Development of a methodology for the design and implementation of solar process heat systems in the food industry

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Abstract
The effects of fossil fuel consumption on the climate lead to changes in international climate policy, hence, the introduction of the EU Energy Efficiency Directive and national standards for industrial energy efficiency. This paper focuses on the reduction of energy and CO_2 emissions in the food industry.

Much of the energy used by the food industry is low-grade heat. Almost 85 % of this heat is supplied at temperatures below 150 °C and most of the heat is raised by the combustion of fossil fuels. The supply of low-grade process heat represents an opportunity for heat recovery systems and solar thermal systems.

A review of existing standards, guides for energy efficiency and results of past projects has shown that the integration of solar process heat in the food industry is a complex task with no established methodology. Such a methodology should be valuable to both the engineers responsible for the design of a process heat system and also the energy engineers employed by the industry to run these systems. Both types of decision maker are responsible for the energy systems of food companies. Their expertise varies and covers a broad range.

This paper presents the development of a methodology for the integration of solar process heating in the food industry. The first part of the development process was the configuration of the tools and measures for analysis, optimisation and design. This is basis for the structure of the methodology and it addresses the deficiencies of existing guidelines. The second part was the application of the methodology within two case companies in cooperation with the energy engineers. Their feedback was used to evaluate the usability of tools and measures within the methodology from the perspective of the food company energy engineer. The experience of application of the methodology with real case companies demonstrates the necessity of energy engineer feedback. The case study results primary energy savings up to 12.5 % on low-grade heat.

Introduction

PROCESS HEAT IN THE FOOD INDUSTRY
The food industry is one of the most important industrial sectors in the EU28. About 4.2 million people work in 286,000 companies and generate a total manufacturing turnover of more than EUR 1,048 billion. SMEs dominate the sector and generate, with nearly 65 % of all employees, more than 50 % of that turnover. As Figure 1 illustrates, fossil fuels dominate the energy supply in the German food industry whereas renewable energies do not play in important role (EC, 2009; FD, 2015).

Dairies and the beverage industry (including breweries) are important subsectors within the food industry in Europe and are responsible for one third of the economic power within this sector (EC, 2009; FD, 2015). Thermal energy at low temperatures dominates the food industry. 83.6 % of its thermal energy is consumed at temperatures below 150 °C (Lauterbach, 2011). However, there are also industrial sectors where temperature levels for processes and other applications are even lower (Vannoni, 2008; Schweiger, 2001): The meat processing or confectionary demand, for example, requires heat at temperatures <100 °C. With a few exceptions, most steps of milk processing do not require temperatures of more than 140 °C. This is quite similar to breweries, where the highest temperature levels are necessary for the boiling processes in the brew house and limited to about 100 °C. These conditions are suitable for solar-thermal applications.

SOLAR PROCESS HEAT IN OPERATION

Despite promising conditions, the number of solar process heat (SPH) systems in operation is still low. Brunner (2013) investigated about 150 systems with an installed collector area of 35,000 m². Table 1 illustrates in contrast the potentials in the food industry defined by Lauterbach (2011). The SHIP (Solar Heat for Industrial Processes) database includes a number of about 190 SPH systems all over the world (SHIP, 2016).

The technology for SPH systems is available and cannot be considered as real barrier. State of the art components (e.g. collector, storage) such as used for medium and large systems for domestic heat energy supply (Solar, 2000), indicate sufficient technical background.

One reason for the low application of SPH-System could be the motivation for investments caused by a lack of capital, but also long amortisation periods (pwc, 2015). Many companies make decisions exclusively with these criteria. Amortisation periods for SPH systems of ten or more years (Lauterbach et al, 2011) cannot reach three years requirements of companies. Another reason is an increasing complexity that discourages investments in efficient technologies pointed out by companies. Further, adequate funding (Eep, 2015) and more specific consulting would better support companies in achieving energy efficiency.

Finally, it is important for companies to see best practice examples to favour investments, but also to understand their technologies. Energy engineers are responsible for the energy supply in companies. Their knowledge is a promising basis but insufficient for many technologies. Unfortunately, they are often not considered regarding the introduction of new technologies and implementation methodologies. However, specific guidelines that aim to implement energy supply systems must also be able to support energy engineers with decision making, planning and implementation.

Covering all that aspects in connection with the design and integration of a SPH-system a methodology is necessary that guides energy engineers from the production companies. This methodology may range from the analysis of the current energy supply system and an energetic optimisation up to technical and economic evaluated SPH-system concept ready for the implementation. Therefore, the methodology shall consider the knowledge background of the energy engineers and provide a high usability. Design engineers shall use the methodology to complement gaps in knowledge of energy engineers and to consult them.

REVIEW ON EXISTING METHODOLOGIES

About 90 % of the industry prefers today a systematic approach with the design and implementation of new energy systems and the improvement of energy efficiency (Eep, 2015). Methodologies that provide a structure and tools for the design of system concepts play therefore an important role and is also for SPH-systems. A literature review analysis available categories of methodologies for example with the procedure and objectives. Important in this connection is the audience or user of the methodology. The review focuses on the aspect of audience or user integration to the methodology design. Each category is describes briefly below.

Energy audits are based on standards and often legislative backgrounds. Such standards are derived in the EU member states from the Energy Efficiency Directive (2012). These energy audits shall improve energy efficiency but aim also to support energy consuming companies in getting more insight into their own energetic behaviour, e.g. DIN EN 16 247 (2012). The

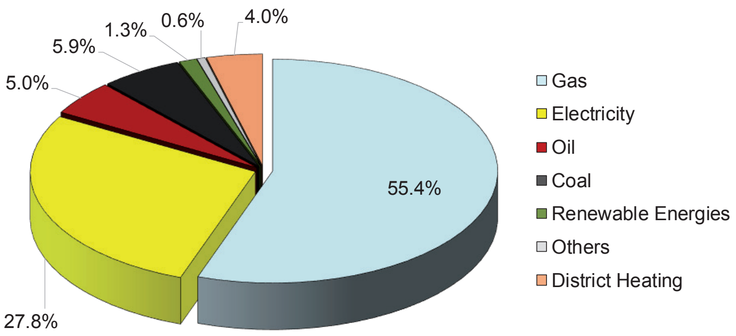

Figure 1. Energy Sources in the German Food Industry (cf. Destatis, 2015).

Table 1. Potential of solar process heat supply in the food industry, dairies and breweries (cf. Lauterbach, 2011).

	Solar process heat potential [GWh]	Solar process heat potential [GW]	Solar process heat potential [m²]
Food Industry	2,694	4.240	6,053,930
Dairies	383	0.602	860,650
Breweries + NAB	264	0.415	593,050

focus is on analysis and documentation of energy data. However, the general procedures give just a rough structure, mainly for energy auditors that can lead to variation in application results. This is also for the quality of energy data. Thollander (2014) figured out, that more detailed process data prevent finally the implementation of energy efficiency measures. Hence, the result of a good application of an energy audit can provide a general basis for energy efficiency, but does not equal the implementation of energy efficiency.

