadable. The simulation models are – if not otherwise specified- steady state models. The models are fixed and

[1] Please read section 2.2.10, regarding the distinction between the tool and the project.

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main parameters can be adapted, but it is not intended to create own models. It requires knowledge of refrigeration cycles and the meaning of the different input parameters. The tool comes along with a tutorial of approximately 50 pages, which includes practical exercises for the tool.

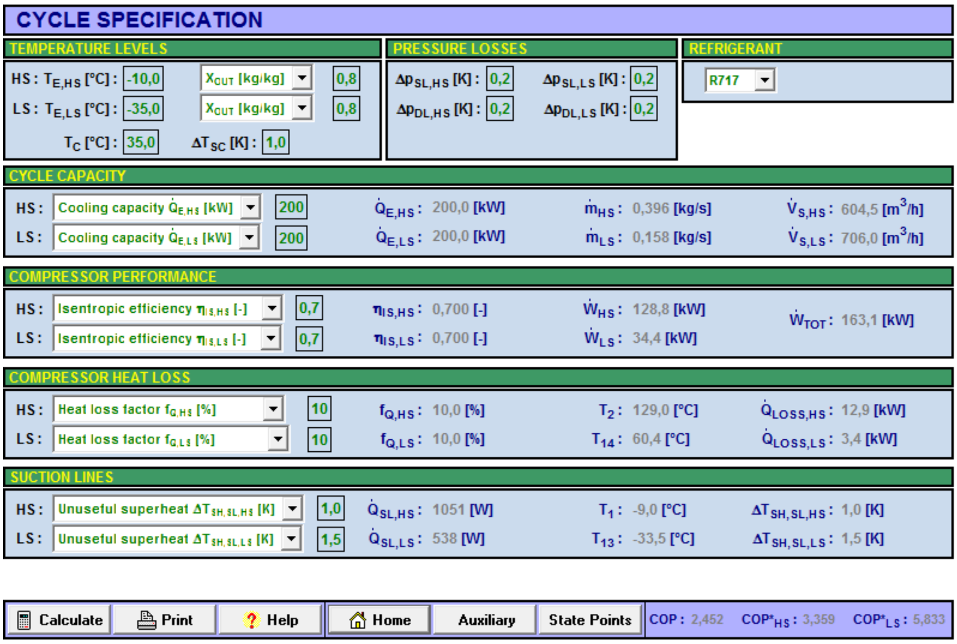

Figure 1: CoolPack- Cycle Specification [CoolPack 2016]

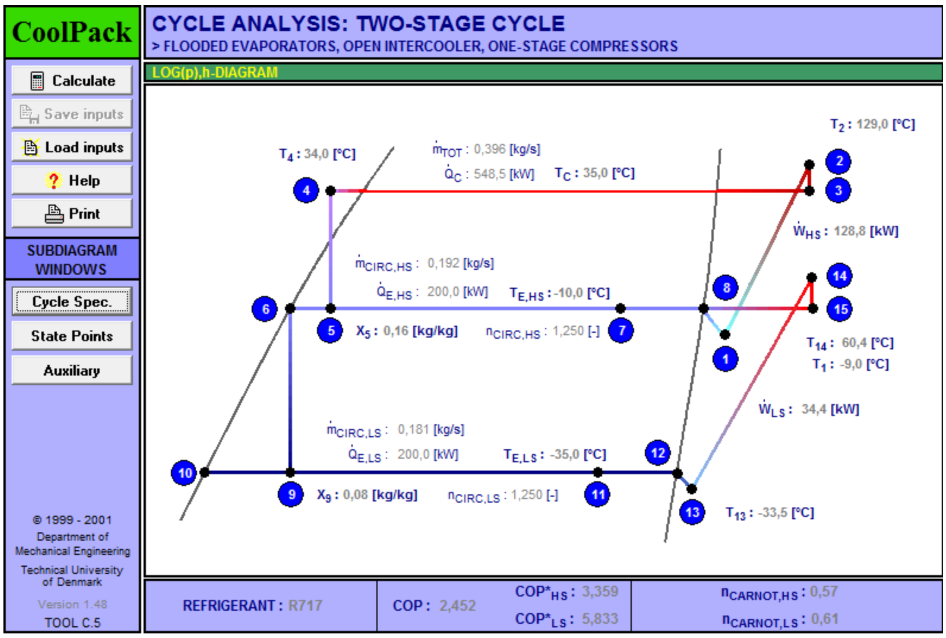

Figure 2: CoolPack- Cycle Analysis [CoolPack 2016]

2.2.2 CoolTool

CoolTool is commercial software for planning and calculation of refrigeration- and air conditioning systems developed by CoolTool Technology GmbH [CoolTool 2016]. It consists of 14 modules for different purposes that contain calculation of one- and two-stage compression refrigeration systems, one-stage plants with compounded direct evaporation, flooded evaporators or secondary fluid systems. Furthermore, it can be used to estimate the cooling load for cold rooms or air conditioning systems or to compare different plant options with each other. One feature is a component database

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with more than 8000 parts from a broad range of manufacturers. Amongst others, the database can be used for the selection of compressors based on real thermodynamic conditions or the selection of evaporators based on the EUROVENT standard. Further applications of the tool are the selection of suitable tubes based on pressure drop calculation. In general there are more than 30 refrigerants available and aspects as energy consumption and CO_2 emissions can be calculated.

2.2.3 CyberMart

CyberMart is a tool for estimating the annual energy consumption of an entire supermarket. It has a user-friendly interface and enables the user to compare the energy consumption, environmental impact (Total Equivalent Warming Potential - TEWI) and LCC. The tool considers the building, the HVAC system, display cabinets and the refrigeration system [CyberMart 2016]. The tool has been developed by Jaime Arias in his PhD Thesis [Arias 2005]. The purpose of the tool is to enable the user to compare the energy consumption of two refrigeration/energy system layouts for a supermarket. So far, it is the only tool that focuses on planning of an entire supermarket and has a specific graphical user interface (GUI) (see Figure 3).

The user is guided through the tool and asked for the relevant input data (see Figure 4). Details of the building that can be added comprise the surface area and the overall heat transfer coefficient of the walls, the window type and sales floor area. There are different types of HVAC systems, amongst others with/without rotary wheel or air recirculation. There are eight different refrigeration systems available, typical for Sweden, amongst others, direct system, indirect system, cascade systems or CO_2 booster system. The user can also choose the number and types of display cabinets and additionally add details as, for instance, pressure drop in the pipes of an indirect system. The results of a calculation with CyberMart are the daily and annual energy consumption, the LCC and the TEWI (see example in Figure 5). The tool has also been used for research, as for instance in [Sawalha 2013].

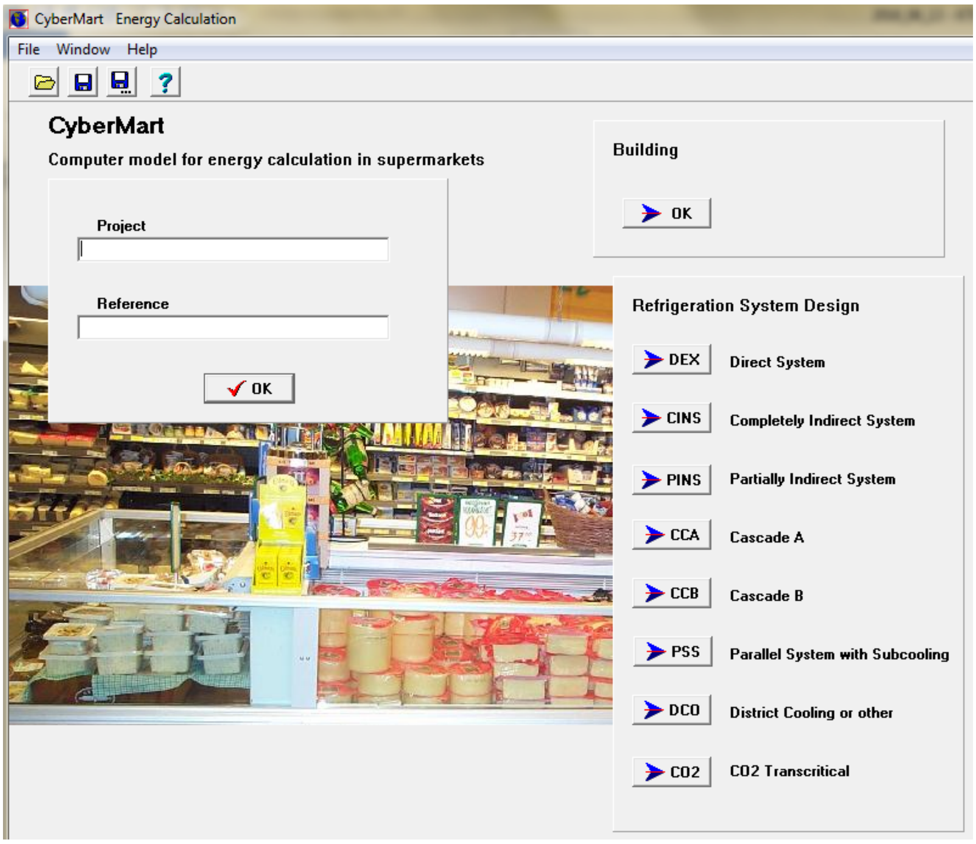

Figure 3: CyberMart- Start Window [CyberMart 2016]

