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Energy Efficiency through optimized coordination of production and technical building services

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Abstract

Specifically for companies which involve high energy consuming production processes and need defined production environments as well as process-related auxiliary media optimizing energy efficiency gets more and more important nowadays. Thereby it is crucial to have a holistic view on the whole system including the strong interdependencies of production equipment and technical building services to derive global optima. Against this background this paper presents an integrated approach which basically enfolds the coupling of four different simulation tools for technical building services, building climate, production machines / material flow and production management. Thereby the approach supports the energy efficient design and management of production facilities and technical building services.

Keywords:

Life Cycle Engineering; Energy Efficiency; Simulation

1 INTRODUCTION

Increasing raw material prices, necessary investments for environmental technologies, potential penalties for lacking compliance with environmental regulations as well as certain regulative incentives, the introduction of CO_2 certificates or the rising public awareness on resource consumption and climate change potentially resulting in challenging consequences on the corporate image are just some examples that underline the increasingly important economic relevance of originally environmentally driven issues in production companies. Energy consumption is certainly a major aspect in this context whereas it incorporates strong effects on both economic as well as ecological dimensions.

In the case of Germany for example, the industry sector alone consumes over 28% of the primary energy [1]. Thereby, electricity with a share of about 30% is strongly used besides gas (37%), coal (17%) and oil (13%) in this sector [1] [2]. Focusing on electricity on a national level, this demand of industrial companies is even responsible for over 47% of the total country's consumption. Speaking from an ecological perspective, just the generation of this amount of electricity for industrial purposes through power plants sums up for about 18-20% of the total CO_2 emissions in Germany (additionally there are further 20% through direct CO_2 emissions of the industry sector) with certain consequences on global warming besides further environmental issues (e.g. radioactive waste, land utilization) [1] [2].

Figure 1 shows the development of energy prices in Germany and underlines the steadily increasing prices for electricity, gas and oil within the last couple of years and therefore the high economic relevance of energy consumption for companies. These tendencies can also be observed in other industrialized countries [1] [3]. In producing companies energy costs can sum up for a share of about 0.5-3% of the total turnover depending on the specific branch. In some branches like the food industry this share is in the range of the typical profit margin of the companies [4].

All these issues are specifically true for companies of branches which involve metallurgical processes (e.g. electroplating, casting) and industries which require defined production environments, process-related changes of temperature zones and diverse auxiliary media for producing (e.g. food, medical, electronic industry). Besides the direct energy consumption of production machines these companies have complex technical building services with certain energy demand to ensure these necessary production conditions. As a consequence of the resulting high energy consumption combined with rising energy costs these companies have a distinctive economic motivation to consciously consider energy issues within the classical production objectives (e.g. cost, quality, time) when planning and managing production facilities nowadays.

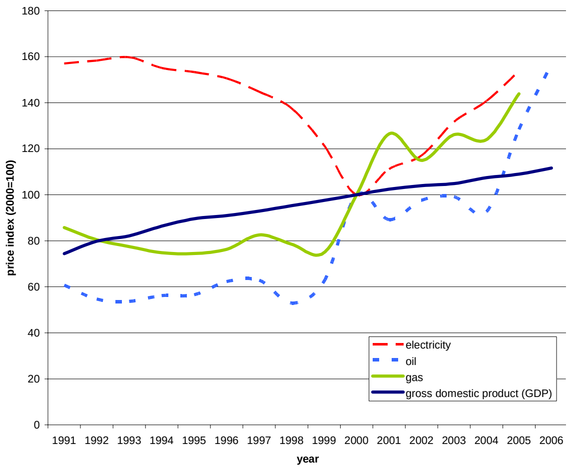

Figure 1: Progression of energy prices in Germany compared to gross domestic product [1] [3].

2 ENERGY EFFICIENCY IN THE INDUSTRIAL SECTOR

2.1 System Definition

Production systems with the addressed background enfold several partial systems like production (machines and personnel controlled through production management), technical building services and the building shell (Figure 2). This results in a complex control system with dynamic interdependencies between different internal and external influencing variables. As shown in Figure 2, one major task of technical building services is to ensure the needed production conditions in terms of temperature, moisture and purity through cooling / heating and conditioning of the air. The essential influencing variables are the local climate at the production site (seasonal influences) and the exhaust air and waste heat that is primarily emitted by production machines but also by other production factors like transportation equipment or even personnel. Besides that, production machines need energy (mostly electricity) and also diverse different media like compressed air, steam or cooling water to fulfill their designated processes. Technical building services are also responsible for the supply with these essential media whereas this involves their generation and (mostly) circuitry as well as the required conditioning (e.g. temperatures, pressures, purity).

