ENERGY SAVING POTENTIAL IN UNIVERSITY BUILDINGS - "LOW HANGING FRUIT"

Benedikt Biechele, Philipp Emmerich, Klaus Vajen

Kassel University, Institute of Thermal Engineering, Kassel (Germany)

1. Introduction

University buildings are responsible for approximately 50% of the energy consumption and an even higher share of the CO_2-emissions of the federal state's properties in Germany. University buildings should be dealt with special attention due to their exemplary role in the implementation of national and international climate protection goals. Furthermore, steadily increasing energy consumption and energy prices lead to a continuously growing burden on university budgets. The energy costs of German universities altogether amount to about 1 billion Euro per year (Statistisches Bundesamt, 2010). However, because of their particular features and utilization as well as the existing organizational structures, there are hardly any approaches for universal solutions for reducing energy consumption and thus CO_2-emissions in university buildings so far.

2. Building stock and energy consumption of universities in Germany

The following evaluation is based on an extensive inventory of energy and building data of German universities. The most important characteristics of the sample are: Building category, net floor area (NFA), electricity and heat consumption. The sample contains the buildings of those universities, with only few incomplete and inadequate data. If two or more buildings with different use have only one common electricity or heat meter, then it's not possible to generate use-specific ratios. Therefore, such data are considered as inadequate. Buildings of university hospitals are also not included as they show completely different usage profiles and equipment. However, Institute Buildings for medical research and teaching are included. The sample consists of 37 universities in four German states with a total of 855 buildings. The universities are divided into:

- 18 "Universitäten": classical universities with scientific orientation and the right to award doctorates. In the following this group is abbreviated as "UNI".
- 19 "Fachhochschulen": universities of applied sciences with a more practical orientation. In the following this group is abbreviated as "FH".

UNI and FH are the most important types of universities in Germany concerning the number of students – more than 95% of all students are enrolled there (Statistisches Bundesamt, 2009). For reasons of data availability, the reference year 2008 (respectively the winter term 2008/2009) was chosen. Figure 1 shows the distribution of all students in Germany by subject of study, as well as the same distribution in the investigated sample. The comparatively small differences are negligible for the energetic considerations in this study because there may be much larger differences in terms of energy use between same disciplines at several universities. Intensity of research, financial strength (third-party funds), content orientation, etc. of the same fields of study significantly varies from one institution to another. At the same time, these are important influencing factors on universities energy consumption.

The sample does not contain special types of universities such as theological or educational colleges. Beyond that, the relation between number of students at UNI and FH in the sample does not meet the corresponding relation in the basic population. Although this is not relevant for the investigation, the sample therefore can't be considered as fully representative.

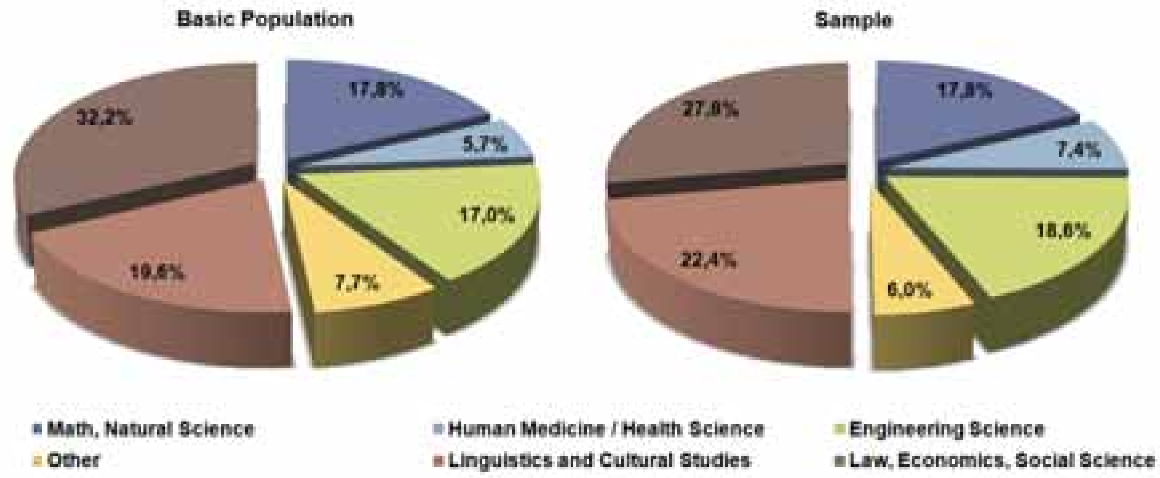

Figure 1: Distribution of all students in Germany by subject of study (left), as well as in the investigated sample (right)

2.1. Total energy consumption and energy costs

Revenues and expenditures of German universities are collected as a part of university finance statistics (as a full survey), based on the respective university's internal administrative data (Statistisches Bundesamt, 2005). This also includes energy costs, which were provided upon request at the Federal Statistical Office. In 2008 they amounted to over 1 billion Euro in total. More than half of the energy costs are caused by state-owned UNI – if university hospitals are comprised, nearly 90% of total costs are allocated to university research and teaching. State-owned FH energy costs amount with 77 Million Euro to ca. 7%, the rest is caused by private, art, administrative and educational colleges as well as universities of the German armed forces (Reference: Statistisches Bundesamt, 2010), see figure 2.

No statistical survey or science-based information exists regarding the total energy consumption of universities. Therefore this consumption is initially estimated based on the sample. Although not all influencing factors on university's energy use are known at this stage, a linear relationship between number of students and energy consumption can be assumed in a first approach, as the composition of disciplines are similar in sample and basic population.

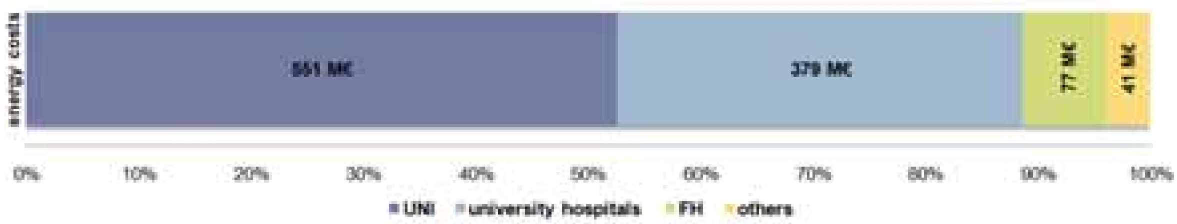

Figure 2: Energy costs by university type in 2008

In order to value the total electricity and heat consumption of UNI and FH in Germany, the sum of each university type is extrapolated according to the share of total students in Germany, see table 1. To verify the estimated energy consumptions on the basis of the energy costs, appropriate energy prices have to be assumed.