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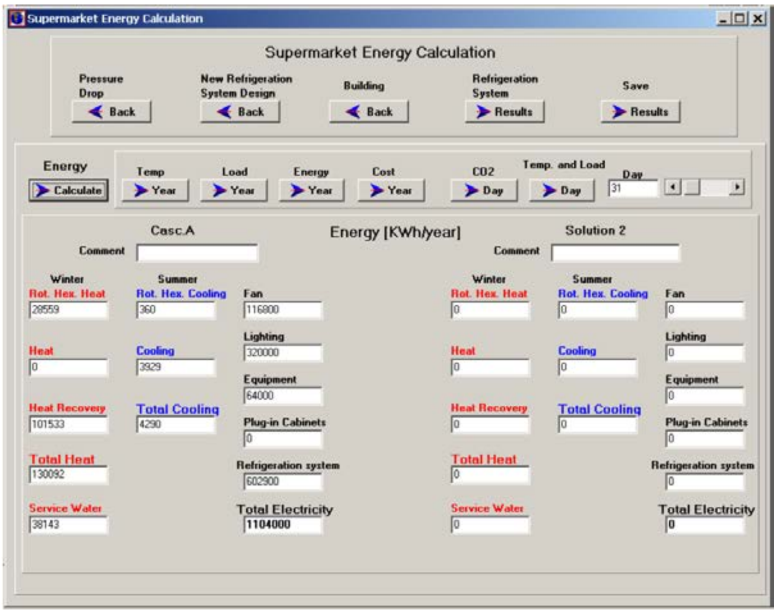

Figure 4: CyberMart- Setting Parameter Window [CyberMart 2016]

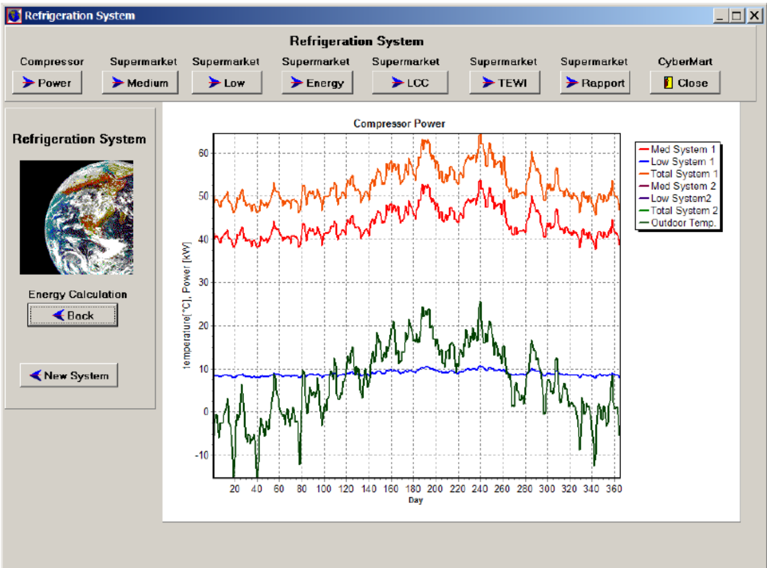

Figure 5: CyberMart- Result Window [CyberMart 2016]

2.2.4 EnergyPlus

EnergyPlus [EnergyPlus 2016b] is "a whole building energy simulation program". It is free and open source and financed by the U.S. Department of Energy´s Building Technologies Office. It is meant to support engineers, architects and researchers with modelling of energy consumption and water use in buildings. The energy consumption includes heating, cooling, ventilation, lighting and process loads. The simulation includes amongst others [EnergyPlus 2016b]:

- integrated, simultaneous solutions of thermal zone conditions,
- heat-balance based solution of radiant and convective effects,
- sub-hourly, user definable time steps,
- combined heat and mass-transfer,
- advanced fenestration models,
- illuminance and glare calculations,
- component based HVAC,
- large number of built-in HVAC and lighting control strategies,
- Functional Mockup Interface import and export for co-simulation.

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There are several third party graphical user interfaces available [EnergyPlus 2016b], which make use of the EnergyPlus calculation engine. Since EnergyPlus is a whole building simulation program, it is also able to simulate entire supermarkets. It includes components for refrigeration systems, as for instance refrigerated cases, compressor racks as well as different options for heat recovery, such as water cooled condensers or the heat rejection to a thermal zone of the building. A detailed description of the heat recovery options can be found in [EnergyPlus 2016c]. A specific description about supermarkets and how they can be modelled can be found in the Input/Output reference chapter 1.34 [EnergyPlus 2016a]. In general, EnergyPlus is a very powerful tool and one of the few tools that are able to simulate an entire supermarket and provide partly predefined models. However, since the tool is very complex and difficult to use and has only a basic GUI, it may be rather suited for research or development of new overall supermarket concepts than for supermarket planners. Further information on the capabilities of Energy Plus have been described in Annex 31 [KTH 2011], and it was also used in other publications, as for example [Stovall 2010], [Witt 2015]. There exists an online helpdesk for EnergyPlus [EnergyPlus 2016d].

2.2.5 Excel

Excel by Microsoft is a widely used spreadsheet-program. Although it is not primarily developed to be used for supermarket planning, it can be a quite useful tool for this purpose. Since it has a broad range of applications, it belongs to the fourth category: “Modelling and simulation platform”. A typical task within supermarket planning that can be carried out with Excel is the calculation of refrigeration cycles. For this purpose, AddIns are needed, that allow the calculation of thermophysical fluid property data (see section 2.1). Being able to calculate the fluid properties of refrigerants, it is possible to perform a thermodynamic analysis of refrigeration cycles. Each state point of the refrigeration cycle has several thermodynamic state variables – for instance pressure and specific enthalpy. These can be calculated via the corresponding functions from the AddIn as a function of other states.

Figure 6 shows an example of a spreadsheet that calculates a two stage R744 cycle. This calculation could alternatively be carried out with other tools as EES, Matlab or tools implementing Modelica. Another relevant use of Excel related to supermarkets is the analysis of measurement data collected by measurement/monitoring systems in supermarkets.

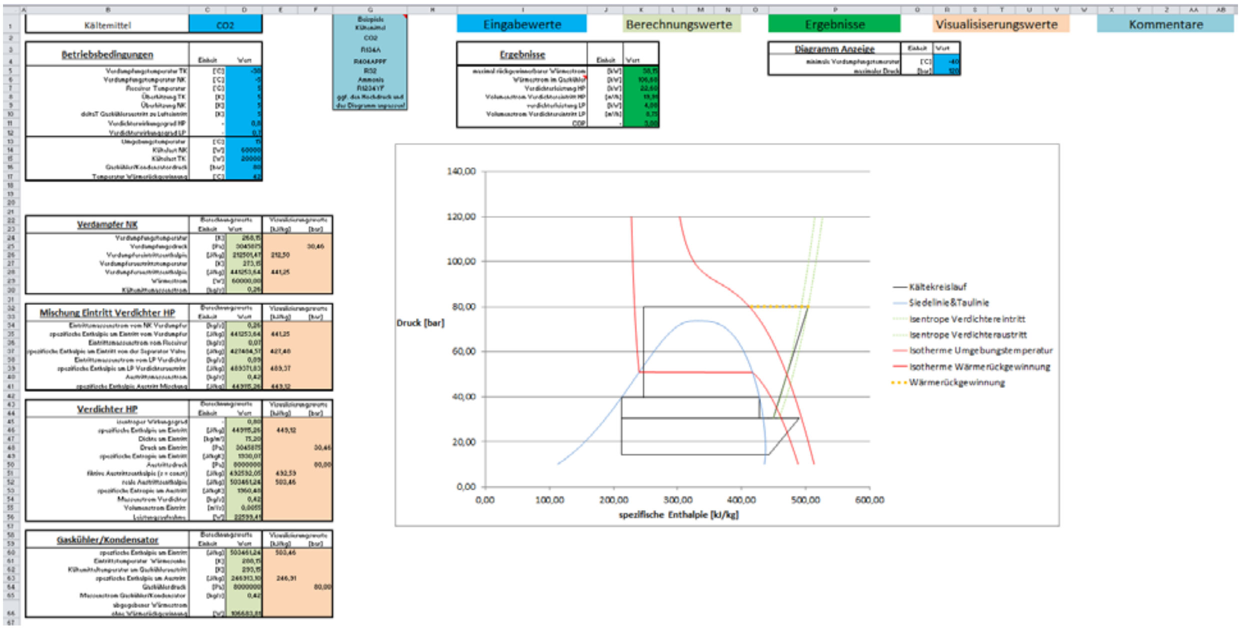

Figure 6: Spreadsheet for Cycle Analysis

2.2.6 Engineering Equation Solver

Engineering Equation Solver (“EES”) is commercial software by the company F-Chart [EES 2016]. The purpose of the tool is to provide the user with the capability to solve a large number of coupled non-linear equations. Thus, it belongs to the category “modelling and simulation platform” and can be used

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for a broad range of applications. In the field of supermarkets, it is mainly used for thermodynamic analysis of refrigeration cycles. The software has built-in thermodynamic property functions, which makes it easy to create simulation models. However, basic thermodynamic and programming knowledge is required, since the models have to be programmed by the user itself. One downside is that it is not object-oriented and that there is no component/model library available for refrigeration systems. The tasks carried out with EES regarding refrigeration systems could also be programmed with Excel. However, it is easier with EES, since it is equation based, and the evaluation order of the equations does not play any role. EES is widely used in research [Karampour 2014], [Sawalha 2008].

2.2.7 IMST-ART

Another tool that belongs to the category “calculation tools for subsystems” is IMST-ART [IMST-ART 2016] that has been developed by the University of Valencia. It is an “advanced performance simulation, computer-aided engineering design system” [IMST-ART 2016] for vapour compression cycles. It has various applications. Firstly, by adjusting the tool to existing systems, they can be analysed and their operation be reproduced. This includes detailed analysis of the thermodynamic states of the fluids in different locations within the system. A second application is the design of systems. The parametrized components can be stored in a database and then used again for designing or adapting a new system, or for the analysis of the performance of an existing system. IMST ART includes a fluid property database. A special aspect of this tool is the detailed pressure drop and heat transfer correlations which have been extensively validated. Furthermore, the connection of the heat exchanger tubes can be freely defined and the effects on the system performance can be analysed.