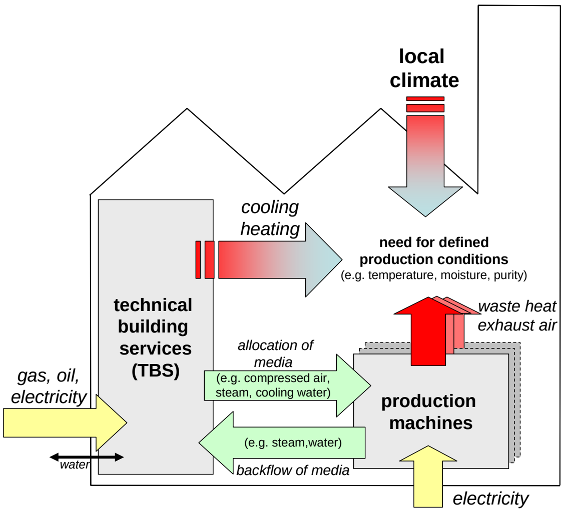

Figure 2: Interdependencies between production and technical building in defined production environments.

In order to provide these essential tasks, the technical building services naturally need additionally energy input through electricity, gas or oil. Referring to a study of the European Union, providing process and space heating, steam and compressed air for the production counts up for about 35-40% of the total industry's energy consumption which underlines the high relevance of these technologies [2] [4]. Whereas this is a branch-spanning average, the share is likely to be even significantly higher in many branches that involve certain critical production processes.

Referring to the production facility as the defined control system with its influencing factors and strong interdependencies, the main objective for companies from an economic as well ecological perspective is to maximize energy efficiency. This means optimizing the ratio of the production output (e.g. in terms of quantities with defined quality) to the energy input (electricity, gas, oil) for technical building services and production machines of the system whereas practically mostly minimizing the energy input is focused.

2.2 Approaches to foster energy efficiency in industry

Certain approaches to increase energy efficiency can be found in research and industrial practice while measures focus on both production factors and technical building services. From a production perspective the deeper energy analysis of the actual machines is an important topic. As diverse studies for different types of production machines show, their energy consumption in terms of electricity is normally not constant during the production process but rather highly dynamic depending on the actual state of the machine. The machines consist of several energy consuming components which generate a specific energy profile as an integrated system when producing (exemplarily shown in Figure 3) [5] [6] [7]. Generally, energy profiles can be subdivided into fixed and variable energy consumption. The fixed energy consumption includes the energy requirements of machine components like control units, pumps (e.g. oil pressure, coolant) or coolers which enable an operating state. The variable energy consumption of a production machine enfolds the required electrical energy for tool handling, positioning and the actual operation (e.g. cutting). Thereby, depending on the specific type and configuration of the machine and its utilization the fixed energy consumption, which is a not directly value-adding, can sum up for a major share on total energy consumption [5] [6]. The detailed analysis of the energy profile of machines allows the identification critical components and the derivation of strategies for the optimization of energy efficiency for single machines (e.g. usage of energy efficient electric motors in production equipment, changing process parameters) [6] [8].

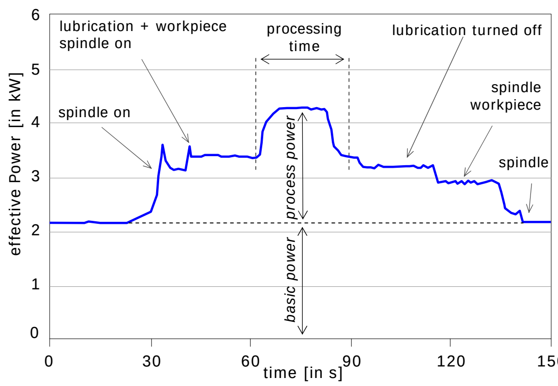

Figure 3: Energy Profile of a production machine (e.g. grinding process) [7]