Energy efficiency not only contributes to the targets for saving energy and reducing CO_2 emissions specified in legislation, but is also important for the industry itself, to manage its energy demand. Experts can get general information or specific information by industrial sector. Exemplary guidebooks are provided by CIPEC (2011) for breweries or by Brush (2011) for dairies. Very little of this information specifically addresses energy engineers at companies. The focus is on cross-sectional energy efficiency that includes heat recovery. These guidelines do not provide a methodology. The information on renewable energies is limited, especially about SPH-systems.

A lot of scientific work has been done on *energy efficiency* regarding *heat recovery* in connection with *low-grade heat supply*. Walmsley (2015) for example analysed heat recovery loops and Seai (2013) aims to provide project management tools for the implementation of energy efficiency measures. The resulting procedures and methodologies focus mainly on appropriate processes. They demonstrate maximum potential using detailed simulation. This leads to a large gap between these and realistic applications. A translation of the results to form usable by energy engineers in companies requires comprehensive work.

A similar situation involves scientific work in the field of *SPH-system* design and solar process heat integration. Sometimes real world systems provide the background information for theoretical studies using complex tools (Baniassadi et al., 2015). Pinch analysis and simulation is often used for the definition and evaluation of maximum energy saving potentials (Quijear and Labidi, 2012). The results on this level are not for company energy engineers.

Sopro (2012), Schmitt (2012) and TU Wien (2013) provide guidelines for the integration of SPH-systems into a company energy supply systems. These *SPH-guidelines* show general facts about SPH-systems and their configuration to energy engineers or design engineers. However, it is missing; first a comparison of competing heat sources, and second, the individual deficiencies missing from some aspect of the integration process. The analysis of the guidelines within the literature review results that they do not provide complete methodologies. Furthermore, they are insufficient in aspects like a detailed energetic analysis of the company. Finally, feedback from applicants on usability is very important, and currently lacking: The methodology audience was not included to the design of the guidelines.

The *branch concepts* from Muster-Slawitsch et al. (2011) and Brunner et al. (2015) provide an approach for minimum thermal energy demand with the lowest possible CO_2 emissions. This demands comprehensive redesign of existing structures and includes energy supply systems as well as production equipment. Hence, the application of a branch concept requires not only expert knowledge in the specific industry sector but also such knowledge of energy efficiency and the whole range of energy supply systems. It is critical that complex redesign of the heat supply is complemented with a redesign of the process technology. Strong intervention requires comprehensive feedback on its acceptance by company decision makers and energy engineers, which is not available yet.

The branch concepts and their results were mainly background for the *EINSTEIN tool-kit* (Brunner C. et al., 2010). This was an attempt to integrate renewable energy sources into the optimisation of thermal energy supply systems. The result, however, is a complex software tool that requires expert knowledge, not only of many different technologies but also about optimisation and design methods regarding application of the tool, along with verification of the results.

Figure 2 illustrates the findings of the methodology review regarding focus/objective, characteristics and the analysis results. Additionally an important finding is, that just one category takes the later user into account. However, the design of methodologies and first of all an evaluation of a real world methodology application with following evaluation has been not carried out.

REQUIREMENTS A NOVEL METHODOLOGY

The results of the literature review illustrates that SPH-systems are usually not specifically included in energy efficiency guides and the specific SPH-guidelines show deficiencies. Additionally, the detailed scientific work highlights gaps between such concepts and real users. This is a fact that needs to be considered because SPH-system implementation also depends on the motivation driving investment and demands well-conceived process heat solutions that are convincing to a company. Therefore, energy efficiency and SPH-System integration need a structured procedure. This procedure should consist of compatible functions applicable by energy engineers.

Methodology characteristic

A methodology focusing on an efficient integration of SPH-systems needs to include technical and energy relevant aspects. Each of the analysed standards, guidelines, branch concepts or SPH-guidelines within the literature review, can therefore contribute useful parts:

- Guidance for the analysis and documentation of energy demand and supply for a company with focus on process heat. This will support the company in understanding its energetic behaviour.
- Energy benchmark of the company with the analysis results combined with production figures. This is for definition of general potential savings.
- Analysis of heat recovery potentials to increase energy efficiency (saving energy and reducing CO_2-emissions).
- Analysis and evaluation of all available and competing heat sources. It is for an energetically useful energy supply and ensures sufficient integration of the defined heat energy consumers.
- Low-grade process heat distribution, can be an efficient heat supply for processes. This requires detailed process-analysis with definition of minimum low-temperature energy demand using methodological process analysis (e.g. pinch method).

Category	Focus / Objective	Characteristics	Analysis Results
Energy Audit	• Data acquisition • Improve knowledge on energy demand • Documentation of basis data for energy efficiency	Background for legislation	• Minimum standard for all industries • Rough, general procedure • Different approaches → different results • Limited on analysis and documentation • Energy efficiency as task (no design recommendations)
Energy Efficiency	• Illustration of efficiency measures • Compilation of mainly cross-sectional technologies • Industry sector specific	Recommendations: • Economic evaluation • Implementation • Tools and Funding	• Illustration of energy efficiency barriers • Missing consideration of EM feedback • Compilation of energy efficiency • No methodology • Limited regarding renewable energies
Energy Efficiency with Heat Recovery Low-grade heat supply	• Illustration of heat recovery measures • Background is low-grade heat supply • Integration in existing structures • (partially renewable energy)	• Methodology structure • Use of scientific tools (Pinch, simulation)	• Use of complex analytical (tools) • Detailed simulation studies • Demonstration of maximum potentials • Distance to real world application • Specifically application cases • Mainly impossible to convert into guidelines for industry • For researcher or high level experts • No consideration of EM (feedback)
Solar Process Heat Systems	• Implementation of SPH-system • Economic implementation • Background are real world cases	• Methodology structure • Use of scientific tools (Pinch, simulation)	
Solar Process Heat Systems	• Implementation of SPH-system • Assistance to audience / user • Increase SPH-system use	• Design recommendations • Nomogram	Missing aspects in each method (Chapter 2.5.4)
Branch Concepts	• Minimisation of thermal energy demand • CO2-free heat supply • Energy efficiency and renewable energy	• Design recommendations • Tools (Pinch, simulation)	• Concepts for maximum potentials (only for a small number of companies) • Strong intervention in existing structures • Methodology is not in focus • Distance to company EM (no feedback from concept user)
Tool	• Expert Tool • Shall support Branch Concept (Background Green Brewery)	• Software • Energy audit • Optimisation recommendations	• Commercial use • Complex application (expert tool) • Verification of results needs expertise

Figure 2. Findings from the literature review.

- Structural conditions for collector mounting can be limiting. An analysis of buildings, combined with possible application of existing components (e.g. storage), is needed for configuration of the SPH-system.
- Development of a multivalent process heat system including heat recovery, solar process heat and conventional process heat, is for efficient energy supply to low-grade heat consumers.

All the steps of a methodology towards an efficient energy supply, with heat recovery and solar process heat, must be arranged to form self-contained elements. Finally, these elements of a novel methodology must consider the completeness and detail required, in combination with helpful tools.