2.2.8 Matlab Simulink

Matlab by MathWorks [Mathworks 2016] is a commercial software tool for programming, simulation, calculation and widely used in academia and industry. Thus, it belongs to the fourth category of tools. Since it is a programming environment, basically any system and the entire supermarket could be simulated with Matlab. It is a very powerful tool, which includes also aspects of object-oriented programming, thus has a high flexibility. However, to simulate refrigeration systems, thermophysical fluid property data are necessary (see section 2.1). Additionally, there are some libraries with predefined models, as for instance [Thermolib 2016]. The target group are researcher or system developers, since it requires specific knowledge to effectively use it.

2.2.9 Software implementing Modelica

Modelica [Modelica 2016a] is a modelling and simulation language that is implemented by several software tools, like Dymola [Dymola 2016], SimulationX [SimulationX 2016] or OpenModelica [OpenModelica 2016]. Amongst these tools, only OpenModelica is free. These tools belong to the fourth category “modelling and simulation platform”. They are not specifically developed for supermarket planning, but have a very wide scope and can therefore be used to simulate an entire supermarket. The programming environment is object-oriented. This means that models for components can be reused. There are a broad range of free and commercial libraries available, which include predefined models, as for instance for buildings, HVAC systems, refrigeration systems etc. An overview of available libraries for Modelica can be found in [Modelica 2016b].

One particular aspect of Modelica is the dynamic simulation. In contrast to other simulation environment, which only use quasi-steady state approaches, with a lower limit for time-steps, Modelica can be used for very small time-steps. Therefore, it can be used for a broad range of applications, including controller design. The target group of Modelica are mainly researchers (for instance [Hafner 2014]) or developers of new system designs. Modelica requires not only thermodynamic and modelling knowledge, but also knowledge of numerics to effectively use the tool. Amongst others, it is used for the development of the “SuperSmart Energy Benchmark Tool for supermarkets” (see section 2.2.10).

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2.2.10 PackCalculationPro

PackCalculationPro [PackCalculationPro 2016] is a simulation tool that belongs to the category of “calculation of subsystems”. It has been developed by IPU, and there are different license options available (free and commercial ones), depending on the usage. The user can use the tool to estimate and compare the annual energy consumption of refrigeration systems and heat pumps. The user can choose between 11 commonly used refrigeration cycles and define their parameters and, to a certain extent, the operation strategy. The simulation models are predefined, but the user can adapt and change several parameters. This includes choosing profiles for the refrigeration load and the evaporation temperatures as well as different climate profiles. On the discharge side, there are several options for the condenser type and the control parameters. In some cases, heat recovery (see section 3.1.3) can be chosen with additional parameters. Figure 7 shows the system configuration interface, where the kind of system can be chosen. Figure 8 and Figure 9 show the interface for parameter setting of the suction and discharge side, while Figure 10 shows an example of the result window.

One main feature of PackCalculationPro is the compressor data base with more than 7,000 commercially available compressors. Besides the estimation of the annual energy consumption of one or several refrigeration systems, the comparison of these systems can be amended by a comparison of the LCC (see section 3.1.5) and the TEWI (see section 3.1.6). An additional, valuable feature of this tool is the possibility to automatically generate a report with the system specifications and the simulation results. Amongst the tools described in this report, it is one of the most useful tools for planning the refrigeration system, since it includes many desired features (component database, user-friendly interface, automatic report generation) and also recent refrigeration system layouts. Some of the features of the tool are described in more detail later in this report (see section 3.1).

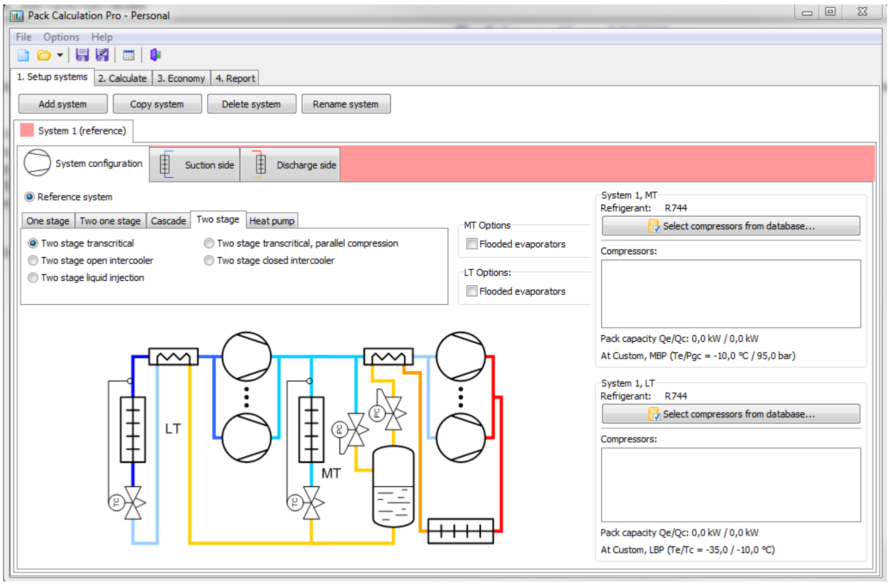

Figure 7: PackCalculationPro “system configuration” Interface [PackCalculationPro 2016]

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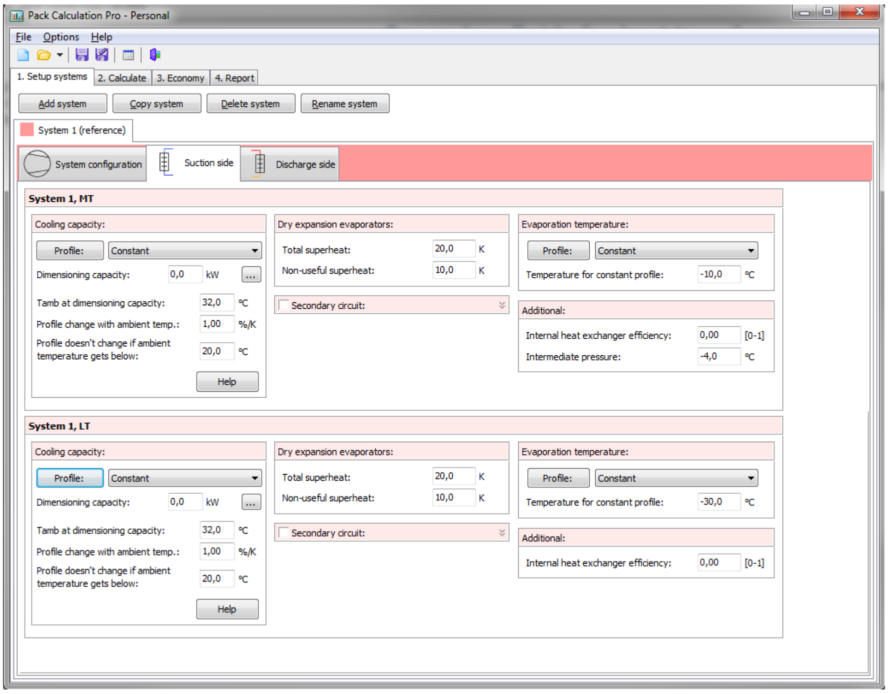

Figure 8: PackCalculationPro “suction side” Interface [PackCalculationPro 2016]

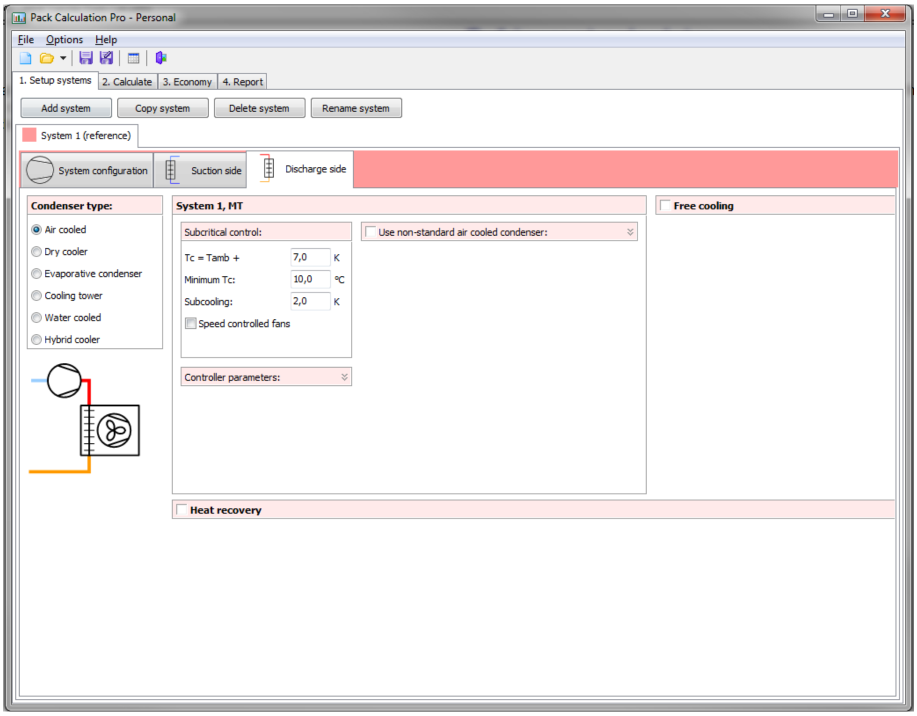

Figure 9: PackCalculationPro “discharge side” Interface [PackCalculationPro 2016]