The average revenue per kilowatt hour of electricity or gas supply companies, which can be recalled from the database of Federal Statistical Office by year and customer group, provide a good indication. It shows an average electricity price of 138 €/MWh and an average heat or gas price of 57 €/MWh (Reference: Statistisches Bundesamt, 2011). This approximately conforms to energy prices determined in 2008 from own evaluations at some selected universities. Since the calculated energy costs differ only slightly from the official statistics, the magnitude of the projected energy consumptions seems to be plausible.

Table 1: Extrapolation of the energy consumption of German universities in 2008

University type	Sample			Extrapolation		
	Energy consumption [GWh]		Share of students	Energy consumption [GWh]		Costs [M€]
	Electricity	Heat		Electricity	Heat	
UNI	538	933	23.15%	2322	4032	550
FH	45	86	14.42%	312	596	77

2.2. Surfaces and energy consumption

Buildings constructed and used by public authorities are normally categorized by "Bauwerkszuordnungskatalog" (abbr: BWZK), a structural classification catalog. In this paper English equivalents are used for the original German building type names. BWZK is developed by the working group of ministers and senators of the federal states, responsible for urban planning, construction and housing ARGEBAU (BMVBS, 2009). Depending on their use, buildings receive a four-digit code which can be assigned to a defined type of building in turn. This allows the declaration of reference values for manufacturing costs or specific energy consumptions as it's required for energy certification for example.

University buildings of the sample are also categorized by BWZK which allows a more detailed analysis of use-specific area and energy distribution. UNI and FH have in common the dominant share in area and energy consumption of buildings for academic teaching and research (Institute and Lecture Room Buildings). In UNI this energy share accounts for 84%, at FH even 94%. Depending on the located discipline they can be divided into five categories:

- Institute Building I: Linguistics, Law, Economics, Cultural Studies, Social Sciences
- Institute Building II: Agronomy, Forestry, Geology, Civil Engineering
- Institute Building III: Engineering Sciences, Physics
- Institute Building IV: Medicine
- Institute Building V: Biology, Chemistry, Pharmacy

Across all UNI in the sample most energy is consumed by Institute buildings V (about 30%), representing only about 18% of the NFA. They are followed by Institute buildings III with a space and energy share of 16%. Institute buildings I energetically arrange only at third position (14%) while representing space-specific the biggest type. Outside the building for scientific research and education particularly library and normal administrative buildings can be mentioned. All other categories are summed up by the term "Others" due to their small size and energy consumption.

Compared to UNI, especially the great share of Lecture Room Buildings is noticed (35% area, 30% energy consumption) in FH. It's followed by Institute buildings III (14% area, 22% energy consumption) and Institute building I (22% area, 17% energy consumption) like in UNI. By contrast there are hardly any Institute buildings V, see figure 3.

In terms of specific energy consumptions there are big differences between both university types as well as between different building types. Institute and Lecture room buildings of UNI have throughout higher specific energy consumptions - particularly higher electricity consumptions - than FH buildings whereas the differences greatly vary depending on the building type. Especially buildings housing energy-intensive disciplines such as natural and engineering sciences (Institute Buildings II, III, V, Institute for Research and Analysis) are clearly much more electricity consuming at UNI than at FH.

To a large extent this can certainly led back on significantly higher intensity of research at UNI plus accordingly much more complex HVAC equipment. FH professors have a teaching load of 18 semester hours and a longer lecture period within the semester. University professors spend 60% of their time on research and have relatively low teaching load (BMBF, 2004). Less energy-intensive buildings, for example

Lecture Room and Institute Buildings I[1], shows relatively slight discrepancies, see figure 4. In these buildings energy is basically used for fulfilling comfort requirements which are in principle the same at UNI and FH. This confirms the assumption that HVAC cause over-consumption in high-tech Institute Buildings.