Methodology design with the methodology user

It is just as important to get feedback on the methodology, as it is to develop the methodology with sufficient procedures and tools. The literature review uncovered a deficiency in this aspect. A methodology is for the use of the defined audience and must take this audience into consideration. The focus is on the energy engineers at companies.

Figure 3 summarises important aspects. The *methodology* for SPH-system integration with a low-grade heat supply (upper centre of the figure) represents the procedure with all the technological and energetic steps. The methodology application requires a *clear structure* (upper right). Opposite, on the left, there are the *elements and functions* that represent the steps beginning with an energetic analysis to an efficient heat supply with solar process heat. The *case study application* is background for user feedback. The dotted lines illustrate that this feedback is for all aspects of the methodology. This is in particular important for the methodology *usability* and *flexibility*.

Case studies enable a common application for development of methodology, with energy engineers to apply the methods. The feedback from energy engineers is essential for evaluation of the methodology elements, and also functions as specific tools. This results in available expertise at the companies, specifically the expertise necessary for application. It also enables conclusions about the necessity of company support from external system designers. Finally, the feedback summarising such efforts provides important background about the overall usability of the methodology by the broader audience of industrial energy engineers.

Methodology development

The methodology development can be separated into three steps. It starts with the design of a methodology structure, which needs the definition of the intended user. The following case studies provide a test bed for the real world application of the methodology in cooperation with user. The final step is the evaluation of the user feedback resulting of the case studies. Therefore, the user plays an important role and influences the methodology design. This is a novel aspect with the development of such methodologies and shall ensure a high usability.

OBJECTIVES OF THE METHODOLOGY

The main objective of the methodology is first a structure for efficient integration of SPH-systems with the conventional process heat systems used in industry. Considering this, the energetic focus is on low-grade process heat and related distribution systems. The definition of efficient means energy efficiency regarding low-grade process heat supply and saving fossil fuels. Heat recovery is therefore a main aspect. Finally, the objective is to integrate the SPH-system considering its economic background. This methodology is intended to support the industry to comply with legislative requirements, but its application must also be able to support the self-defined goals of the companies, such as:

- Reduce the consumption of fossil energy for process heat supply.
- Save CO_2 emissions by decreasing fossil energy demand and use SPH-systems to substitute for fossil fuel energy.
- Contribute to the company sustainability strategy.
- Control energy costs.

STRUCTURE OF THE METHODOLOGY

Solar process heat is a technology that cannot supply all process heat demand; thus, it is limited to specific industries. The literature review found that the food industry, particularly breweries and dairies are promising for SPH-system operation. Hence, the development of the methodology must be adapted to these branches of the food industry with its specific conditions:

- Thermal energy dominates energy consumption of production processes and other applications.
- This industry sector needs large fractions of its process heat at low temperatures (<100 °C).
- Thermal energy demand remains steady during the year and production is not typically interrupted.
- The production processes are mainly discontinuous and batch processing is characteristic.
- There is enough area usable for mounting solar thermal collectors on company buildings or on the ground close to the company site area.

The literature review provided several categories of background information. Important findings included existing guides for energy efficiency and SPH-guidelines, but also scientific work and branch concepts. The analysis, particularly of the SPH-guidelines, identified different gaps regarding a complete methodology towards solar process heat integration. One aspect almost completely missing is the integration of the user audience with the development of methodologies. However, this is essential for usability. With the background of the existing information, this novel methodology aims to close the gaps and provide users a guide for design and implementation of SPH-systems.

- The category *energy audit* is the background for analysis of a company's energy consumption. Such tools help to manage energy supply and distribution better, and also to introduce this topic into company policy. This makes energy subject to long-term attention and requires action from responsible energy engineers within the company.
- The category *guides for energy efficiency* supports the industry with energy efficiency and includes all forms of energy.

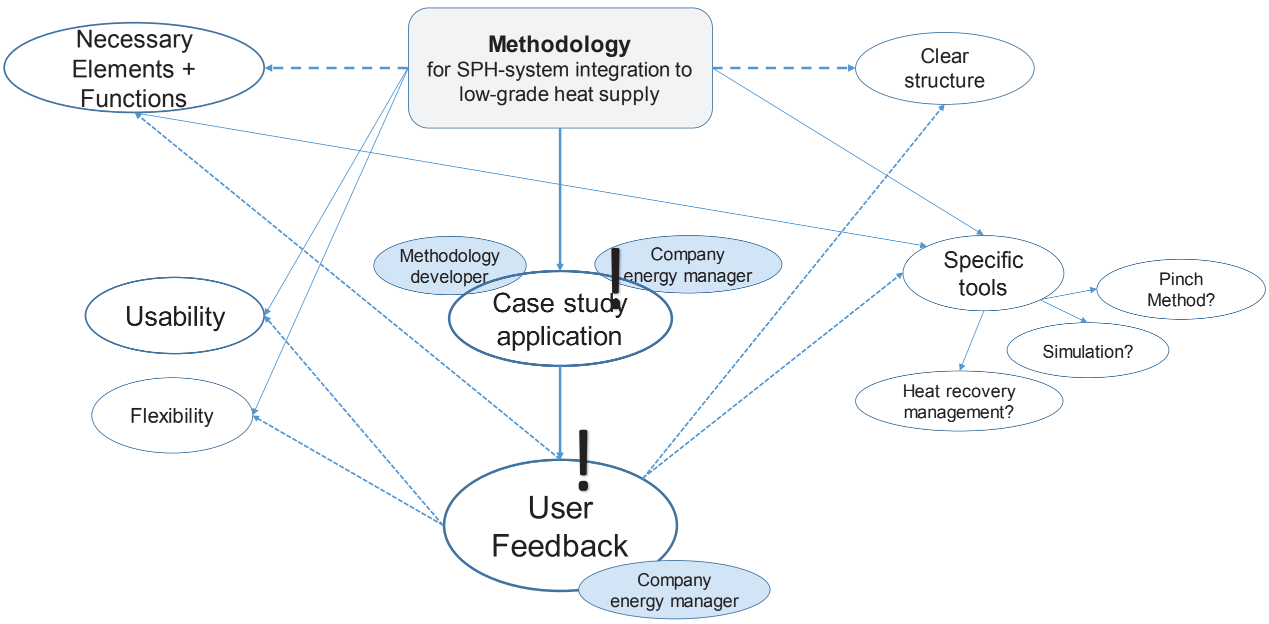

Figure 3. Outstanding unmet requirements for a methodology for SPH-system integration.

They are, in most cases, a compilation of various measures and 'consult' (advise) the industry in general, but not industrial sectors, about this topic. In addition, the scientific work available presents barriers and approaches for the evaluation of energy efficiency measures.

- The category *solar process heat systems* for SPH-systems, already focuses on promising industry sectors. Low-grade energy supply and concepts for such systems are discussed.
- The category *industry specific concepts* in proposes a comprehensive redesign of heat supply and process technology. However, the procedure for providing the concepts gives useful background for the analysis and optimisation of heat supply systems.
- In addition to the information categories, are tools for system *simulation* that are very helpful for planning and configuration. The simulation enables analysis of the dynamic behaviour of entire systems regarding energy consumers and energy sources. Detailed knowledge of the system and comprehensive data input about it is necessary. This is an essential aspect of the implementation of an SPH-system.