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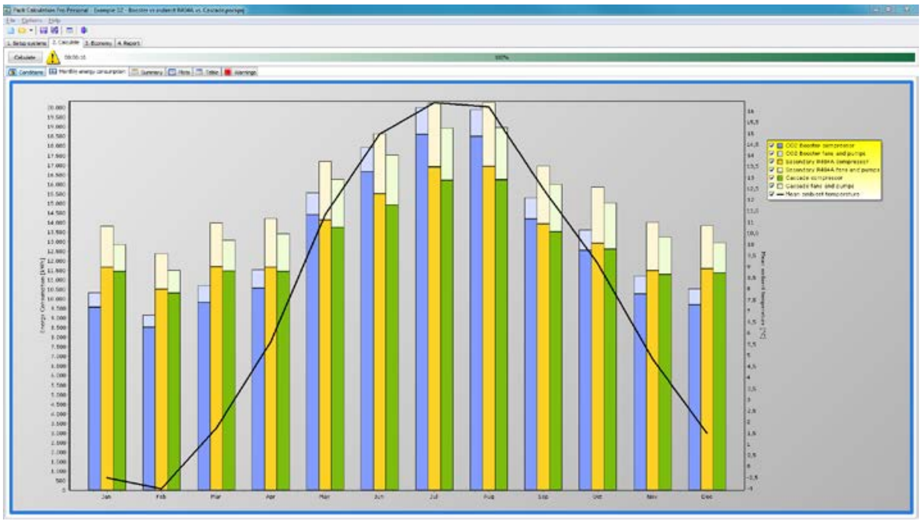

Figure 10: PackCalculationPro Results Window [PackCalculationPro 2016]

2.2.11 SuperSmart-Tool

The “SuperSmart Energy Benchmark tool for supermarkets” (short “SuperSmart-Tool”) is a software tool that is under development since 2012. The main idea of this tool is to provide the user with an energy benchmarking tool, which shall consider the entire supermarket and all relevant subsystems and interactions between them. The development of the “SuperSmart-Tool” was initiated in the CREATIV project [CREATIV 2016] of SINTEF and described in several publications [Fidorra 2013], [Fidorra 2014a], [Fidorra 2014b]. The tool development is still ongoing as part of a PhD thesis at TU Braunschweig. During the development of the basic ideas for this tool, the name “SuperSmart” was created and consequently used for projects related to supermarkets as for instance the present European Horizon 2020 project “SuperSmart or the “SuperSmart-Rack” project, which aims “to increase knowledge related to design and control issues of ejector supported commercial refrigeration units” [Hafner 2016]. Although these projects and the tool share the name “SuperSmart” and have the goal of improving energy efficiency in supermarkets, they are strictly separated in terms of funding.

The objective of the SuperSmart-Tool is to provide the user with a tool to evaluate the energy consumption of an entire supermarket and all its subsystems. This shall enable the user to evaluate the interactions between the different subsystems in the supermarket and choose the best equipment. As it aims to help the supermarket designer in the daily work, it shall have a component data base with predefined models, commercially available components and still leave the opportunity to load one´s own models. The aimed target groups are both planners as well as researchers. Figure 11 shows an early concept of the SuperSmart-Tool.

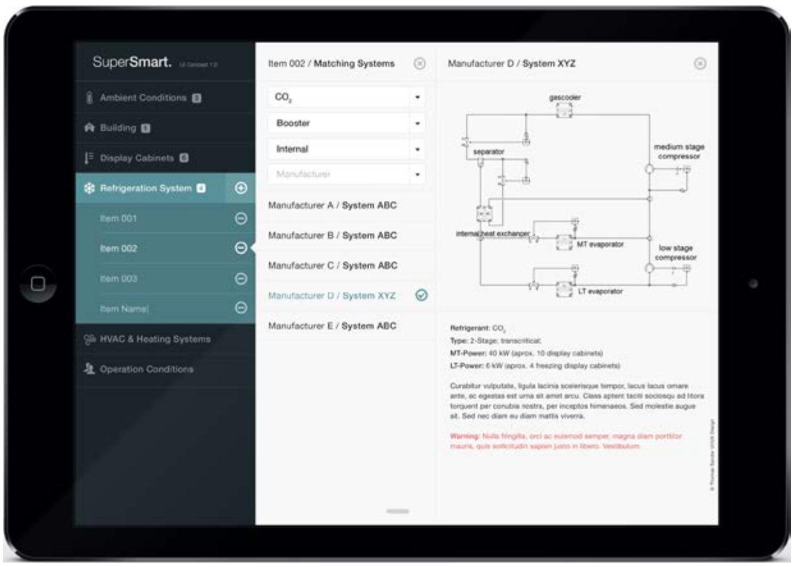

Figure 11: Concept of "SuperSmart-Tool" [Fidorra 2014a]

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2.2.12 Software from Component Manufacturer

Another type of software for supermarket planning are component selection tools. They help the user to choose an adequately dimensioned component for their application from a catalogue. These tools are often provided by component manufacturers to help the user to choose from their product catalogue. These kinds of tools are often available both online and for download. The scope of these tools depends very much on what is required for the component that has to be selected. The target group of these tools are the planners who have to choose the equipment. There is not much additional knowledge required to use those tools, apart from what is necessary to choose the components from a paper-catalogue. Some examples for this category of tools can be found at the homepages of the following compressor manufacturers: Bitzer [Bitzer 2016], Dorin [Dorin 2016], EmersonClimate [EmersonClimate 2016] or GEA [GEA 2016].

2.2.13 TRNSYS

TRNSYS (TRaNsient System Simulation program) [TRNSYS 2016] belongs to the category of modelling and simulation platform. It is commercial software which is widely used especially for building simulation. It is object-oriented and comes along with a large amount of predefined components ("types" as they are called in TRNSYS). TRNSYS has been used for simulating supermarkets. Specifically the so-called "SuperSim" model [Ge 2011b], [Ge 2011a] is based on TRNSYS. An innovative supermarket in Raststatt in Germany has been planned using TRNSYS [Réhault 2013] (Figure 12). The tool is also used in research, for instance in [Polzot 2015]. However, it is not specifically designed for supermarket simulation and thus the supermarket system models have to be created by the user, based on the component database. This requires experience with the tool, and therefore, it is more suited for research and development of new system designs, rather than day to day work of planners, designers or engineers.

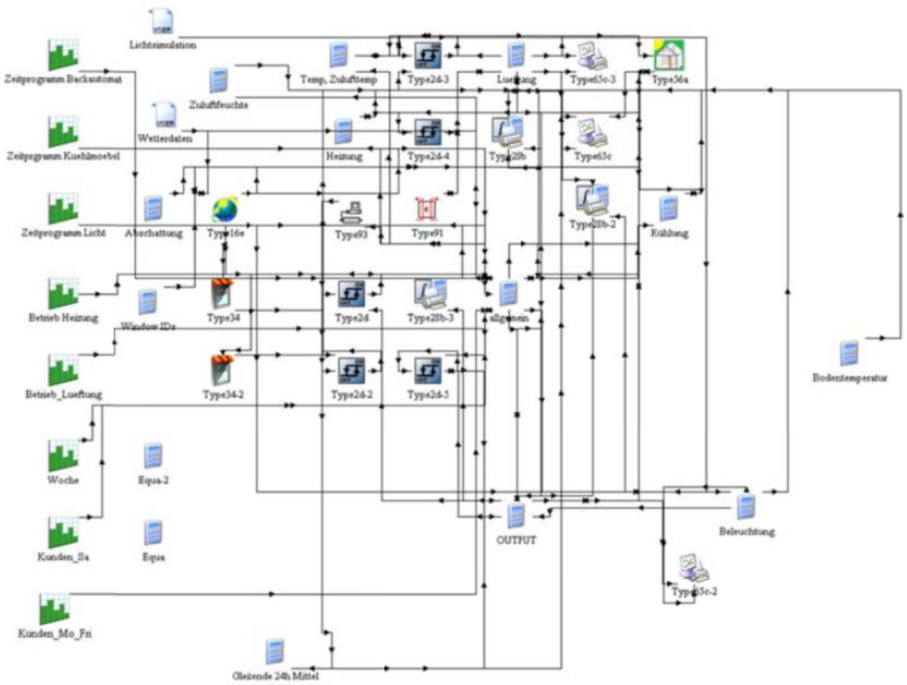

Abbildung 26 Simulationsmodell des Supermarkts

Figure 12 TRNSYS Simulation Model for Supermarket Aldi Süd in Germany [Réhault 2013]

2.2.14 VDMA Quickcheck

The online tool “Quickcheck” [Quickcheck 2016], has been developed by the German Mechanical Engineering Industry Association VDMA (Verband Deutscher Maschinen und Anlagenbau) [VDMA 2016]. It does not simulate or calculate the energy performance of a supermarket or one of its subsystems, but compares the energy performances of supermarkets. It thus belongs to the fourth category of tools. Quickcheck is an online tool. The user has to introduce data (few mandatory and several optional variables) and can consequently compare the energy efficiency with all other supermarkets introduced in the data base. This tool is more specifically described in section 3.1.7.