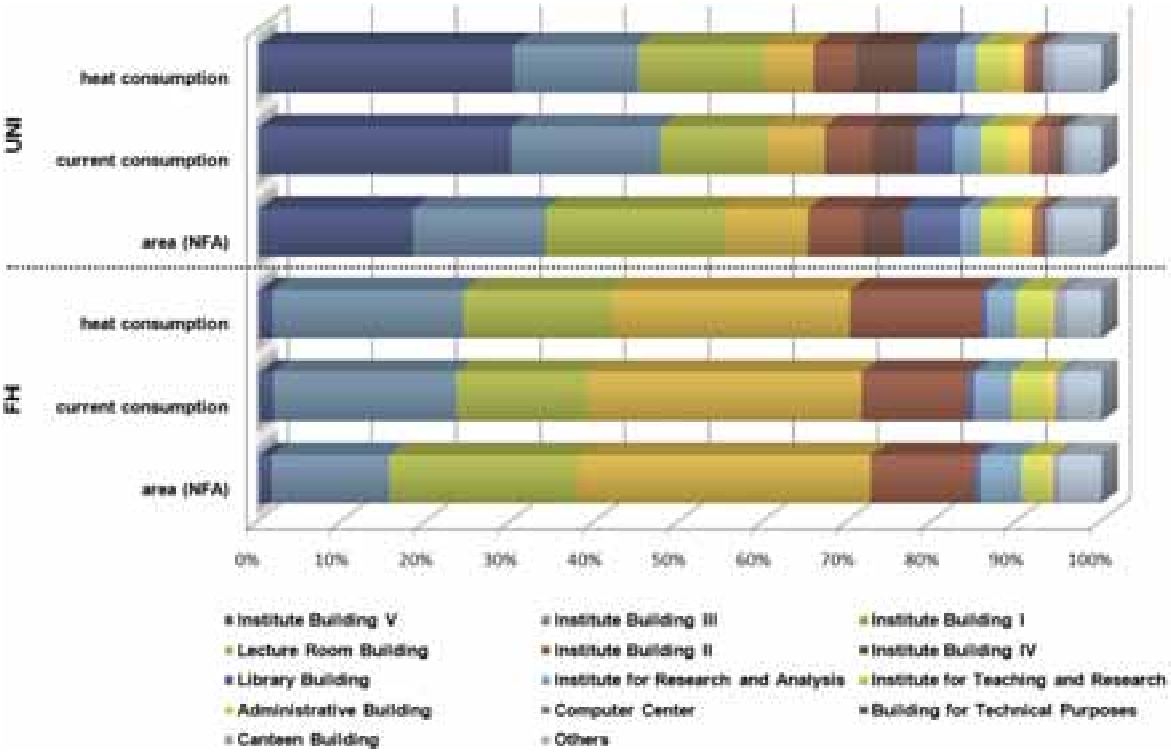

Figure 3: Energy consumption and area by BWZK

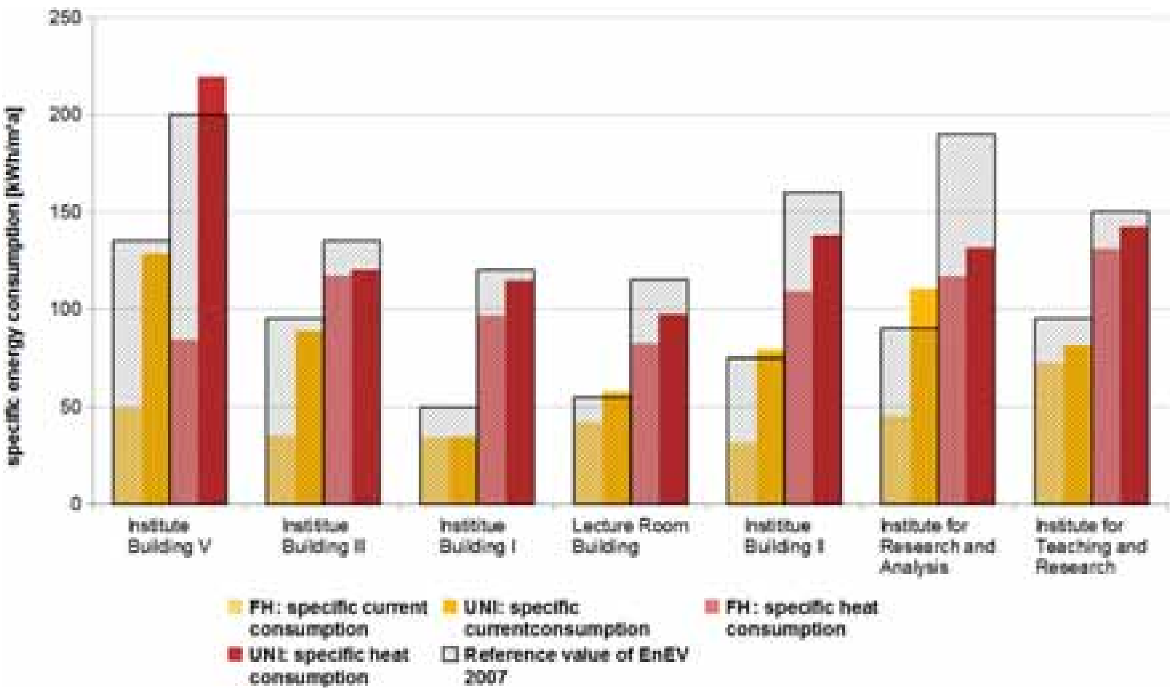

Figure 4: Specific energy consumptions of UNI and FH buildings with reference values from EnEV 2007

[1] Median values; For Institute Buildings I the reference value for buildings >3.500m² was used because the majority of this buildings falls into that category.

The predominantly small differences in specific heat consumption (excluding Institute Building V) are explained by the much older historically grown UNI building stock. This results in a wide variety of building structures and ages. While half of all today's state UNI in Germany were founded until the beginning of the 20th century, state FH were founded mainly in the early 1970s and 1990s (also BMBF 2004). Although the direct inference from building age to energy consumption is not possible, the increase of energetic quality of buildings in relation to the respectively valid statutory provisions can be identified (Bauministerkonferenz, 2009).

Along with the first Heat Insulation Ordinance ("Wärmeschutzversordnung") in 1977, energetic demands were placed on new buildings for the first time. Until that point nearly 60% of today's FH but nearly 90% of today's UNI had been founded, see figure 5. Although the foundation of a university isn't necessarily associated with construction of new buildings UNI buildings tend to be worse in relation to the energetic quality. It can be assumed, that the respective differences compared to FH buildings were only fractionally adjusted through remediation measures. This means lower thermal insulation and thus higher heat consumptions.

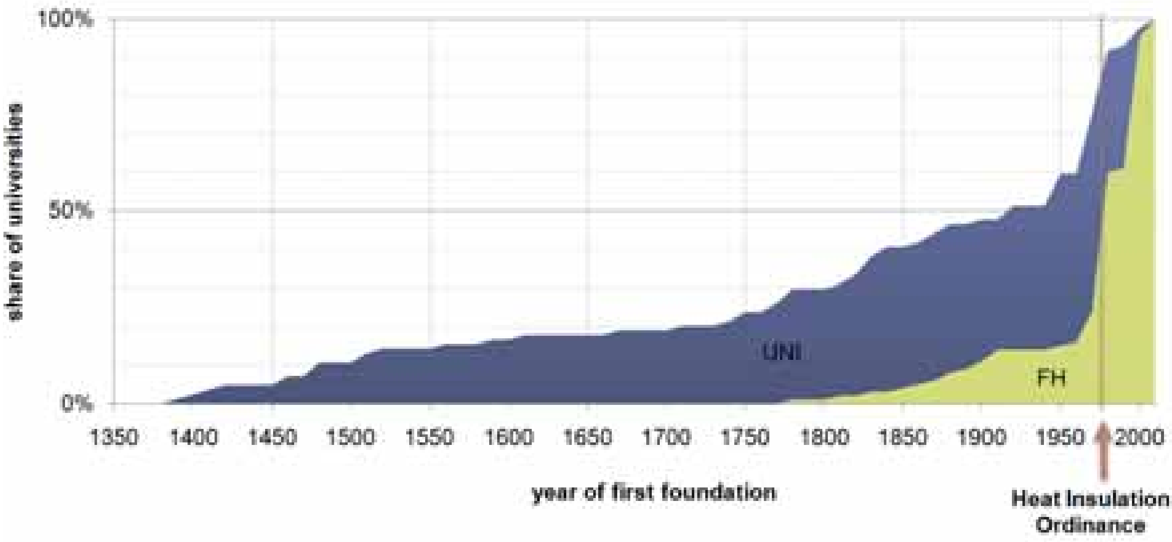

Figure 5: Development of state universities in Germany over the years[1]