The basic structure of the methodology is formed with *elements that* are derived from the categories above. Each element exchanges information with the others but should be usable independently. Figure 4 shows the order of the elements: energetic analysis, energetic optimisation, solar-thermal system integration and simulation.

The *functions* divide each element into several activities. A function therefore represents the specific tools or measures necessary to reach intermediate results. The assignment of these functions to each element constitutes an additional procedure.

The methodology is designed for energy engineers and system designers. Figure 4 shows, therefore, the allocation of both to each element and represents the required expertise. The responsibility of energy engineers decreases with each element and increases for system designers. The indication of overlapping expertise emphasises the necessary cooperation.

I. Energetic analysis

The basis of the methodology is a comprehensive company analysis with focus on energy consumption. CO_2 emissions and production figures complement the company analysis. The approach is a top-down method from a holistic view, towards a detailed analysis of processes and applications of energy consumers. A completed energetic analysis illustrates the current energetic status of a company and is basic knowledge needed for the optimisation. This is the most comprehensive part of the methodology and should be mainly the responsibility of the energy engineers. The energetic analysis includes tools like energy balance or specific key figures.

II. Energetic optimisation

Energetic optimisation is focused on energy supply and distribution of process heat. On the one hand, its objective is to save energy and emissions via the implementation of energy efficiency measures for the process heat supply. On the other hand, it aims to configure a platform for the integration of a SPH-system. The resulting energy supply concept of the optimisation is the basis for the solar process heat supply. It should provide suitable integration points for the SPH-systems and provide the energy demand that must be provided with solar process heat. The energetic optimisation is largely in the area of responsibility of the energy engineers. Support from external

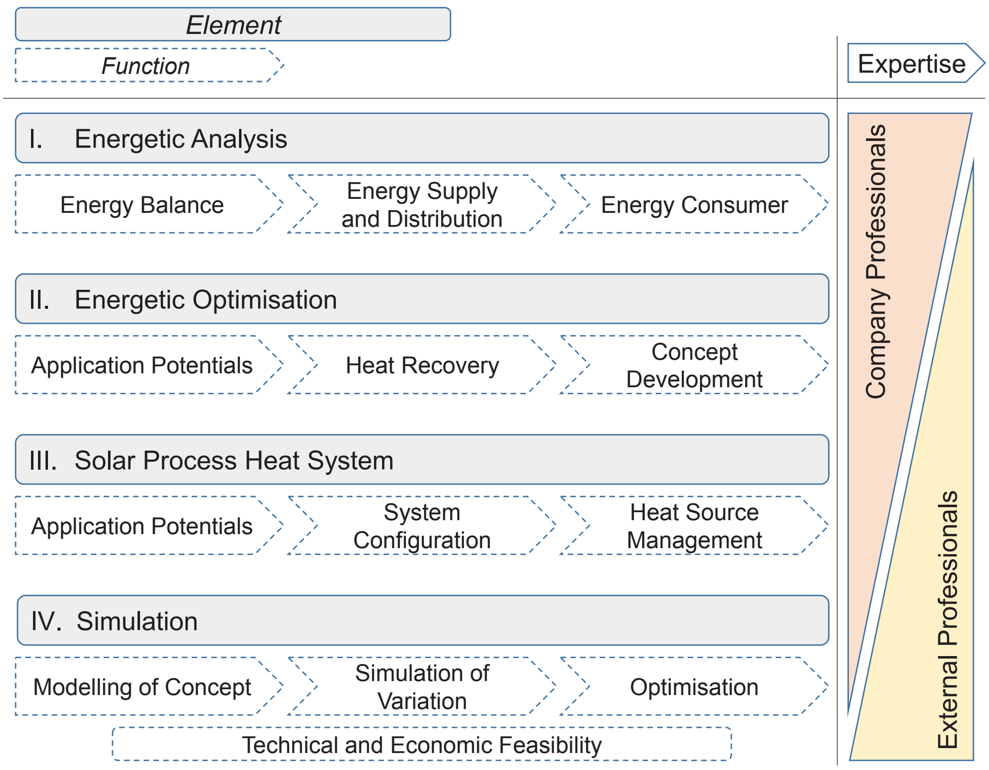

Figure 4. Structure of the proposed methodology.

system designers should extend the discussion and evaluation of promising optimisation measures. An important tool for the energetic optimisation is the pinch analysis.

III. Solar process heat system

The integration of solar process heat is the essential part of this methodology and starts with the system configuration. Its aim is to design an efficient and simple system combining the conditions of the company buildings as well as the energy supply and distribution. The configuration of the SPH-system and its integration with the optimised low-grade heat supply completes the conceptual development for the low-grade heat supply. The following system simulation can be done using the results from this element. The SPH-system configuration requires the expertise of an external system designer. Energy engineers support this part of the method with data input (e.g. for analysis of available collector mounting area). Important tools within this element are the roof evaluation and the heat source management (Müller, 2013).

IV. Simulation

Simulation is a useful tool for testing concept configurations and verifying the energetic results. Simulations enable analysis of the dynamic behaviour of system components and optimisation of the configuration. This is important regarding the solar-thermal component and its contribution to the overall results. Modelling and simulation support not only the energetic optimisation, but also the detection of configuration errors. The result of the system simulation is an optimised system concept with a maximum use of waste heat and an integrated SPH-system. The energy balance from the energetic analysis is used for the concept analysis. This enables a comparison to the initial system configuration and figures out energy savings and a reduction of CO_2-emissions. A technical and economic feasibility evaluation of the SPH-system completes the concept development. Simulation of the energy supply systems require detailed knowledge. Such expertise is mainly limited to external system designers. Energy engineers can support the simulation process with data input and the evaluation of simulation results. The methodology uses MATLAB&Simulink (The Mathworks, 2010) with the CARNOT Toolbox (Hafner et al, 1999).

IDENTIFICATION AND DEFINITION OF METHODOLOGY USER

Two groups of users are defined for the methodology development: Energy engineers in industry are the first group and will operate SPH-systems. It is necessary that companies develop their own knowledge of their energetic behaviour. This is essential for informing decisions about company strategy for planning future energy systems, and relates more to SME's than to large companies. Hence, they need usable methodologies that support their work. System designers from planning companies provide consultation to those in industry and are the second group. They should use knowledge about the companies and combine it with their own expertise to develop innovative solutions. Furthermore, system designers are independent from specific system technologies and are able to consult different manufacturing companies to gain objective benefits for the client. This expertise also includes design and implementation of energy systems using specific planning tools (e.g. simulation) and is defined as broad knowledge of various technologies. Therefore, both groups must use their individual knowledge in complementary fashion.