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Table 1: Overview of the different tools

Tool	Scope/Category	Difficulty to use	License	Comments
CoolPack	Refrigeration Systems	Medium	Freeware	Little flexibility
CoolTool	Refrigeration Systems	Easy/Medium	Commercial tool	Component catalogue available
CyberMart	Entire Supermarket	Easy/Medium	Freeware	Only tool that is specifically developed for supermarket planning
EnergyPlus	Modelling and Simulation Platform	Medium/Difficult	Freeware	Includes refrigeration equipment models
Excel	Modelling and Simulation Platform	Easy/Medium	Commercial tool	AddIns are required
Engineering Equation Solver (EES)	Modelling and Simulation Platform	Medium/Difficult	Commercial tool	Not object-oriented
Matlab Simulink	Modelling and Simulation Platform	Difficult	Commercial tool	Not specifically developed for supermarkets or refrigeration cycles
Software implementing Modelica	Modelling and Simulation Platform	Difficult	Commercial and free software	Different tools available; use of component library recommended
PackCalculationPro	Refrigeration Systems	Medium	free/commercial (depending on usage)	Includes a compressor database
SuperSmart-Tool	Entire Supermarket and Subsystems	Easy/Medium	Not yet defined	Not yet available
Software from Component Manufacturer	Others	Easy	Mainly free	Very broad range of tools
TRNSYS	Modelling and Simulation Platform	Medium/Difficult	Commercial	Broad range of predefined components available
VDMA Quickcheck	Others	Easy	free	Comparison of supermarkets` energy use with a data base

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3 TASKS IN SUPERMARKET PLANNING

In this section, tasks that can be carried out with the previously specified tools are described. For each task, a short description and relevant background information is provided. Tools from chapter 2 that can be used to carry out a specific task are named and more specific information regarding their utilization is given. Additionally, some more complex, research-type tasks are shortly described. It has to be noted that the tasks described in this chapter are only examples, which show the capabilities of the different tools. The different tasks may overlap, and in practice they may be different.

3.1 List of tasks

3.1.1 Estimation of cooling load of display cabinets

Display cabinets are central elements in a supermarket, since they thermally connect the sales area with the refrigeration system. The cooling loads of refrigeration systems are heavily dependent on the number and types of display cabinets and also on the indoor thermal conditions (such as temperature and humidity). Naturally, the refrigeration load increases with the number of display cabinets, as well as with higher indoor temperature and humidity. The higher the sales floor indoor temperature, the higher is the heat infiltration into the cabinet and consequently the heat flow that has to be withdrawn from the cabinet. Additionally, humidity in the air condenses and forms frost on the surface of the heat exchangers, reducing the heat transfer abilities and hence increasing the refrigeration load.

There are many scientific publications discussing display cabinets and the influences of air and heat infiltration as a function of sales floor climate conditions, as for instance [Howell1993], [Orphelin 1999]. There are several investigations showing that display cabinets with doors can reduce the cooling demand and thus the electrical energy consumption, for instance [Fricke 2010]. In order to plan a remote refrigeration system, it is important to know the maximum cooling load it must provide. Thus, the cooling load for a certain display cabinet has to be estimated. There are two examples of tools, which can be used for this task:

1. **CoolPack** (section 2.2.1) has a module (CoolTools: Auxiliary: "Cooling demand for a display cabinet") to calculate the cabinet cooling demand. The input values are the length of the display cabinet and the display area. Additionally, data from the manufacturer and thermal conditions of the surroundings have to be provided. The results of the calculations are the values of heat conduction, infiltration of air and thermal radiation.
2. **EnergyPlus** (section 2.2.3) has a predefined simulation model named "refrigerated cases" [EnergyPlus 2016c], which can be used to estimate the cooling load of a display cabinet.
3. **Modelling and simulation platforms**: The relevant physical phenomena taking place in refrigerated display cabinets are well described in scientific literature. Thus, it is possible to create an own model using tools like Matlab, TRNSYS, EES or Modelica. Due to the effort to model these physical interactions, this approach may be suitable for researcher, rather than for daily planning work.

3.1.2 Estimation and comparison of energy consumption of refrigeration systems

One of the main tasks in planning the technical equipment in supermarkets is the selection of an adequate refrigeration system. There are many types of refrigeration systems available. Predominantly used in supermarkets are vapour compression systems. Currently, there is a trend towards natural refrigerants, especially R744/CO_2 [SuperSmart D2.3]. However, R744 systems perform better in cold climates, and in very warm climates it is still difficult for them to compete with "traditionally used" synthetic refrigerants (for instance R404A). There exists a broad range of different modified/improved CO_2 refrigeration systems, which also perform well at high ambient conditions – as for instance those using ejectors or parallel compression [SuperSmart D2.3]. The performance of these systems depends very much on the boundary conditions, especially the ambient temperature, as well as on the specific components used in the refrigeration system. The following tools from chapter 2 can be used for comparing the energy performance of specific refrigeration systems for given boundary conditions:

1. **PackCalculationPro**: In PackCalculationPro the user can choose between various, predefined refrigeration system layouts (one stage, two single stages, cascade, two stage and heat pumps).

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Parallel compression systems are available only with a commercial license. The user can set various input values and parameters of the system, and the values can also be read from a file. For instance, the cooling capacity can be a constant value or a profile. The input data is divided into suction side and discharge side. One main feature of this tool is the data base with commercially available compressors. The user can auto-create a compressor pack or select compressor from a database. The tool performs an annual simulation of the defined systems. As an output, the values of the annually consumed electrical energy are provided. Based on these results, further information, as LCC or TEWI can be calculated, as described later (section 3.1.5 and 3.1.6). Additionally, the user gets warnings, in case the desired cooling load could not be provided.

2. **CoolPack**: In CoolPack several one- and two-stage cycles exist, both with direct expansion and flooded evaporators and also some R744 cycles. The module is called "CoolTools: CycleAnalysis". The user can specify various details of the cycles, such as temperature levels, cycle capacity, compressor performance and heat loss, heat infiltration to the suction line and pressure losses. Additionally, an auxiliary module helps to calculate pipe diameter and volumetric efficiencies of compressors. The outputs are the energy consumption and the values of the variable at the state points (Figure 2).
3. **IMST ART:** This tool focuses on single vapour compression cycle. The main advantage of the tool is that is has detailed pressure drop and heat transfer correlations implemented. Thus, this tool is suitable for estimating the detailed selection and design of single components in the cycle, as for instance heat exchangers.
4. **Modelling and simulation platforms**: Using a tool from this category, there exist two options how simulation models for a refrigeration cycle can be created. Firstly, creating entirely new models. Besides needing thermophysical fluid property data, the models have to be programmed in this option. Secondly, specific libraries with predefined models could be used. These libraries are normally available for tools, which allow object-oriented modelling. These tools are normally more complex and thus the parametrization of these models is more difficult and more details of the system are required.
5. **CyberMart**: is able to compare energy consumption from different refrigeration systems (see section 2.2.2).

3.1.3 Calculation of recoverable heat flow

Heat recovery from the refrigeration systems for space heating is an important option to increase overall efficiency in supermarkets (see [SuperSmart D2.3], chapter 2.2.8). Depending on the boundary conditions and operation strategy, between 40 - 100 % [Ge 2013] of the supermarket heating demand can be covered by heat recovery. The space heating demand depends on the building envelope, the climatic conditions, the number and type of display cabinets (with/without doors) and the number of customers, amongst others. The recoverable heat flow depends specifically on the type of refrigeration system, the cooling load and the temperature level needed for space heating. Floor heating systems require a lower temperature than space heating via the HVAC system [Titze 2013], [SuperSmart D2.3]. CO_2 systems operating in transcritical mode are specifically suitable for heat recovery [Sawalha 2013]. When comparing refrigeration systems, not only fulfilling the cooling demands for the display cabinets and cold store should be considered, but also the possibility to recover waste heat.

This chapter consists in the estimation of the recoverable heat flow from a specific refrigeration system. The starting point is the specification of the refrigeration system, the cooling loads and ambient conditions. The following tools listed in chapter 2 can be used to assess the possibility of heat recovery.

1. **PackCalculationPro:** In PackCalculationPro, the user can define details of the discharge side of the refrigeration system and choose between different condenser types. For several condenser types (air cooled, dry cooler, evaporative condenser, cooling tower and hybrid cooler) there is an option for heat recovery. The user can choose between two control options: 1. Heat recovery is a linear function of ambient temperature and 2. Run heat recovery at all times (Figure 13). As a result, the user can see the recoverable heat flow for the entire year as well as the total recoverable energy for the entire year (Figure 14).

2. **Modelling and Programming Tools**: Another option is to adapt own simulation models that have been created with tools from the category "modelling and simulation platform". This, however, requires knowledge of the options for heat recovery in different kind of refrigeration systems, as

well as the skills to model them with the corresponding tool. An overview of different options for heat recovery in different refrigeration system can be found in [SuperSmart D2.2].