Furthermore, apparently the median values of specific consumptions of nearly all considered UNI and FH buildings are below the reference values from the Energy Saving Regulations ("Energieeinsparverordnung 2007", abbr. "EnEV") [2]. However, this must not leave the impression that these buildings are unremarkable in energetic regard. As the following analysis will show there are some huge differences between buildings of same categories.

[1] Figure 5 considers also the predecessor of FH whose foundation (in the present form) was decided at the end of October 1968. About one-third of FH have their origin in institutions ("Höhere Technische Lehranstalten", "Höhere Fachschulen", "Ingenieur-, Wirtschafts- und Sozialakademien") which were founded before 1969 (BMBF, 2004).

[2] Since there are obviously differences in usage-based building energy consumption in FH buildings, the reference values for UNI buildings are used instead of using the one uniform reference value for FH buildings of EnEV 2007.

2.3. Energetic characteristics of UNI buildings

To take account of the identified differences between UNI and FH in section 2.2 in the following only UNI buildings are reviewed in a detailed way. This is also reasonable since UNI have seven times higher energy consumptions and costs. However, the results should basically be transferable to FH.

If the total energy consumptions of UNI buildings in the sample are compared with theoretical consumptions, calculated by using the reference values from EnEV 2007, a completely other impression is given compared to figure 4: Most building types are consuming considerably more energy in sum than their calculated equivalents – particularly Institute Building III and V, see figure 6. According to EnEV 2007, the over-consumption of both building types alone accounts for 14% of total heat and 10% of total electricity consumption of the sample.

In total, all buildings even consume 26% more heat and 29% more electricity as they may use in this regard. Although these figures can't easily be defined as potential, they are in range of frequently cited figures of saving potentials by optimizing operations.

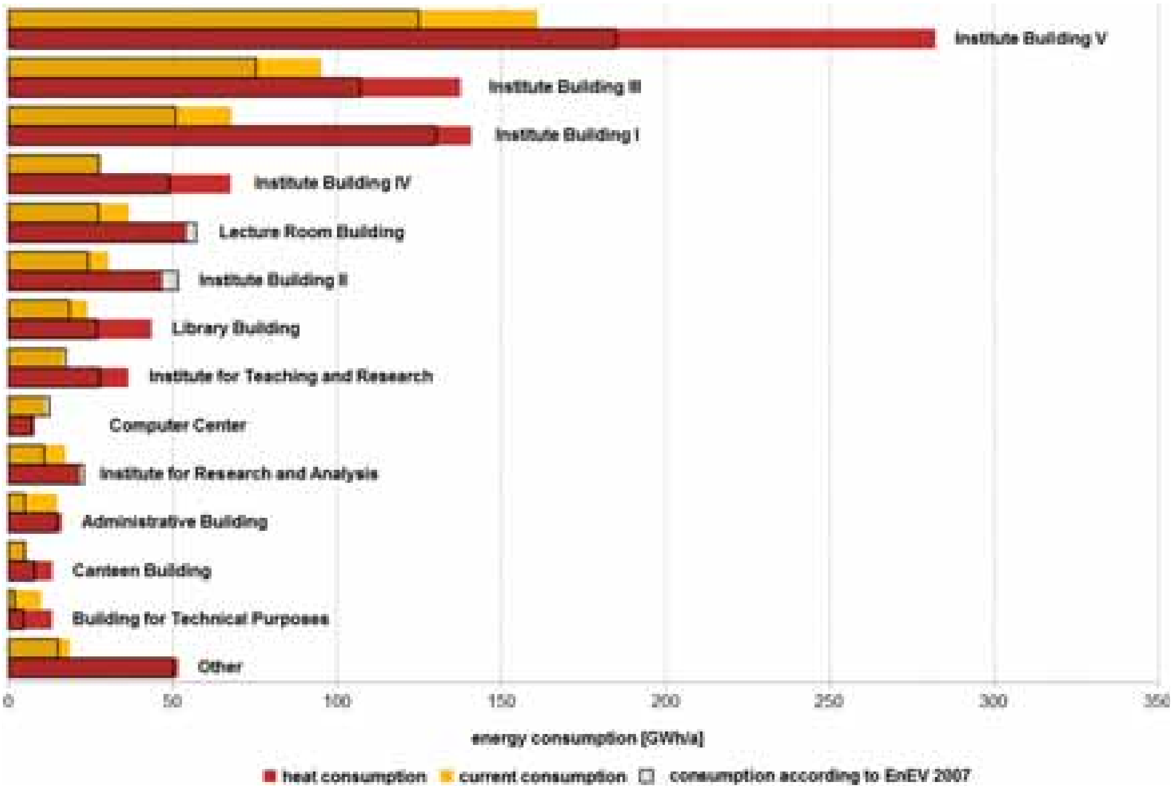

Figure 6: Energy consumption with reference value of EnEV 2007 by building category

A closer look at the statistical distribution of specific energy consumptions reveals big differences between buildings of same categories. As figure 7 and 8 show, half of the buildings (0.75-0.25 quantile) in most categories scatter in the range of 100 kWh/m²a. However, especially energy-intensive Institute Buildings feature a big range of specific current and heat consumption.

Mainly the upper quartile (1-0.75 quantile) has a much bigger statistical spread than the lower quartile (0.25 quantile). Hence there are many buildings with roughly similar consumptions, whereupon one fourth shows multiple higher consumptions. Despite the classification by BWZK, the real usage within the building can vary greatly. For example a physical Institute Building can be used mainly for lectures – not an energy extensive use. In contrast it can also be used as pure laboratory with high-energy experiments.