A technical production system within a company involves several machines with certain energy profiles resulting in a cumulative load curve for the whole process chain within the plant. Sporadically companies try to use this load profile to identify major energy consumers and unfavorable interaction of processes to adapt their production program nowadays when realizing that besides energy consumption specifically surcharges because of high peak loads can make up a major share of up to 50% on energy costs depending on the contract with the energy supplier [4]. However, as shown above, realistically considering energy consumption (based on energy profiles) on a production system level (coupled production equipment) to avoid unnecessary energy consumption and high peak loads results in a dynamic and complex planning problem which can normally only be solved by using simulation techniques. Whereas in the industrial practice traditional considerations in terms of costs, throughput time, quality et cetera still dominate, first approaches which apply an integrated evaluation of production systems can be found in research. While including selected environmental variables (e.g. energy consumption, emissions) this enables the holistic evaluation of different production strategies (e.g. alternative processes or process sequences, modulation of machines, lean production methods) to foster energy efficiency on a production system level [9] [10] [11] [12].

As already stated above, in a producing company technical building services are responsible for essential tasks like heating and refrigeration (e.g. space and process heat), ventilation and air conditioning (e.g. exhaust air purification, air technology), power engineering (e.g. energy supply, lighting), fire protection systems or sanitarian accessories (e.g. waste water treatment) – naturally also including the whole control technology [13]. Therewith they provide the needed production environment and necessary process energy in different forms as well as process-related media like water. Technical building services sum up for a significant share on energy consumption in producing companies. Studies also underline the high potential for saving energy in that field [2] [4].

As basic principle to restrict energy consumption through technical building services it is important to avoid waste of energy or media which can be realised through organisational orders or technical measures (e.g. avoiding of unnecessary high temperatures in buildings or processes, avoiding idle equipment – shut down when not necessary). Besides that, important influencing factors are the actual technical configuration / design of the equipment (e.g. materials, usage of energy efficient components, detail design of tubes et cetera), an efficient process control (e.g. high utilization – avoid standby, continuous runs versus start-stop-operation, processes at favourable working point), choosing the right dimensioning of the equipment in terms of potential to necessary performance and the avoidance of losses through leakage or lacking insulation. Interacting with requirements of the production, higher energy efficiency can also be reached through choosing alternative processes which may require less or more favourable forms of energy (e.g. avoidance of compressed air – efficiency of electro mechanics 14 times higher [2]). Furthermore concepts like combined heat and power cycles (CHP), heat recovery within linked systems or the integration of regenerative energy sources are very relevant approaches nowadays to improve energy efficiency in producing companies [2] [4]. The configuration of technical building services especially in complex linked systems is naturally also a difficult planning problem and the derivation of cost- and energy-optimal solutions can be supported by simulation approaches. Whereas this is quite established and works well for the private sector and office buildings, the calculation of the optimal dimensioning for industrial plants of producing companies is significantly more difficult due to unclear internal loads and interdependencies [14] [15].

3 CASE STUDY – MEDICAL INDUSTRY

The following case study underlines the complexity and dynamics when producing within a defined production environment. The considered production system consists of several production lines which produce infusion solutions for different medical purposes in varying bottle sizes. The production process is essentially the same for all variants and can be abstracted to three basic steps:

- Manufacturing the bottles (injection moulding) and filling with prepared liquid. Due to the high hygienic requirements the whole process has necessarily to take place in a clean room environment. As process input electricity, compressed air, cooling water, steam and WFI (water for injection) are needed.
- To avoid any potential infections all bottles have to be sterilized. This takes a defined time in a sterilizer under usage of hot steam and water. Afterwards the bottles are getting dried in order to enable the next production steps. Process inputs are electricity, cooling water, ´regular´ steam as well as specifically pure steam and, again, WFI.
- After detailed and extensive checking processes to ensure product quality the bottles are getting labelled and packed in cardboards and on pallets. Typically for this kind of machines electricity and compressed air are needed for operating.

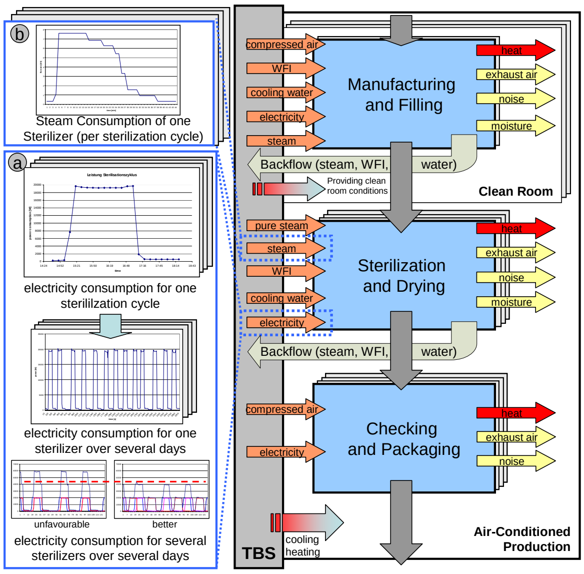

Figure 4: Case study - energy and media consumption in medical industry.