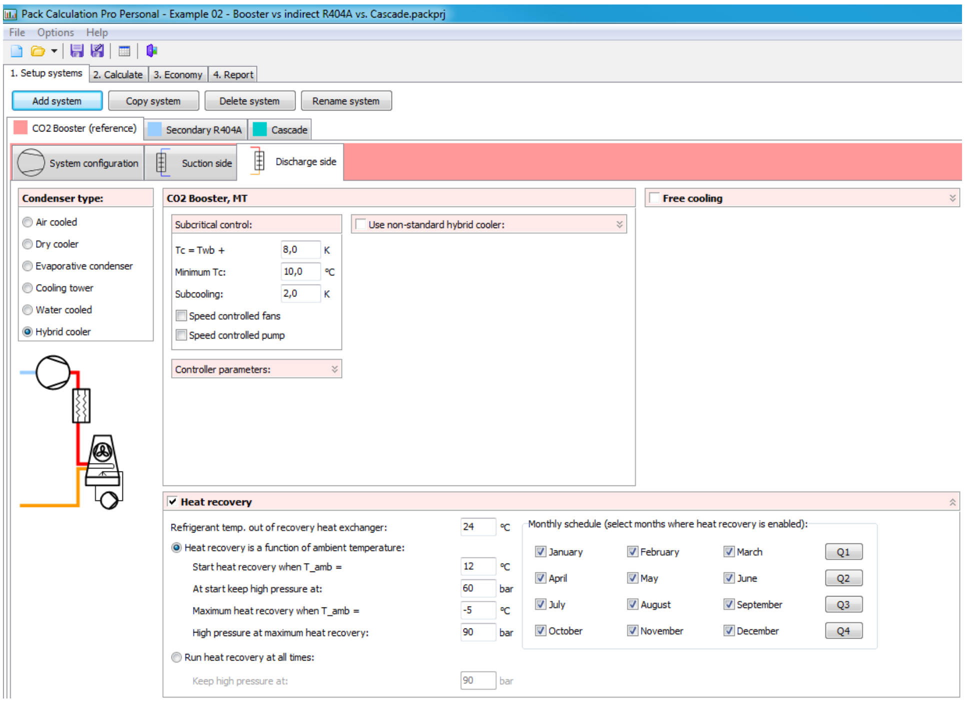

Figure 13: PackCalculationPro: Parameters for Heat Recovery [PackCalculationPro 2016]

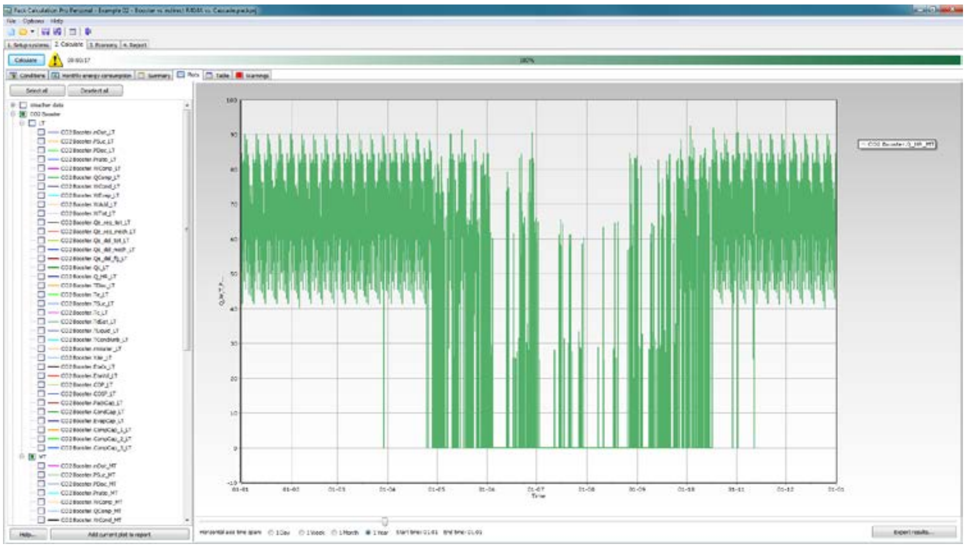

Figure 14: PackCalculationPro: Heat Recovery Result [PackCalculationPro 2016]

3.1.4 Selection of commercially available refrigeration systems components

Once an overall design of a refrigeration system has been defined, the next step is to find the components that are commercially available and fit the requirements of this system. Once, for instance, the main characteristics of a compressor are known, the next task is finding a suitable commercially available compressor. Depending on the tool, there are different input values required to find a suitable compressor. Normally, the refrigerant, the cooling load, pressure ratio and type of compressor (speed

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controlled and/or OnOff controlled) is required. Examples for tools that can be used for the selection of commercially available refrigeration system components can be found in section 2.2.11.

3.1.5 Estimation of Life Cycle Costs

The LCC of a supermarket refrigeration system take into account not only the investment costs, but also costs for operation as energy consumption, maintenance etc. The relevant point regarding supermarket planning in this report is the comparison between investment costs and operational costs. In supermarkets, more efficient equipment is normally more expensive, but consumes less energy. Thus, the LCC perspective can help to take this into account. Details about LCC can be found in [Ruud 2015] Chapter 14.12). Amongst the previously described tools, there are three which include an LCC calculation:

1. **PackCalculationPro** has a module „Economy". The user can enter different parameters such as interest rate, inflation rate, energy cost, expected lifetime, as well as initial costs and annual operation costs. As a result, the user receives the LCC as well as several other costs and rates, as for instance "effective interest rate [%]", "internal rate of return [%]", "present value of maintenance cost" and some more costs/rates. The data for the energy consumption are directly taken from the previous calculation of the system. The outputs are the LCC, payback time and some further economic indicators.
2. **CoolPack** has also a module "Life Cycle Costs" in the tab "CoolTools: Auxiliary". The user can enter initial costs of equipment, cost of installation, annual operation costs (for energy, maintenance and energy consumption) and system life time. As a result, the user gets information on the payback time or the LCC.
3. **CyberMart** has different options to enter the values of the initial investment, the costs for operation and maintenance, etc. They are specifically described in ([CyberMart 2016], chapter 2.16) and ([Arias 2005], chapter 5.4.5).

3.1.6 Calculation of Total Equivalent Warming Impact

The TEWI is a measure to assess the environmental impact of a refrigeration system, specifically how much it contributes to global warming. It consists of the direct and indirect emissions. In case of refrigeration systems, the direct emissions are the losses of refrigerants with global warming potential. The indirect emissions are caused by the consumption of the electrical energy that is required for the operation of the refrigeration system. There are therefore two ways to reduce the TEWI of the refrigeration systems: To reduce the direct and the indirect emissions. When using natural refrigerants, the direct emissions are already quite low (or zero), thus the indirect emissions are more important. In order to estimate the indirect emissions, it is crucial to know the electrical energy consumption of the refrigeration systems. The basic formula for the TEWI is quite simple. The challenge is to estimate the electrical energy consumption of the refrigeration system.

General information on the calculation of the TEWI can be found for instance in [AIRAH 2012]. The task is the estimation of the TEWI for a given refrigeration system with given boundary conditions. Additionally, information on the emission factors for electrical energy is required, which depends very much on the electricity production. The following tools can be used for TEWI-calculation:

1. **PackCalculationPro:** With PackCalculationPro, the CO_2 equivalent emissions can be calculated for the analysed refrigeration systems. As input data the refrigerant charge [kg], the recycle rate [%] and the leakage rate [%/year] have to be provided, as well as the CO_2 release due to the electricity generation in [kg/kWh]. The tool uses the calculated energy consumption of the systems to calculate the CO_2 emissions of the refrigeration system during its lifetime. The results are given as both a bar chart (Figure 15) and tabulated values.
2. **CyberMart**: In CyberMart, it is also possible to calculate the TEWI. The input data in this program are the lifetime, the loss rate [%] and the regional conversion factor [kg CO_2/kWh]. The results are the direct and indirect emissions as well as the total emissions as CO_2 equivalents. More information can be found in ([CyberMart 2016], chapter 2.7) and ([Arias 2005], chapter 5.4.6).

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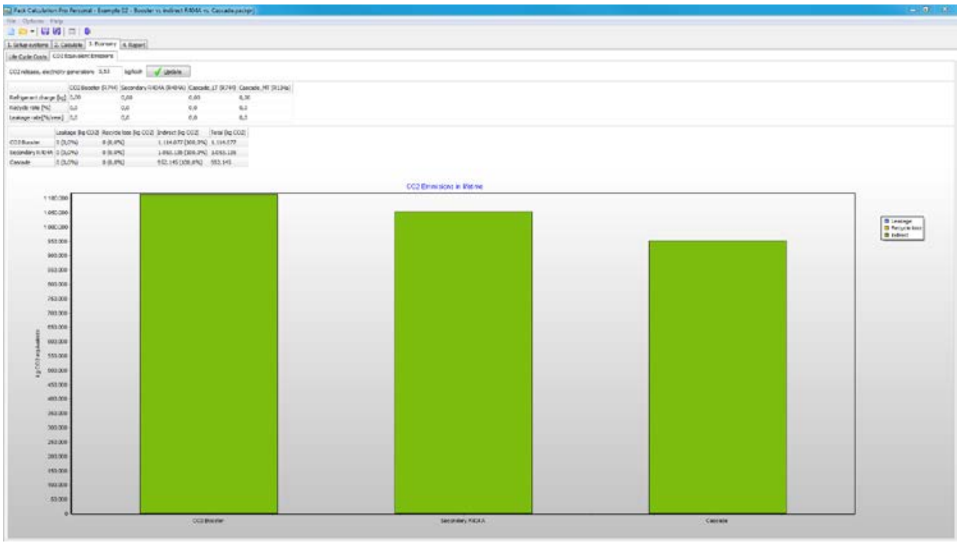

Figure 15: PackCalculationPro: Result of TEWI Calculation [PackCalculationPro 2016]

3.1.7 Comparison of energy efficiency with other supermarkets

Being able to compare the energy performance of different refrigeration systems in a supermarket can be advantageous in several occasions. When building a new supermarket, the comparison with similar markets can help to assess the chosen design. In the case of refurbishment of a supermarket, a comparison of the energy performance can help to choose the supermarket with the poorest performance to be refurbished first. The main challenge for comparison of supermarkets is that the energy consumption depends on many factors, primarily the size and number of display cabinets.
To facilitate the comparison, so called key performance indicators (KPI) are used. They relate the energy performance to the number of display cabinets, sales floor area or other variables and therefore make it possible to compare the supermarkets. There are several research activities which deal with the development of suitable KPI for supermarkets (for instance [Kansal 2016]). Some KPI have already been described in IEA Annex 31 [KTH 2011].