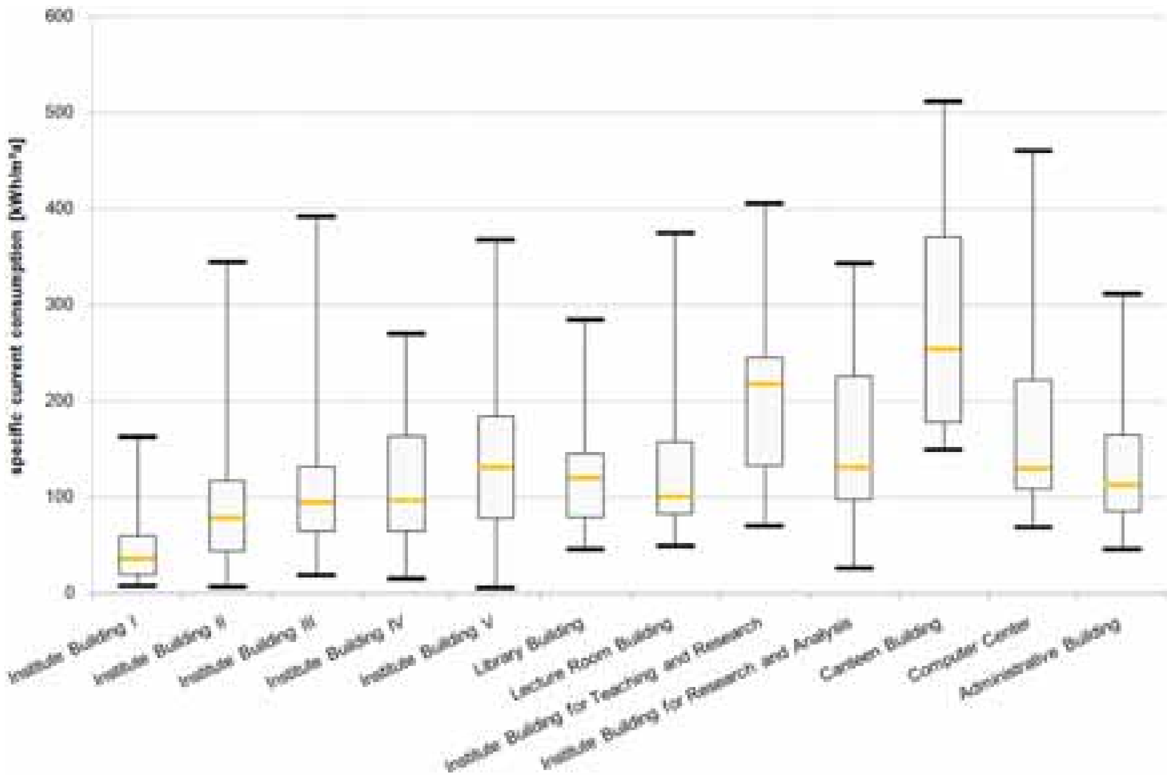

Figure 7: Specific current consumption of most important UNI buildings within the sample[1]

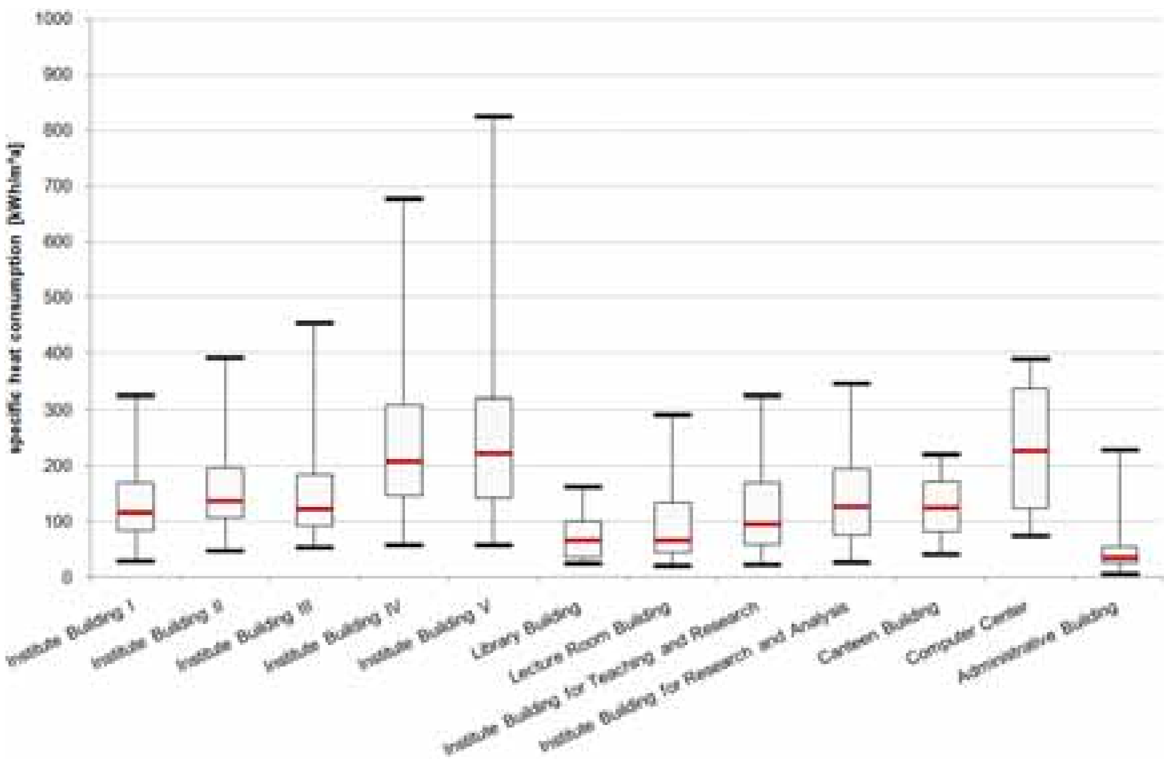

Figure 8: Specific heat consumption of most important UNI buildings within the sample[1]

[1] Both figures don't include outliers.