While these process steps are quite simplified each single phase involves several complex production machines of diverse types in reality. The production lines are fully automated and naturally also include diverse transportation and handling equipment (e.g. conveyors, industrial robots). Each machine (process, transportation, handling) requires energy and / or different media and emits heat, exhaust air and noise in the production building. However, the whole production takes place in an air-conditioned environment; manufacturing and filling even needs a clean room environment. The whole system is depicted in Figure 4 whereas it is important to point out again that in reality several of these process steps take place in the same building (indicated by the shaded process boxes). Additionally the figure only concentrates on the value-adding processes whereas the input and output relations of transportation / handling equipment is not shown.

The technical building services need to ensure the production environment within the building and the supply of all production machines with energy and media. It is very obvious that this system is by far more complex and dynamic as the idealized basic system depiction in Figure 2. Specific energy profiles (regarding electricity) of all involved equipment for production respectively transportation directly lead to a distinctive load curve. An example for that is the energy consumption of the sterilizer during a sterilization cycle and over the day (Figure 4a). Whereas several sterilizers are involved simultaneously uncontrolled operation of these machines can lead to high energy peak loads which increase the energy costs and could also cause technical problems in the energy supply system (e.g. failures).

Additionally the need of other forms of energy or media and also the emission of heat, exhaust air et cetera also underlies variation depending on the state of the process respectively machine. Coming back to the example of the sterilizer, Figure 4b shows the demand on steam of one cycle. Again, several sterilizers with certain dynamic demand on steam lead to a fluctuating total demand over the day which has to be covered by the technical building system. While this is just one example, in a production system with diverse energy consumers respectively sources for emissions there are also interdependencies and interactions which result in complex and dynamic requirements on the technical building services. Therefore, an energy efficient dimensioning and operation of the system is almost impossible with conventional methods under these circumstances. Besides the unnecessary waste of energy and low energy efficiency, the uncontrolled fluctuating demand may again lead to further peak loads whereas the technical building service itself is a significant energy consumer.

4 PROBLEM DEFINITION

As the previous discussion clearly points out, an isolated consideration of production equipment (single machines, production system) and technical building services within a production building is certainly a necessary but not sufficient approach to foster energy efficiency in producing companies. Distinctive profiles (depending on the operating state) regarding energy and media demand as well as emissions and complex interactions within coupled systems crucially have to be considered – therefore, an integrated, holistic perspective to achieve global optima is needed. As a result, on a system level the problem is highly dynamic depending on the actual operation state of all involved technical equipment and can not be solved with static approaches.

Prior research work as well as industrial practice lacks this holistic perspective. These approaches mostly only focus on parts of the problem or assume insufficiently realistic consumption and emission behavior. Related to energy consumption an optimal dimensioning of technical building services and conscious management of production is not possible nowadays due to undefined impacts and interdependencies of internal and external influences (e.g. production machines, weather, cooling systems). Results are a wrong dimensioning and hindered control of technical building services which incorporates unnecessary investment and inefficient operation modes. This causes wasted energy through higher energy consumption with both economic and environmental impact as well as potentially suboptimal production conditions with certain consequences for the product quality.

5 SOLUTION APPROACH

Derived from the requirements discussed above essential opportunities to foster energy efficiency on a system level are lying in the integrated consideration of production factors and technical building services resulting in:

- an optimized dimensioning and efficient process control of technical building services with respect to dynamic influences from production
- an energy efficient product management which includes restrictions and opportunities given by technical building services. This involves the planning of the production program (e.g. avoidance of unfavourable interaction of critical production processes), the actual control of production and processes (e.g. lot sizes, cycle times), plant / layout planning (e.g. optimize material flow, avoidance of unfavourable spatial interdependencies) and certain production strategies (e.g. maintenance strategies, lean production principles and methods)