In case of existing supermarkets, the data source for calculating the KPI can be the monitoring system. In case of planning and building a new market, the predicted energy performance of the market has to be used. The energy performance of the new market can be predicted using various tools (see section 3.1.2). One tool to compare the energy performance of supermarket refrigeration systems is the VDMA Quickcheck (section 2.2.13). The user has to introduce the running meter for each type of refrigerated display cabinet and the annual energy consumption of the refrigeration system [Quickcheck 2016]. Optionally, the user can add further data such as climatic region, opening hours, heat recovery etc. to obtain more accurate results. The result of the comparison is a key figure which compares the energy performance of the market to an average of the stores opened since 2009. Figure 16 shows part of a presentation of the Quickcheck and its result screen. Further information can be found on the VDMA website [VDMA 2016].

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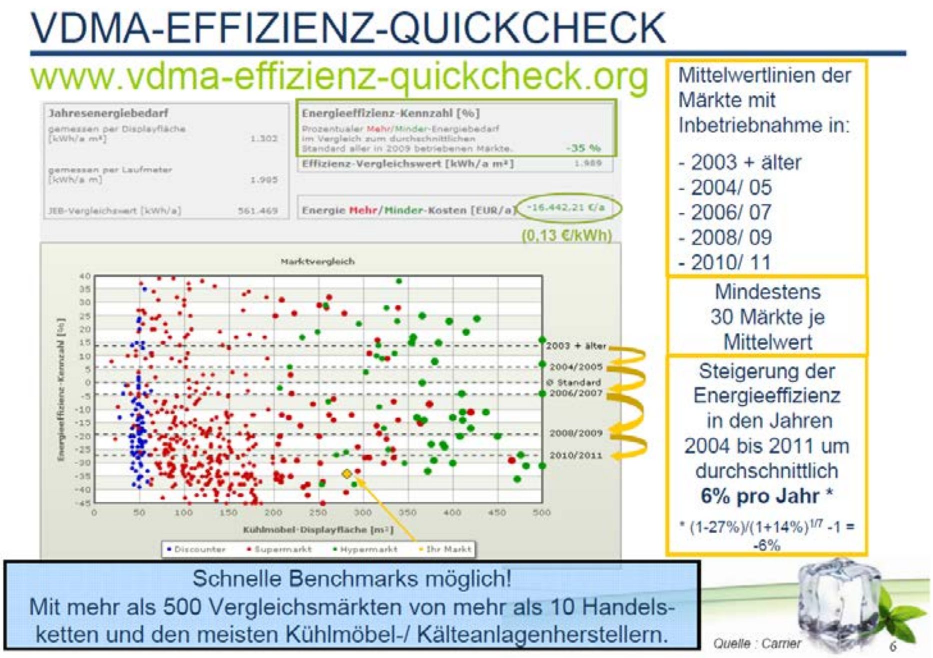

Figure 16: Energy Performance Comparison with VMDA Quickcheck [Heinbokel 2013]

3.1.8 Simulation of entire supermarkets

Supermarkets are complex systems, consisting of many subsystems, which all interact with each other. In order to gain high overall energy efficiency in the supermarket, the interactions and interdependences between the systems have to be considered:

"To estimate the energy requirement in a supermarket it is necessary to evaluate the interrelatedness between the different subsystems and their energy demand." (p.24, [KTH 2011])

This requires assessing the effects that changing or varying of one parameter or subsystem of the supermarket has on the other systems. Tools that are used for this purpose have therefore to be able to change parameters in individual systems and observe the impact on the other systems.

One example of such an assessment is retrofitting glass doors on display cabinets. They lead to a lower air infiltration to the display cabinets and thus to a lower cooling load and lower energy consumption of the refrigeration system. Depending on the climatic conditions and other systems (building envelope, HVAC – system), this can also lead to a lower heating demand and higher cooling demand for the air conditioning system.

In general, possible questions that could be investigated via simulating entire supermarkets are:

- Estimate the number of self-contained display cabinets and cabinets connected to the remote refrigeration system (Figure 17);
- Assess different options for remote refrigeration systems;
- Estimate the options for heat recovery, for instance using floor heating or thermal storage systems;
- Asses the actual performance of the display cabinets as a function of the salesroom indoor conditions. Depending on temperature and relative humidity, they might operate in part load and their control strategy could be optimized [Vallée2015].

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A tool for assessing these kinds of interactions should ideally not only be able to change parameters of the systems with a fixed design, but allow changing the topology of the subsystems. This is facilitated by an object-oriented approach, explained in more detail below.

Figure 17 (a) shows a simple supermarket system consisting of a building, a display cabinet, the ambient and a simple one-stage refrigeration cycle. This graphics exemplifies the utilization of object-oriented modelling and physically motivated connections. Each subsystem consists of a separate model, which can be added via drag-and-drop. The models are connected via connections, which represent a mass or heat flow. In this figure, mass flows of air (yellow) and refrigerant (green) are shown. In the given example, the building exchanges air with the ambient through windows and doors. A heat flow connection (red line) accounts for all heat flows (radiation, convection), transferred from/to the ambient. The condenser of the refrigeration system exchanges air with the ambient. The display cabinet includes the expansion valve and evaporator, thus exchanging two refrigerant flows with the refrigeration system. Furthermore, it exchanges air with the sales floor as well as a heat flow.

Using an object-oriented approach for each subsystem and connecting them via connections that represent actual mass or heat flows are concepts that are widely used in Modelica. This approach allows high flexibility in terms of creating simulation models of entire supermarket systems, changing models of subsystems as well as the topology.

Figure 17 (b) shows a supermarket system with a self-contained display cabinet. In this case, the refrigeration system is a part of the display cabinet. The display cabinet does not exchange refrigerant mass flows with the remote refrigeration system, but only air (to cool the condenser) with the sales floor area. The application of these concepts of high flexibility, object orientation and physically motivated connections for supermarkets have been described by [Jaeschke 2016] and [Tegethoff 2016]. [Tegethoff 2016]Additionally, these concepts are taken into account for the SuperSmart-Tool (2.2.10).

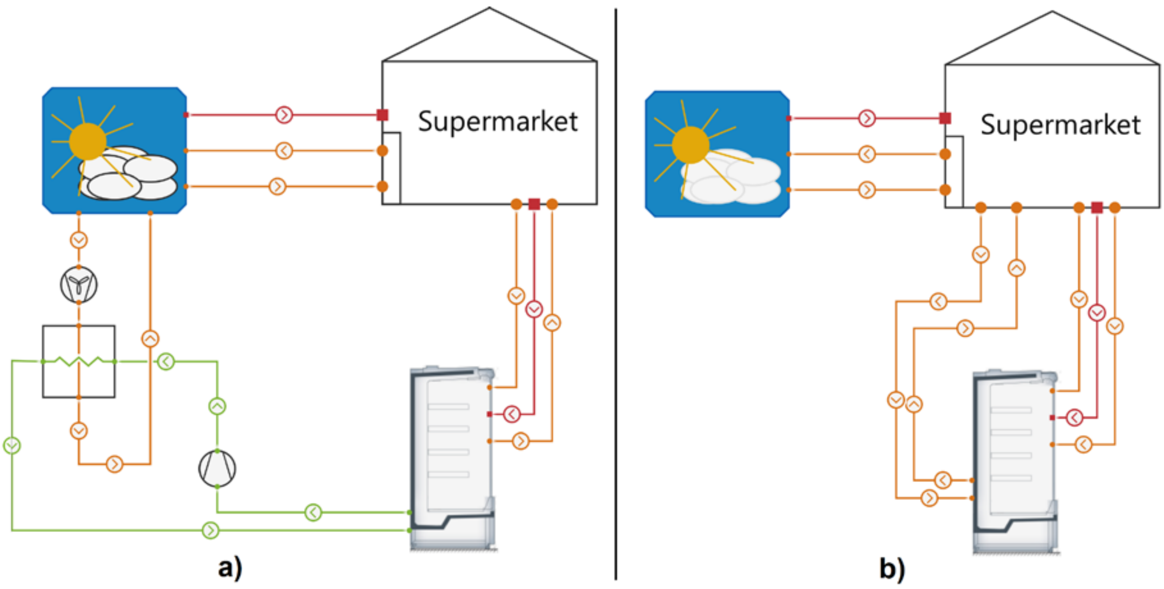

Figure 17: Connection of Supermarket Systems: remote refrigeration system (a), self-contained display cabinet (b)

Thus, the task “Simulation of entire supermarkets“ consists of modeling and simulating an entire supermarket. The relevant and required input data are the details and parameters of all relevant subsystems of the supermarket (building, number and type of display cabinets, refrigeration system, HVAC system, internal heat gains as for instance bakery, etc.). Which data is specifically required, depends on the models actually used in each case. Additionally, boundary conditions, the ambient temperature, ambient relative humidity and solar irradiation as well as the number of customer/opening hours should be known. The outcome of the simulation should be the time-dependent energy consumption of all relevant subsystems. The available tools which are suitable for this task are:

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1. CyberMart
2. EnergyPlus
3. TNRSYS
4. Modelica or Matlab Simulink

The SuperSmart-Tool[2] aims to be another tool for simulation of entire supermarkets, which shall incorporate a component database as well as flexible, object-oriented approaches to design the supermarket layout. Amongst the existing tools listed above, CyberMart is the most user-friendly, since it has a dedicated user interface and predefined supermarket models. The other tools (2-4) are more flexible and some of them have a component database. Since they are programming platforms, they are more difficult to use.

3.2 Summary

This chapter has provided a list of tasks to be considered in supermarket planning. It has to be pointed out, however, that the described tasks are merely examples; there are more tasks that can be done with the tools described in the previous chapter, and in the planning practise, the tasks may be defined differently or may overlap.