Such buildings can be found in nearly every university. Together they generally account the lion's share of consumption - in the UNI sample, 10% of universities' buildings are responsible for about 50% of total energy consumption in average. The average share of high-tech buildings (Institute Buildings III, IV, IV, Institute for Research and Analysis, Institute for Teaching and Research) in this group is much higher than the respective share in total, see figure 9.

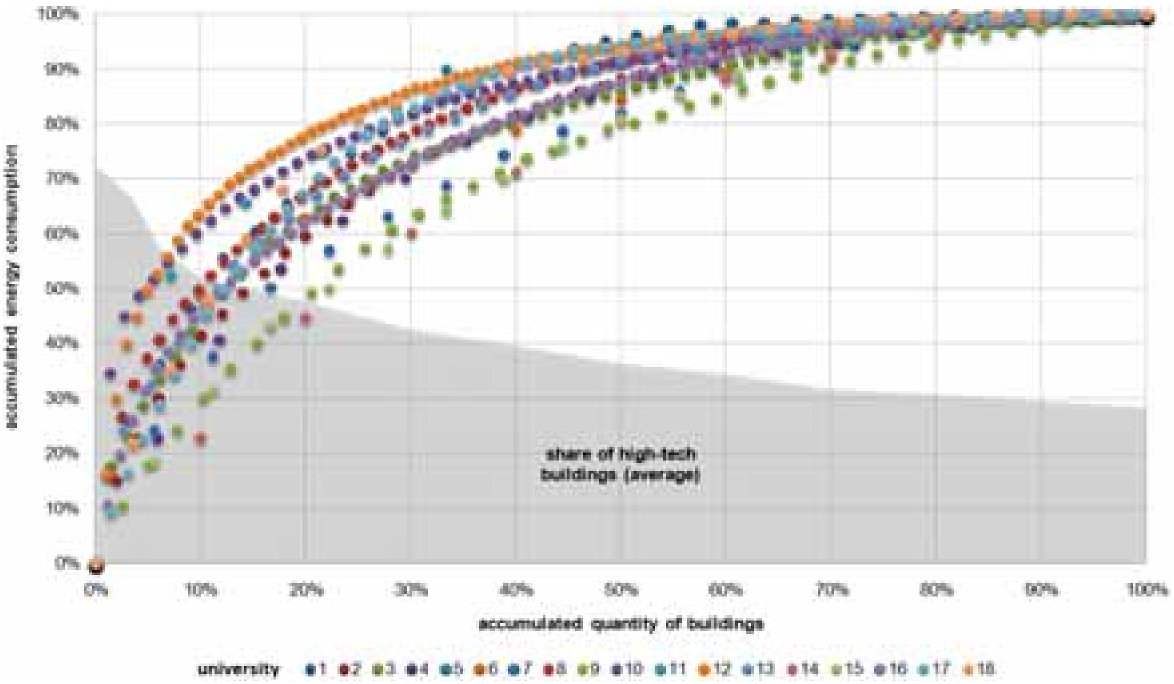

Figure 9: Relation of building quantity and energy consumption in universities

2.4. Energy management in universities

Technical departments of universities normally maintain central building control systems to guide the technical buildings equipment. Their overall aim is to ensure function and availability of central building services (HVAC). These structures are usually not suitable for an effective energy management in their current form.

The sheer number of managed buildings and equipments, lacks of financial and personnel resources as well as conversion of buildings leads to faulty HVAC operating states in time. They particularly occur through intermittent increased requirements by building users, and thus increased equipment operation that isn't canceled after the requirements decrease to their original level.

While insufficient HVAC operation (for example lacking ventilation of a lecture room) is noticed negatively and reported to the central building control system, a contrary situation (for example over night lecture room ventilation) can't be sensed per se. In these cases missing feedback ("open loop circuit") leads to steady over-operation of HVAC and thus inflated energy consumptions. Error detection in such situations exacts continuous comparison between user requirements and HVAC operations – ideally within an independent energy management, see figure 10. Therefore ad hoc personnel positions should be created.

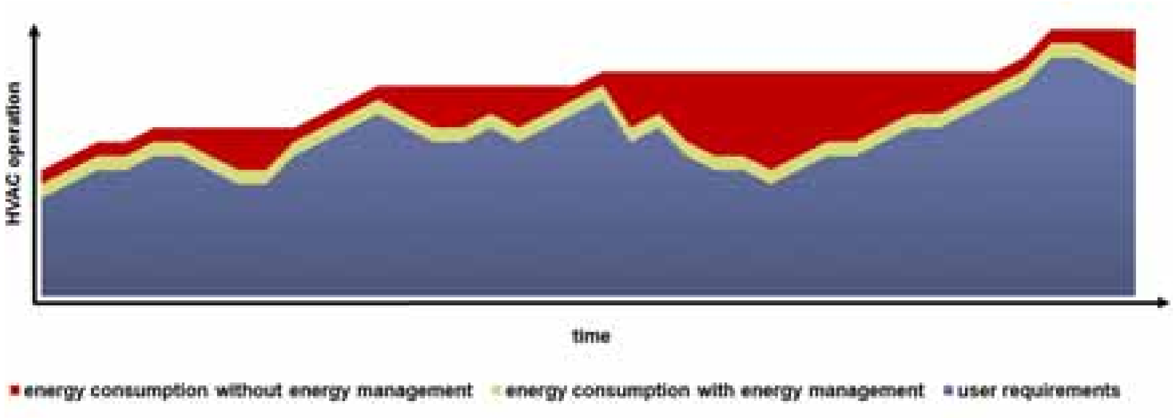

Figure 10: Influence of systematic energy management on energy consumption at universities over the years (schematical)

3. Case studies at Kassel University

The organizational conditions at universities result in several classic non- and low-investive energy saving measures. Basically they tend to improve unnecessary HVAC operation as well as excessive HVAC operation. The following case studies refer to two big Institute Buildings for engineering sciences with mixed use (laboratory, office, lecture room). They are among the biggest energy consumers and had been noticed already during previous investigations because of their high specific energy consumptions and base loads.

3.1. Ventilation operation

Energy consumption for ventilation of high-tech Institute Buildings has a big share of total building consumption. Through adaption on real requirements, significant energy savings can be achieved. This calls only for simple changes in control and regulation – a non-investive measure which may generally be implemented right away (Bauministerkonferenz, 2009).