Energy engineers from the manufacturing companies are the other group of users and the most important regarding methodology application. The methodology supports their work as decision makers, or when preparing others to make decisions at companies. It must be assumed that the expertise of energy engineers differs from that of system designers. With the background from the definition and preparation of the case studies, a further distinction should be made between two categories of energy engineers.

The first category of energy engineers is specified as 'part time' energy engineers (PTEE). Characteristic of this group is that energy issues of the company are not their main area of responsibility. This limits his available time regarding energy matters and can lead to limited expert knowledge. Hence, this group of energy engineers require more support from external system designers.

The second category of company engineers is specified as 'full time' energy engineers (FTEE). Characteristic of this group is that energy issues of the company are their main area of responsibility. Such companies often maintain a department exclusively for energy issues of the company. The staff has detailed and comprehensive expert knowledge that is sometimes similar to that of external system designers

Table 2 summarises the most important aspects of the expert definitions for energy engineers and distinguishes system designer.

Case study

The focus of the case study is on verifying and evaluating application of the methodology. The choice of the two company categories of the defined food industry sector enables not only an evaluation of individual energy management within each, but also comparison. The two categories also reflect the defined user categories (company energy engineers). The case studies are the real world test bed for the application of the designed methodology. Therefore, the application follows the defined procedure (Figure) and is done in strong cooperation with the methodology developer and the energy engineers. The user feedback is a key element of application-related verification of the methodology.

One company category is a small and medium-sized brewery and represents the PTEE. The other company category is a large-sized dairy that represents the FTEE. The energy supply systems of the case study companies provide background for the methodology application. The available real world data are necessary for testing the methodology elements (Figure 4) energetic analysis, energetic optimisation, solar process heat system and simulation as well as all functions with the included tools. The user feedback is important for the evaluation of usability and flexibility of the methodology. Therefore, the methodology application is carried out in cooperation with the methodology developer and the energy engineer of the case study companies. This complete involvement of the energy engineers enables further a comparison of the available level of expertise of energy engineers with the necessary level of expertise that is starting point of the case study.

Table 2. Definitions of methodology users.

Expert	Works for	Description	Abbreviation
System designer	Planning and energy consulting companies	• Energy engineer for industrial energy supply and distribution systems • Independent from specific system technologies • High level of specific expert knowledge	SD
Energy engineer (full time)	Manufacturing companies	• Responsible for energy supply, energy distribution and production equipment • Main focus is on energy issues of the company • High level of industrial sector expertise	FTEE
Energy engieer (part time)	Manufacturing companies	• Responsible for energy related issues of the company among others (e.g. production planning, personal planning, maintenance activities) • Main focus is not on energy issues of the company • Low to high level of industrial sector expertise	PTEE

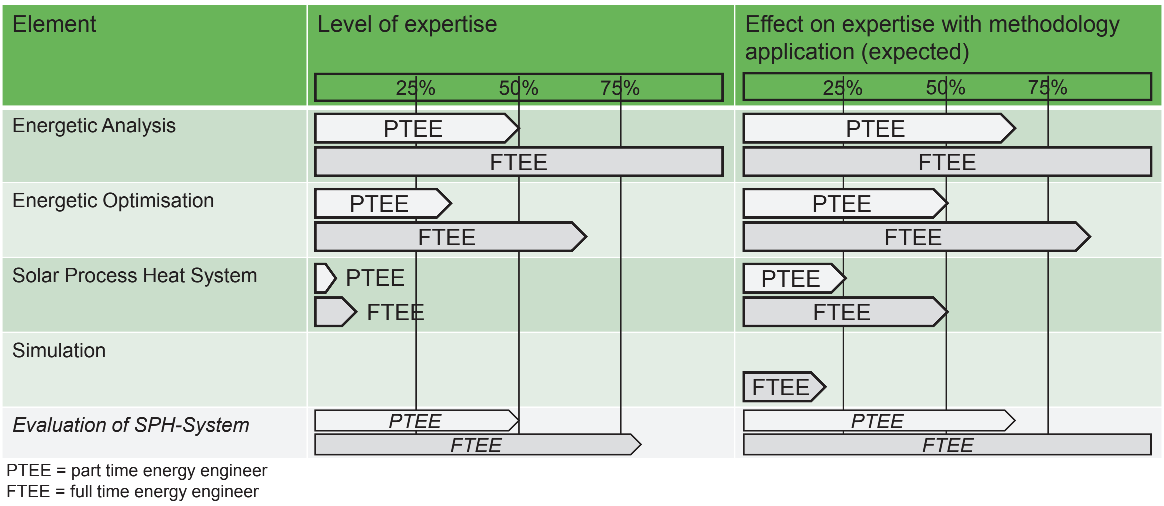

Figure 5. Expertise level and effect with methodology application.

EXPERTISE OF METHODOLOGY USER

The preparation of the case studies with the two companies and the energy engineers resulted, that energetic analysis and energetic optimisation are their responsibility and are part of their basic knowledge. This level of expertise (Table 2) is often focused on the energy requirements of their specific industrial sector. Hence, FTEE also require support from external system designers, but for a later element of the methodology. The energy engineers of the case study companies do not have expertise in solar process heat systems and simulation as this requires very specific knowledge, which is not part of their daily business. Support from external experts is a mandatory requirement.

The application of the methodology by energy engineers not only affects the energy efficiency of a manufacturing company and help to implement SPH-system technology, but can also increases the awareness of energy demand and company-specific energy behaviour. An important side effect, therefore, will be an enhancement of company expertise regarding energy issues. Figure 5 compares this with the level of expertise, and the expected effect on expertise, as the methodology is applied.

APPLICATION OF THE METHODOLOGY

Each element and function (Figure 4) of the methodology is individually applied by the energy engineer as much as possible with their own expertise. Assistance gives the methodology developer. This enables to compare the available expertise of the case study user with the necessary expertise to apply the methodology. That complements the user feedback and contributes to the methodology evaluation.

Figure 6 illustrates exemplary the definition of specific key figures from the methodology element energetic analysis. The necessary input of energy and production data but also the handling of specific key figures is part of the daily work of the energy engineers. Hence, can be done nearly complete by the energy engineer. Assistance is just necessary with preparation of data.

Another example illustrates Figure 7. This is a result of the methodology element energetic optimisation. Therefore, tools of the pinch analysis are used (Krummenacher, 2002). The pinch analysis is not part the expertise of the energy engineers. Hence, they can just assist the methodology developer. This means they provide the data input for the analysis and evaluate the results of the analysis.

This kind of methodology application results in a direct feedback from the energy engineers. The direct feedback can be documented and focus first on usability and flexibility of the methodology (described below). Further, an evaluation of available energy engineer expertise and its comparison with necessary expertise is possible.

Definition of essential functions

The application of the methodology with the case study shall on the one side identify the essential functions of the methodology for design and implementation of a process heating system. A function is essential for the methodology if the user needs detailed instructions for its application. In contrast, a function is important (more or less so) if the user has the necessary expertise for its application. This, however, does not mean that such a function can be left out, as it is still necessary for completeness of the methodology and to meet the objective of SPH-system integration.