However, there are some aspects that should be kept in mind when working with tools such as those described in this report. Firstly, software is only a tool without intelligence. The user needs to have knowledge of the topic he is working with. The quality of the results is only as good as the quality of the used models and the used input data. Therefore, the user has to be able to understand and interpret the results of the tools. In the end, it is the user who is responsible for the results and who has to further work with them. An advantage of the tools with predefined models is the lower effort for the user. However, the user has to be able to understand the results and know about the limitations of the models. Sometimes, it may be easier to create own models than figuring out what a predefined model does and what are the reasons for a certain behavior. A general advice is to always question and double-check the calculated results!

[2] Please read Section 2.2.10, regarding the distinction between the tool and the project.

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4 USER PERSPECTIVE

So far, this report has given an overview of existing tools and possible tasks that can be carried out with these tools. In this chapter, some additional remarks will be given regarding the tools. The perspective of the potential users will be covered. Additionally, the non-technological barriers regarding computational tools in supermarket planning will be described.

4.1 User groups

In chapter 2.1, some relevant aspects to distinguish computational tools have been described, as for instance a component library, required knowledge to use the tools, flexibility of the tools etc. Based on these relevant aspects of the tools, the potential user of computational tools can be segmented in three categories: supermarket operator, planner and researcher.

4.1.1 Supermarket operator

In this report, the operator is defined as the person who owns and runs the supermarket and thus is responsible for the overall operation, including sale, supply chain, marketing etc. The technical part regarding heating and cooling systems plays only a minor role, as the operator has to consider the entire supermarket. Therefore, the operator may not have much specific knowledge of the technical aspects.

Regarding the heating and cooling system, the operator is firstly interested in the correct operation and maintenance [SuperSmart D2.6]. Secondly, the operator is interested in comparing the current energy performance of the supermarkets with other similar markets. This, however, has a strategic perspective, namely to know whether actions have to be taken regarding the heating/cooling systems in a certain supermarket.

Thus, the comparison with other supermarkets (section 3.1.7) could be relevant for the supermarket operator. Furthermore, when it comes to investment decision regarding new refrigeration equipment, he could be interested in the LCC comparison (section 3.1.5). In general, it will be difficult to find this "typical" supermarket operator, since the specification depends very much on the business structure (chain, single shop etc.).

To what extent the operator wants to get involved in the planning depends on his knowledge of heating and cooling and his awareness of its relevance. Therefore, the required training for operators should not focus on the technical details, but in general on the possibilities and limitations of computational tools. Additionally, it would be helpful to have tools that are very simple to use and only require very little, easy-understandable input data that could give a quick and rough estimation about the general design choices for heating and cooling solutions in supermarkets. An important aspect for the operator is to understand that a better energy performance during the lifetime of the equipment may justify higher initial costs.

4.1.2 Planner

A supermarket planner is the stakeholder who plans the heating and cooling equipment in supermarkets and chooses the specific components to be used. The planner needs to have detailed knowledge of refrigeration, HVAC and thermodynamics in general.

Since the planning of supermarkets is the daily business for a planner, an efficient and smooth usage of computational tools is desired. Thus, calculation & simulation models cannot be programmed again and again for each supermarket, but have to be reusable. Ideally, the planner can use the tool in his day-to-day work without much need to adapt it. A component database with commercially available components is very useful. The relevant objectives of a planner are to choose a suitable set of refrigeration, heating and ventilation system that complies with the requirements of the supermarkets. He has not only to choose the overall system design, but also to dimension the system and give clear specifications to the manufacturers and installing company. Doing all this, the costs of all equipment have to be considered.

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European Union/EASME H2020 Programme under Grant Agreement No 696076.

4.1.3 Researcher/System Designer

Researchers work at universities and research institutions and investigate new concepts for heating and cooling equipment and entire supermarkets. System designers further develop the concepts up to readiness for production. Both, researchers and system developers are similar in the way they use computational tools. They want to understand the details and improve the systems and not only build systems that work. They have a very deep understanding of the technical systems and the thermodynamics and also have knowledge of simulation, modelling, programming and numerics. Since they work not only with off-the-shelf products and well-established system designs, it is important for them to be able to have tools with high flexibility. They are the users with highest demand for tools from the category modelling and simulation platform. They can make use of component libraries. However, since they have more time to work with one system, databases with commercially available components are not as relevant for them as for planners.

4.1.4 Non-technological barriers in this field

The non-technological barriers are closely related to the users of computational tools for supermarket planning and specific barriers can be found in this field (Table 2). The solution for many of the barriers consists of raising awareness and spreading information among the supermarket stakeholders, which is one of the main goals of the SuperSmart project.

Table 2: Non-technological barriers regarding computational tools

Lack of awareness	
Barrier	**Solution**
Lack of awareness about existing tools	Awareness raising and information campaigns
Lack of awareness about applications of these tools	Awareness raising and information campaigns
Lack of awareness about possible benefit of using tools	Awareness raising and information campaigns
Lack of knowledge	
Barrier	**Solution**
Lack of overview of different tools, their features, requirements and limitations	Awareness raising and information campaigns
Lack of knowledge how to use the tools	Information on required knowledge to effectively use the tools
Social barrier	
Barrier	**Solution**
Reluctance to start working with new tools	Education regarding the existing tools and required effort to effectively start working with these tools
Ignoring or neglecting the relevance of tools	Education about the interactions and interdependencies of thermal systems in supermarkets, which require computational tools
Organisational Barrier	
Barrier	**Solution**
Most tools have a limited scope, covering only a small part/a subsystem of supermarkets. Tools that can be used effectively for planning do not cover the entire supermarket and all its thermal systems	Development of new tools
Tools are seldom compatible with other tools for other planning stages	Existing tools have to be adapted and/or new tools have to be developed
Legislative Barrier	
Barrier	**Solution**
Lack of legislation demanding high energy efficiency and penalizing poor efficiency	New EU Ecolabel for food retail stores may eventually lead to such legislation
Lack of legislation demanding supermarket planning certifications, to avoid under- or over-dimensioning of equipment	New EU Ecolabel on supermarkets may eventually lead to such legislation Modified and/or new tools have to be developed

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4.2 Summary

Computational tools are an important support for planning the heating and cooling systems in supermarkets. The interactions and interdependencies between the thermal systems in supermarkets are complex and computational tools are required to understand and quantify them. Some tasks can already be carried out very well by existing tools, for instance the comparison of refrigeration systems (section 3.1.7). In general, there are different requirements and expectations towards the tools, which are sometimes contradictory. On the one hand, the tools shall be easy to use and little input data as well as little knowledge should be required to use them. On the other hand, accurate results are desired, which require accurate input data and a high level of understanding by the user. Another example of contradictory requests refers to predefined models versus high flexibility.

There is no tool which complies with all requirements and wishes of the user. Thus, there is a need for further tools. A type of tool which is required should be able to give a rough estimation on the qualitative changes of the energy performance depending on the system design and very little further input data.

This new tool should include aspects such as more efficient systems (which may have higher investment costs) and lower annual energy consumption. Additionally, there is a need for further tools for planners, which are able to consider the entire supermarket and are compatible with other planning tools. These needs are reflected by the following quotes from the IEA Annex 31:

"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)." (p.22, [KTH 2011])

"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." (p. 78, [KTH 2011])

Regarding the non-technological barriers, the main measures to remove them are information and awareness rising. This is the primary objective of the SuperSmart project.

4.3 Scope and limitations of the SuperSmart training

There are two main non-technological barriers in the field of computational tools that can be removed in the SuperSmart project: awareness barrier and knowledge barrier. The actions to remove the awareness barrier consist primarily of information spreading activities/campaigns. The knowledge barrier is more difficult to remove. Beside few tools, like VDMA Quickcheck (section 2.2.13), all tools require knowledge of the technical systems and basic thermodynamics. Without this previous knowledge, it is not possible to effectively use the tools. This lack of knowledge is the first limitation of the training sessions within the SuperSmart project. The training material and trainings sessions aim at providing an overview of different tools and the relevant aspects of their selection and usage (see chapter 2). Out of the scope of this project are manuals and "how to" instructions for the tools. Additionally, tools from the "programming and simulations platform" category require additional knowledge of programing, modelling and sometimes numerics. This cannot be taught within this project´s training sessions.

The trainings are rather intended to provide information on the possibilities of existing tools and to demonstrate the need of using tools to quantify the complex interactions and interdependencies of supermarkets. The training sessions can raise awareness for these interactions and improve the need for using more holistic evaluation approaches like LCC.

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5 CONCLUSIONS

The objective of this report was to provide an overview of “computational tools in supermarket planning” for the reader. Supermarket planning in the context of this report is limited to the planning of the heating and cooling equipment and more specifically, the refrigeration systems.

Tools are necessary because they facilitate carrying out simple and repetitive tasks, as for instance choosing components from a catalogue or calculation of thermophysical property data. Furthermore, high energy efficiency in supermarkets can only be achieved when all subsystems work optimally with respect to each other. Since there are many interdependencies between the different subsystems in a supermarket, it is necessary to use computational tools to evaluate their operation.
In total, there are a limited number of tools which deal specifically with the planning of thermal systems in supermarkets. The tools can be distinguished by a variety of aspects, as for instance the scope (entire supermarket or subsystem), relevant features (component database) or the required knowledge to use them.

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European Union/EASME H2020 Programme under Grant Agreement No 696076.

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The research leading to these results has received funding from the European Union/EASME H2020 Programme under Grant Agreement No 696076.

SuperSmart is funded by the European Union, under the Horizon 2020 Innovation Framework Programme, project number 696076.

Horizon 2020
European Union funding
for Research & Innovation