An example for extremely inappropriate parameterization of a ventilation system can be found in Institute Building "Technik I/II" at Kassel University. With a current consumption of 1.770 MWh/a in total (2010) it's the biggest consumer in this respect at the university. The building hosts branches of mechanical engineering, building physics and natural science. Furthermore it's categorized by classical mixed use including offices, laboratories and lecture rooms.

Within measurements over several weeks, electric input power of the ventilation system has been analyzed. Looking at minimal and maximal values for several working days, only relatively small differences appear. Moreover especially high base load (70% of maximum within utilization period) outside building occupancy (on the basis of DIN V 18599) attracts attention, see figure 11. This base load is constant at weekends, too. However, an inspection of the building showed that there are hardly any valid requirements for ventilation.

Electric energy consumption outside occupancy accounts for approximately 320 MWh/a meeting nearly 140% of the consumption within occupancy. Through a shutdown outside occupancy, electricity consumption of the building could be reduced by 19% right away.

In all probability, ventilation operation within occupancy isn't fitted to user requirements, too. On this account additional saving potentials may be supposed. Both measures only require simple changes in time-programmes of the system which are hardly time consuming.

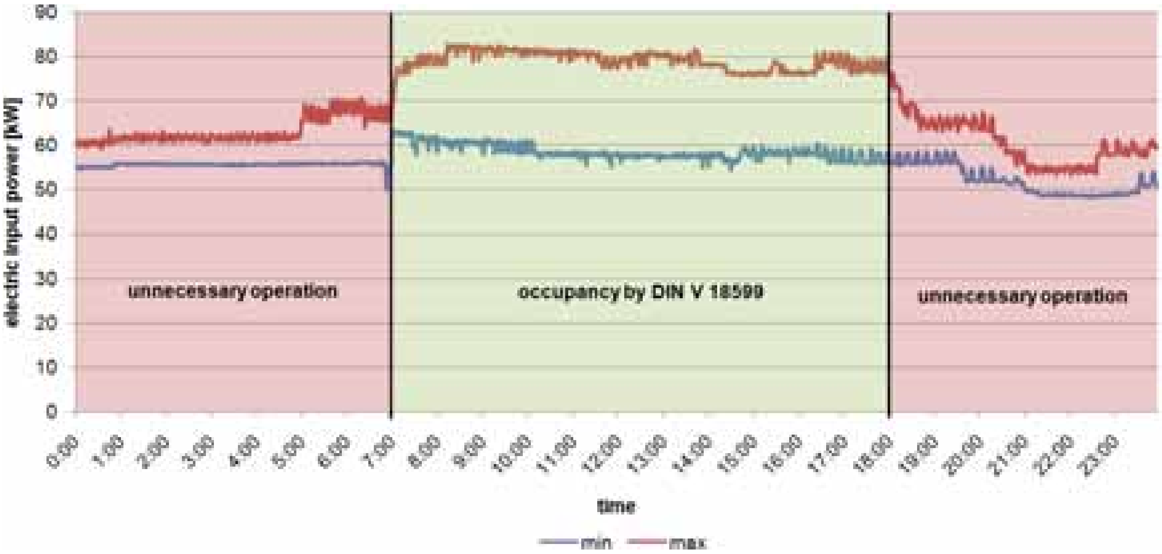

Figure 11: Electric input power of ventilation system at several working days

3.2. Central water heating

Due to their original planning some buildings dispose of central water heating and circulation systems without having considerable water consumption in reality. For example Institute Building "Technik III/2" which is most heat consuming at university, provides hot water at several extraction points around the clock and without delay. Because of the greatly expanded circulation pipes over several hundred meters the corresponding losses are considerably high. About 89 MWh/a are lost, whereas only 4 MWh/a are needed for the actual warming of tapped water. Moreover, in summer months there is hardly any heating requirement – the building's heat supply then is only maintained for water heating. According to a conservative estimation this results in additional losses of about 100 MWh/a, see figure 12. As a matter of fact, energetic effort is totally disproportionate to real hot water consumption (about 70 m³/a).

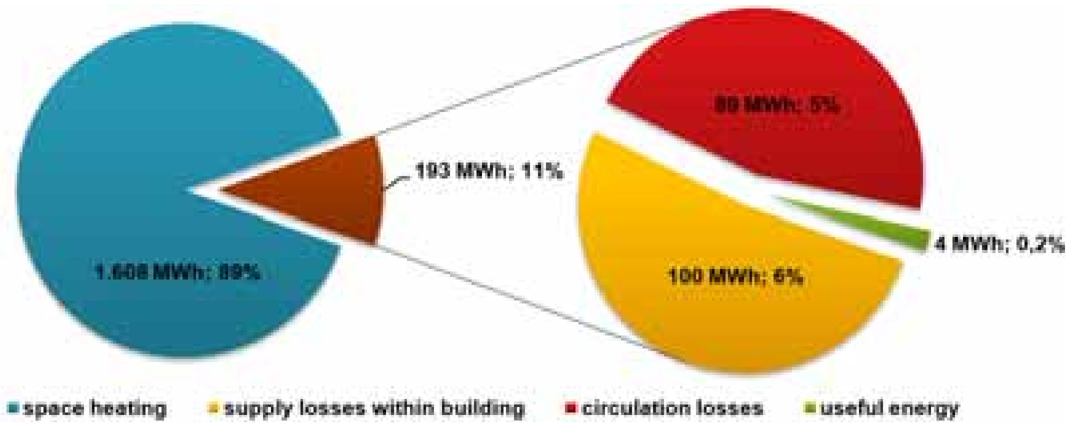

Figure 3: Losses through central water heating and circulation within the building

Furthermore there is a third big loss factor: A part of the local heating network has to be maintained as long as building requires heat – hence only for water heating and circulation in summer months. According to projection the corresponding losses accounts for about 165 MWh/a, see figure 13. In conclusion the water heating in this example has an efficiency of 1%. Other factors as power consumption of the pumps or maintenance efforts aren't considered for reasons of simplicity. The situation can easily be solved by shutting down the circulation. If necessary, extraction points may be equipped with electronic instantaneous water heaters.