To cope with the dynamics and complexity, simulation techniques have to be applied while static approaches are not able to provide sufficiently realistic results in this case. Therefore, a holistic simulation approach is introduced here which integrates and dynamically couples different simulation tools for all relevant layers of the problem through certain interfaces (Figure 5):

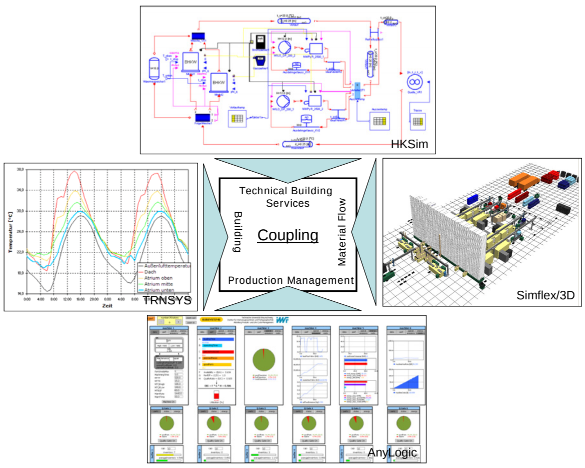

Figure 5: Coupling of simulation approaches.

- **Technical Building Services**: the simulation tool HKSim was invented by the company Imtech Deutschland GmbH & Co KG. It allows simulating dynamically the generation, circuitry and consumption of energy and media within technical building services. Thereby HKSim supports the design and control of these complex systems [14] [15].
- **Building (climate)**: naturally the (plant) building itself is the place were technical building services (e.g. air conditioning) and production (e.g. waste heat, exhaust air) interact which is specifically important when a defined

production environment is crucial. To simulate the thermal processes TRNSYS as established tool in this field is used.

- **Production Machines / Material Flow**: the actual material flow within the production system can be simulated with SIMFLEX/3D which was developed by the University of Kassel. It allows analysing the physical consequences of layout planning, detail design of production equipment (machines, transportation et cetera) or measures within the production management [8] [9].
- **Production Management**: the software AnyLogic from XJTek as multi-paradigm simulation platform allows hybrid simulation with both discrete and continuous modelling. Whereas this is specifically useful for the considered case (e.g. production of discrete objects combined with continuous variables like emissions, energy consumption, process related liquids), AnyLogic is used to simulate the influence and interdependencies of production management measures (e.g. production program, production control, production strategies) within the process chain. Furthermore it can serve as control entity for the integrated simulation approach and also allows optimization experiments to derive optimal solutions [10].

The simulation tools themselves are not new; they are all established solutions within their specific fields of application. The most important aspect is the shift away from an isolated usage to an integrated approach through coupling them. This allows a realistic and holistic modelling of the whole system of production and technical building services. Under consideration of all relevant interdependencies and dynamics of the system, different scenarios can be analyzed and evaluated with both economic and ecological criteria. As a result, this enables the derivation of optimal solutions from a global perspective.

6 SUMMARY AND OUTLOOK

The paper shows the necessity for an integrated consideration of production factors and technical building services to foster energy efficiency in producing companies. This is specifically important for companies which involve defined production environments, changing temperature zones, fluctuating energy demands and the supply with diverse kinds of media as it can be found in the food, medical or electronic industry. However, focusing on energy consumption an optimal design and managing of technical building services and production equipment is not possible nowadays while impacts and interdependencies of internal and external influencing factors (e.g. production machines, weather, cooling systems) are hardly to define. Results are unnecessary investment and energy consumption with both economic and environmental impact as well as potentially suboptimal production conditions.

Against this background this paper provides an approach which enables to consider these influences and interdependencies when designing and managing production facilities and the technical building services. Whereas isolated approaches are not sufficient here, it involves an integrated perspective including the coupling of four different simulation tools for technical building services, building climate, production machines / material flow and production management. Combined with an economic and ecological evaluation the proposed approach allows to consider different scenarios and the derivation of measures for optimization from a global perspective in different fields of application with specific regard to increase energy efficiency in production companies.

The presented methodology is applied and tested in concrete industrial cases in the first step where identified measures for optimizing energy efficiency are also going to be implemented. This allows the validation / verification of the approach. Furthermore, general principles and recommendations can be derived which can directly support other companies as well. The long term objective is to provide an integrated and verified tool based methodology that can be relatively easy applied in companies of different branches to enable improving energy efficiency on a broader base.

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