Usability and flexibility for energy engineers

The development of the methodology aims to provide a platform with good usability and flexibility to support energy engineers in the design of cost-effective solar process heat systems:

- Usability in this case is defined as having functions that can be easily understood (good learnability) and used by energy engineers, with their available knowledge. Hence, use of the function can enhance company expertise.

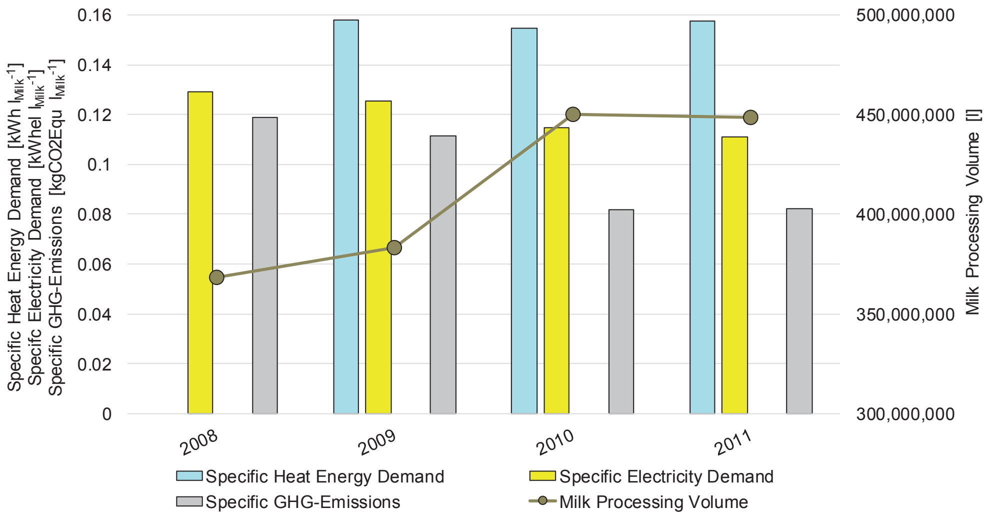

Figure 6. Specific key figures and production volume.

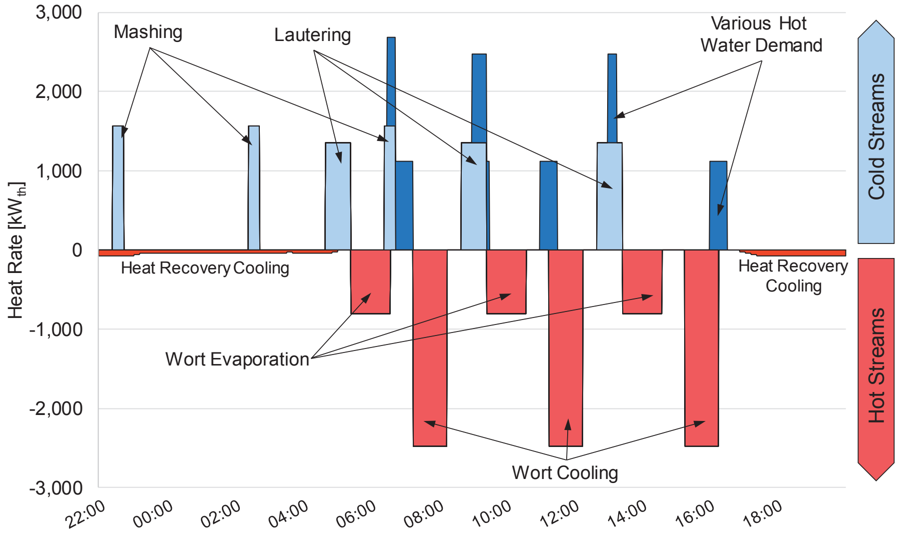

Figure 7. Time event chart of the low-grade heat supply.

- Flexibility means, on the one hand, that the functions can be adapted to various uses within the defined application area. On the other hand, it is advantageous if the methodological elements can be used independently from each other (for example, a company already works with an optimised LGH-network and can directly start with the solar process heat system element).

Assessment of functions

Both case studies conclude with a review of application of each element (as defined in Figure 4), and a related assessment of functions (as defined in Figure 4) and tools. The assessment first identifies functions and related tools, also describing necessary conditions and challenges of application (Table 3). It further describes the benefit to the company of using a particular tool (as mentioned exemplary above in chapter 'Structure of the methodology'. Also of importance is function assessment (last column). This describes, within a range from 0–100 %, whether the function and its tools are covered by company expertise (100 % means full) and therefore, whether or not these are essential for application of the methodology. If this is not essential, however, this does not mean that it can be omitted, because its inclusion remains necessary to ensure methodological completeness. The last row finally provides the element average for all functions (equal value for each).

Table 3 shows the exemplary assessment of the 'energetic analysis' element for the brewery. The tools used can be applied by the brewery PTEE to a large extent (Table 3). This is indicated by low percentages in the tool assessment column (Table 3), e.g. energy balance or energetic benchmark. Limitations include missing energy data and unavailability of software tools (e.g. for the Sankey diagram). The brewery benefits from complete and detailed energetic analysis. The PTEE will be calculating energy balances with reference to key figures and energetic benchmarks, extending his expertise. The 'energetic analysis' element had average function assessment of 38 %, requiring only slight support from design engineers.

This assessment is done for each element of the methodology within the two case studies. The following chapter describes the findings.

Case study summary

METHODOLOGY FUNCTIONS

Table 4 summarises the function assessment of the case studies and compares the brewery and the dairy results. A first result of the function assessment relates to differences between the two case study applications (green frame in Table 4), illustrating the influence of available background energy knowledge on methodological application. A broader and larger knowledge base leads to lower requirements for support from external experts (e.g., design engineers). The energy department of the dairy has more staff that is exclusively responsible for technical and energetic topics, providing an advantage over the brewery, where the PTEE is also (and primarily) responsible for production. This needs to be considered within the context of methodological application.

The main results relate to essential functions and are defined by two criteria. Therefore, observations by the methodology developer, feedback from the energy engineer and continuous discussions on the application of the methodology functions are background:

- The *function assessment* average is 45 % or higher.
- The case study *function assessment* is 65 % or higher.

The common methodology application with the resulting feedback from energy engineer and observations by the methodology developer is basis for the assessment values. This considers both the average of the case studies and individual methodology application within case study companies. For such a function, the applicant (company with its PTEE or FTEE staff) would therefore require instruction regarding the proposed methodology, as knowledge is insufficient.

Table 3. Assessment of energetic analysis with brewery PTEE.