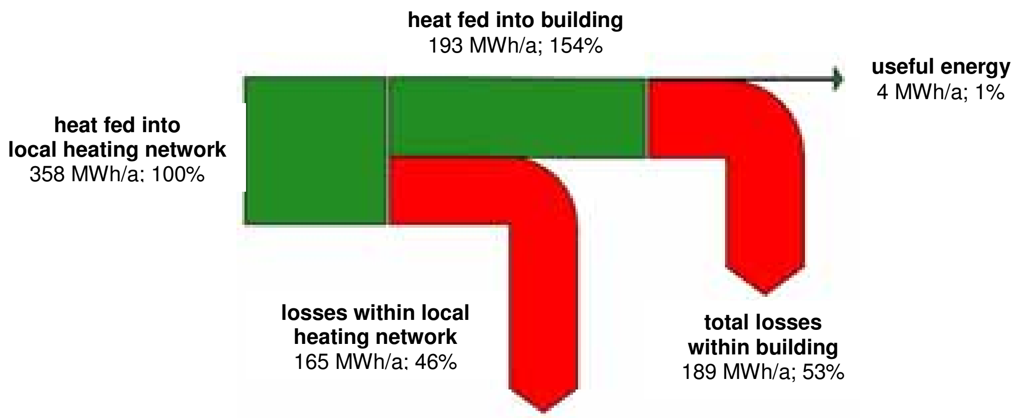

Figure 4: Losses through water heating in total

3.3. Central water cooling

Beside a central water heating and circulation, Technik III/2 also has a central water cooling and circulation. It's in fact a half-open system and allows cooling water withdrawal. As this amount (0,5m³/d) is negligibly low compared to daily flow, the system can be considered as closed system for reasons of simplicity. In contrast to the hot water circulation, cooling water circulates between taker and center on demand only.

However, some laboratories use cooling water for their installations 24 hours per day, while having hardly any requirement. This situation was noticed during a building walk-through. Conducted measurements confirm this situation: Over one week, the flow rate is nearly constant. Thus, cooling consumption leads to higher return temperatures respectively a bigger temperature difference (as flow temperature is constant).

Despite there is temporary a slight cooling consumption, cooling water circulates most time without need and is thereby warmed by 0.4 K, see figure 14. This corresponds to a constant cooling loss of 12 kW. Outside operation time (defined by constant temperature difference of 0.4 K), losses account for 70% total cooling respectively 90 MWh/a. As the respective refrigerating machine has very bad work figures, this equates to a current consumption of about 80 MWh/a and thus 5% of total building current drain (2010).

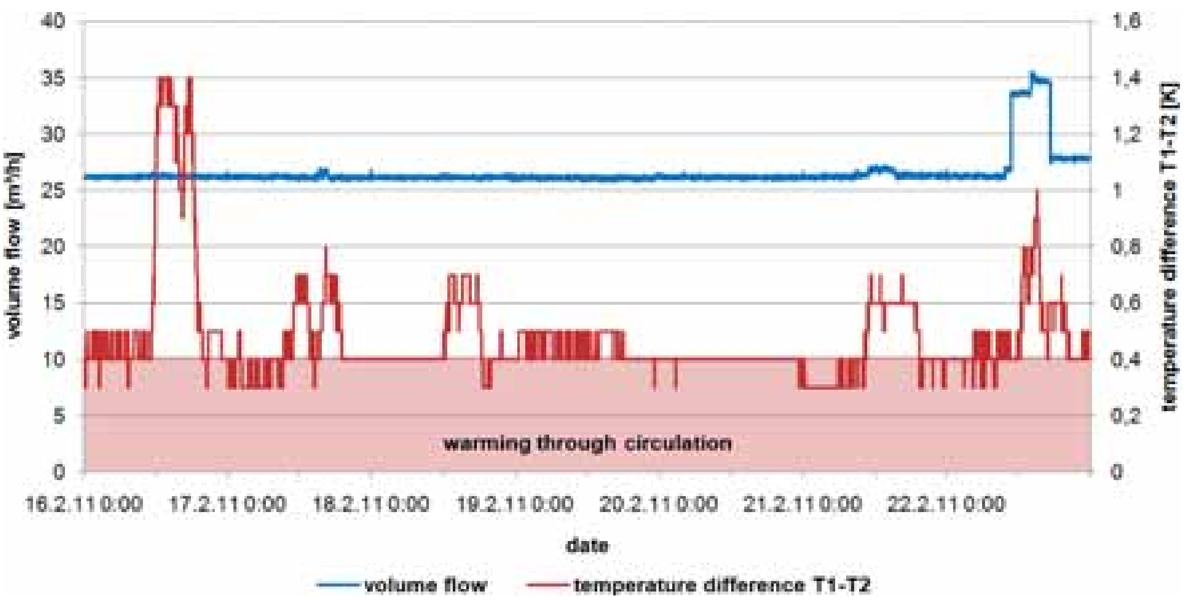

Figure 14: Losses through central cooling

4. Summary

- There is a large energy saving potential in university buildings: The UNI buildings of the sample consume 26% more heat and 29% more electricity than they should consume according to the reference values in EnEV 2007. These figures can't be defined as potential easily, but they are in range of frequently cited figures of saving potentials through optimization of HVAC. Furthermore it can be assumed that there is additional saving potential – independent of HVAC operation.
- As a general rule saving potential can predominantly be found in big high-tech Institute Buildings (especially for natural and engineering science). About 10% of universities' buildings are responsible for about 50% of total energy consumption in average. The average share of high-tech buildings in this group is nearly twice as high as the respective share in total.
- Big energy savings can be achieved with rather simple non-investive measures, especially by improving HVAC operation. At Kassel University for example, the following potentials have been identified so far:
    - Electricity consumption of a high-tech Institute Building can be reduced by 19% (320 MWh/a) through a shutdown of the ventilation outside occupancy.
    - About 190 MWh/a or 11% of another building's heat consumption can be saved by a shutdown of the central water heating and circulation system.
    - Based on this a shutdown of the local heating network in summer months allows for a reduction of additional 165 MWh/a.
    - The electricity consumption of this building can be reduced by 5% (80 MWh/a) through a hydraulic alignment of the central water cooling system.
- However, permanent savings requires an appropriate energy management.

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