Function	Tools	Condition(s)	Challenge(s)	Brewery benefit	Tool assessment	Function assessment
Energy Balance	Energy balance	---	---	• More detailed analysis than before • Graphical representation of energy figures	0%	3%
	Specific key figures	---	---	• More detailed analysis than before (over several years) • Analysis of final energy, heat energy, electricity and CO_2-emissions	0%	
	Energetic benchmark	Availability of current industrial sector data	---	• Energetic status of the brewery • Background for internal analysis	10%	
Energy Supply and Distribution	Energetic analysis of energy distribution networks	Continuous data, energy load profiles	Missing (EMS) data	• Analysis of heat energy distribution • Analysis of time related heat capacities	50%	35%
	Analysis of production sections	Production know-how in specific industry sector	Useful section division with energetic background	• Detailed allocation of energy consumption in production sections	20%	
Energy Consumer	Analysis of energy consumer	Continuous data, energy load profiles	Missing (EMS) data	• Time-related analysis with load profiles • Analysis of heat capacity peaks	70%	75%
	Sankey diagram	Expertise in Sankey analysis	Missing Software Tool	• Complete and detailed heat energy flow • Graphical representation	80%	
				Element Average of function assessment	38%	

Table 4. Comparison of function assessment with the case study results.

Element	Function	Function assessment Case Study brewery		Function assessment Case Study dairy		Function assessment Average		Function Proportion	
Energetic Analysis	Energy balance	3%	38%	3%	13%	3%	25%	1	0,21
	Energy Supply and Distribution	35%		13%		24%		4	
	Energy Consumer	75%		23%		49%		5	
Energetic Optimisation	Optimisation Potential	50%	68%	30%	40%	40%	54%	2	0,23
	Heat Recovery	65%		50%		58%		5	
	Concept Development	90%		40%		65%		4	
Solar Process Heat System	Application Potential	100%	89%	100%	83%	100%	86%	3	0,26
	System Configuration	88%		88%		88%		4	
	Heat Source Management	80%		60%		70%		5	
Simulation	Modelling	100%	76%	100%	70%	100%	73%	5	0,30
	Simulation of Variations	90%		70%		80%		3	
	Optimisation	100%		100%		100%		4	
	Evaluation	15%		10%		13%		2	
								47	1

Average functions (in Table 4) of element 'energetic analysis' are less important. Except for the energy consumer function within the brewery case study, this was the same for all functions. This confirms that there is comprehensive background energetic analysis for both case study companies; the required methodological knowledge is therefore available.

Energetic optimisation functions are also generally less important but have clearly higher assessment values. This illustrates lower company expertise in energetic optimisation in comparison to energetic analysis. Heat recovery and concept development are essential for the brewery. As a result, concept development is also essential for the average value of the function assessment. The results of the two case studies clearly differ. In these specific application cases, this is as a consequence of the different distribution of tasks among responsible staff.

Despite heat source management for the dairy case study and evaluation of both case studies, all element functions of 'solar process heat systems' and 'simulation' are considered to be essential. SPH-systems are a specific heat supply technology and are not common in either industrial sector. This results in low design expertise of responsible staff. Simulation is not exclusively useful for SPH-systems but is nevertheless not popular at either case study company. Simulation expertise is considered a service and is commissioned if necessary for decision-making. An exception is the economic efficiency study, based on a method that is standard in all companies and that only needs to be adapted to the specific case.

The case studies finally provide conclusions regarding different proportions of time and effort required for the functions. These aspects need to be evaluated with reference to function proportion. Background is the methodology application by the energy engineers in cooperation with the methodology developer. The methodology developer defines an evaluation value of 1–5 for each function. The sum of functions of one element divided by the sum of all functions gives the proportion for an element. This ultimately reflects the proportion for each element within the methodology (*Function Proportion* in Table 4). However, this does not determine whether a function is essential or not.

USABILITY

Table 5 gives the usability of methodology functions. The usability valuation is within a range of 1–5, where 5 is maximum usability and 1 is minimum usability. Background for the valuation is the common methodology application of energy engineers and the methodology developer. It represents the feedback of energy engineers and the level of application support by the methodology developer.

Energetic analysis and energetic optimisation requirements are in agreement, in many respects, with the working method of energy engineers and confirm high usability. Apart from pinch analysis (a complex tool with specific software requirements) for heat recovery, the application of the tools can enhance company expertise. For example, key figures from company internal analysis and industry-sector benchmarks, as well as Sankey diagrams, were transferred to companies' tool boxes. These tools have good learnability, in contrast to the pinch method. Consequently, companies are able to analyse their energy use in a more detailed and comprehensive manner, giving better background for decision-making regarding energy efficiency measures.

Another situation illustrates the usability of solar process heat systems and simulation elements. Design and integration of an SPH-system requires specific expertise but also has similarities with other process heat technologies. Prior knowledge of energy engineers hence leads to partly good usability (e.g., heat source management). However, system simulation has low usability, as this is not part of the standard requirements of energy engineers. Despite the fact that a company is not able to implement these elements on its own, system simulation and its results have high value for decision-making, as confirmed by energy engineers. Even participating in the process of system simulation and in analysis of simulation results can therefore contribute to enhancing company expertise.

Table 5. Function usability.

Element	Function	Usability
Energetic Analysis	Energy balance	5
	Energy Supply and Distribution	5
	Energy Consumer	4
Energetic Optimisation	Optimisation Potential	5
	Heat Recovery	4
	Concept Development	3
Solar Process Heat System	Application Potential	2
	System Configuration	3
	Heat Source Management	4
Simulation	Modelling	1
	Simulation of Variations	1
	Optimisation	2
	Evaluation	4

Methodology usability is hence high for energetic analysis and energetic optimisation, but decreases in the case of solar process heat systems and simulation.

FLEXIBILITY

The proposed methodology was applied at a brewery and dairy with comparable energy systems and with similar requirements for LGH-networks as a basis for SPH-systems. These conditions are transferable to other food industries and represent similar use cases. The application of the methodology to the two case studies therefore shows sufficient flexibility. Flexibility is additionally linked to independent use of the elements. Each element of the methodology therefore needs to be self-contained, requiring input (e.g., energy data) and providing a result (e.g., system concept for LGH-network).

The approach was to analyse application of each element independently. The application of the methodology to the two case studies confirms this element independence (Appendix B and Appendix C), as described in the following examples:

- Previous energetic analysis conducted by the dairy energy department makes it to possible to start directly with the energetic optimisation element.
- The 'energetic optimisation' element provides an optimised LGH-network concept that can be implemented independently from other elements.
- The 'simulation' element can be carried out on the basis of 'energetic analysis' and 'energetic optimisation', focusing only on heat recovery. The 'solar process heat system' element is therefore not necessary.

This independence applies, not only to complete elements, but also to single functions or tools, as described in the following examples:

- Specific key figures are very useful for energetic benchmarking and for internal analysis, as confirmed by energy engineers. These can be used completely independently of the methodology. Both companies use these as standard analysis tools.
- Heat source management was also developed for use independently of the methodology, as it aims to first provide a priority list of heat sources. The dairy, for example, is able to do this using available expertise relating to energetic analysis and optimisation.

The flexibility of the methodology was therefore confirmed.

Conclusions

The objective of this research was to develop a methodology that guides system designers and company energy engineers in the process of integrating solar thermal heating systems within process heat systems of food and drink companies. The usability by energy engineers was an essential goal. The case study application therefore commenced with a draft methodology and then involved the user in the process of developing a final methodological design. This enhanced usability.

The literature review analysed different methodologies for analysis, optimisation, and reconfiguration of heat supply with implementation of solar process heat systems. These include standards for energy audits, guidelines, and research into energy efficiency and solar process heat systems, as well as industry-specific concepts. This was input for the methodology design.

A specific background for the methodology development were SPH-guidelines as they focus on the use of solar process heat for industries. As analysed, these guides are incomplete and insufficient designed without user feedback. The developed methodology provides now a complete procedure for integration of solar process heat systems for industrial heat supply. The general approaches of increasing energy efficiency, saving energy, and reducing CO_2-emissions enable flexible application.

Case studies and the collection of user feedback improve usability of the methodology. This was demonstrated with the two case study companies and evaluated. This was an important element of its design, focusing on user feedback from energy engineers. The involvement of later users is novel in developing a methodology for SPH-system integration and was a neglected aspect in previous research.

The defined development procedure for the methodology – with a draft of the methodology structure, a comprehensive application with case studies and the integration of the intended user – turned out very purposeful. First the user feedback ensures the development of a methodology with high usability for a real world application.

Test bed for the methodology were the case study companies of the food industry sector. As the methodology focus not exclusively on specific food industry processes but on company energy supply systems (low-grade heat). It is intended to transfer the methodology application also to other industry sectors with a similar background of energy demand. However, this needs further investigations to verify the methodology application.

References

Baldwin, C. (2009) *Sustainability in the Food Industry*. 1st ed. Iowa: Willey-Blackwell and the Institute of food industry.

Baniassadi, A. and Momen, M. and Amidpour, M. (2015) A new method for optimization of Solar Heat Integration and solar fraction targeting in low temperature process industries. *Energy*, pp. 1674–1681.

Brush, A. and Masanet. E. and Worell E. (2011) Energy Efficiency Improvement and Cost Saving Opportunities for the Dairy Processing Industry, October 2011. Berkley: Ernest Orlando Lawrence Berkley National Laboratory.

Brunner, C. et al. (2010) EINSTEIN – Expert System for an Intelligent Supply of Thermal Energy in Industry – Audit Methodology and Software Tool. In: *Chemical Engineering Transactions, Volume 21, 2010.*

Brunner, C. (2013) Solar Process Heat – Best Practice Plants and Future Developments. In: *Solar Heating and Cooling Conference, Freiburg, September 2013.*

Brunner, C. et al. (2014) GREENFODS branch concept for enhancing energy efficiency in the food and drink industry [WWW] European Council for an energy efficient economy. Available from: http://www.eceee.org/ [Accessed 30/11/2015].

CIPEC (2012) Guide to Energy Efficiency Opportunities in the Canadian Brewing Industry. 2nd ed. Ottawa. Natural Resources Canada.

DIN EN 16247 (2012) Energy audits – Part 1: General requirements. Oktober 2012. Berlin: DIN Deutsches Institut für Normung e.V.

EEP (2015) Energieeffizienzindex [WWW] Universität Stuttgart – Institut für Energieeffizienz in der Produktion. Available from: http://www.eep.uni-stuttgart.de/eei/ [Accessed 20/07/2015].

EU (2012) Directive 2012/27/EU on energy efficiency [WWW] European Union law. Available from: http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1399375464230&uri=CELEX:32012L0027 [Accessed 10/07/2015].

Hafner, B. and Plettner, J. and Wemhöfer, C. (1999) CARNOT Blockset: Conventional And Renewable eNergy systems OpTimization Blockset – User's Guide, Solar-Institute Jülich, University of Applied Sciences Achen.

Hauff, M. (2014) *Nachhaltige Entwicklung*. 2nd ed. München: Oldenbourg Wissenschaftsverlag GmbH.

Krummenacher, P. (2002) *Contribution to the heat integration of batch processes (with or without heat storage)*. Published thesis (PhD), École Polytechnique Fédéral de Lausanne.

Lauterbach, C. and Schmitt, B. and Vajen, K. (2011) *Das Potential solarer Prozesswärme in Deutschland*. Kassel: Universität Kassel – Institut für Thermische Energietechnik.

Lauterbach, C. et al. (2011) *Solare Prozesswärme in Deutschland – Potential und Markterschließung*. 21. Symposium Thermische Solarenergie, Bad Staffelstein 2011.

Müller, H. and Brandmayr, S. and Zörner, W. (2013) Development of an evaluation methodology for the potential of solar-thermal energy use in the food industry. In: *Proceedings of the 2nd International Conference on Solar Heating and Cooling for Buildings and Industry. Freiburg, September 2013*. Amsterdam: Energy Procedia, Volume 48 pp. 1194–1201.

Muster-Slawitch, B. et al. (2011) The green brewery concept – Energy efficiency and the use of renewable energy sources in breweries. *Applied Thermal Engineering*, pp. 2123–2134.

PWC (2015) Energiewende im Mittelstand 2015 [WWW] pwc. Available from: http://www.pwc.de/de/mittelstand/wie-der-mittelstand-von-energieeffizienz-profitiert.jhtml [Accessed 11/08/2015].

Quijera, J. and Labidi, J. (2012) Pinch exergy based thermo-solar in dairy process. Applied Thermal Engineering, pp. 464–474.

Schmitt, B. and Lauterbach, C. and Vajen, K. (2012) *Leitfaden zur Nutzung solarer Prozesswärme in Brauereien*. Kassel: Universität Kassel.

SHIP (2016) Solar Thermal Plants Database [WWW] Solar Heat for Industrial Processes. Available from: http://ship-plants.info/solar-thermal-plants [Accessed 02/02/2016].

SEAI (2013) Energy Efficient Design Methodology – A design methodology to deliver the most energy-efficient plant and processes [WWW] Sustainable Energy Authority of Ireland. Available from: http://www.seai.ie/Your_Business/Public_Sector/Best_Practice/Energy_Efficient_Design/ [Accessed 01/11/2015].

SOLAR (2000) *Solarthermische Demonstrationsanlagen für öffentliche Gebäude mit Schwerpunkt in den neuen Bundesländern – 1993 bis 2002Solarthermie 2000*. [WWW] Solarthermie 2000. Available from: http://www.solarthermie2000.de/projekt2/projekt2.htm [Accessed 29/05/2016].

SOPRO (2012) *Solar Process Heat – SO-PRO*. [WWW] Solar Process Heat. Available from: http://www.solar-process-heat.eu/ [Accessed 09/18/2013].

The Mathworks (2010) *SIMULINK 7.5 – User's Guide*. [WWW] The MathWorks Inc. Available from: http://www.mathworks.de/de/help/simulink/index.html [Accessed 02/04/2012].

Thollander, P et al. (2014) International study on energy end-use data among industrial SMEs (small and medium-sized enterprises) and energy end-use efficiency improvement opportunities. Journal of Cleaner Production, pp 282–296.

Tu Wien (2013) *Solar Foods* [WWW] Technische Universität Wien. Available from: http://www.solarfoods.at/ [Accessed 08/09/2013].

Walmsley, T. et al. (2015) Integration options for solar thermal with low temperature industrial heat recovery loops. *Energy*, pp. 113–121.