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Measures for energy optimization for resource-saving consumption development on a university campus

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Abstract

The CAMPER-MOVE research project addresses the challenges arisen in connection with the transformation processes that a university campus is currently undergoing. Further to the recognition of undesirable developments and the development of effective counteracting strategies, the main objective of research project is the scientific monitoring, evaluation and optimization of the practical implementation of measures of a constructional-technical nature as well as supporting an economical user behavior. The experience to be gained in this process will be incorporated in further conceptual considerations to reduce energy consumption.

Keywords: Sector Coupling, Waste Heat Utilization, Autonomous Power Supply, Energy Management, User Behavior

1. Introduction

Founded in 1828 as a technical educational institution, the Technische Universität Dresden (TUD) is today one of the largest and oldest universities in Germany. Due to its former orientation as a technical university, scientific and engineering disciplines still dominate the university today. This is reflected by a significant number of buildings with a high to very high proportion of laboratory/experimental space. The TUD is a classic campus university with a historic core campus, the main campus, south of the city center. In addition, the university also includes several sites away from the main campus, such as the Botanical Garden, the Forest Botanical Garden and the Faculty of Medicine. However, the majority of university buildings are located on the main campus.

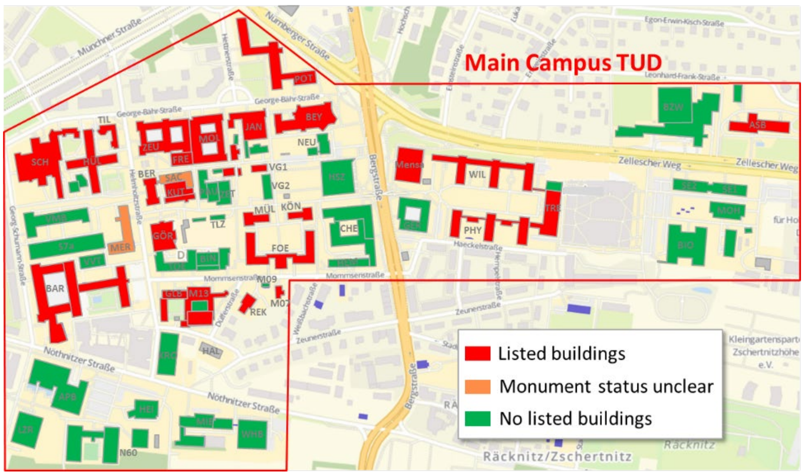

Fig. 1: Monument status of the buildings of the main campus of the TU Dresden

More than 50% of the buildings need renovation, whereas a majority of the buildings are historic monuments, which poses particular challenges for the energy retrofitting and integrating renewables (Fig. 1).

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In total, the main campus comprises 50 larger building complexes with a net floor space of approx. 390 000 m². In addition, a low-temperature local heating network of smaller size exists at the south end of the campus, which is used to transport waste heat from the university's largest data center to surrounding buildings (Fig. 2).

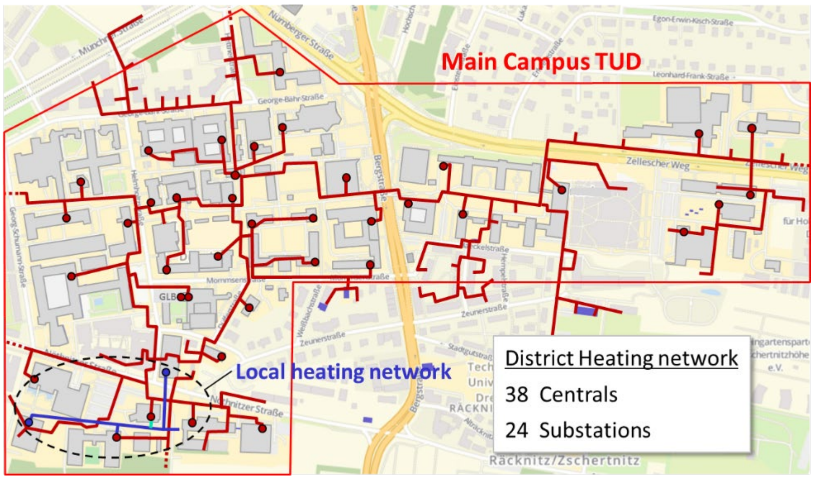

Fig. 2: District heating network in the area of the main campus of the TU Dresden

The cooling supply for the campus is provided by seven smaller local cooling networks as well as a number of decentralized small cooling generators. In total, cooling generators with a nominal capacity of approx. 25 MW are installed on the main campus, thus reaching the level of the heat supply. The cooling is mainly required for technological processes in laboratories and workshops, for cooling computer technology and for lecture hall air conditioning.

The electrical power supply of the main campus is connected to the public power grid at two central transfer stations. From there, seven internal medium-voltage rings supply all buildings. This also enables the flexible redistribution of electricity generated on the campus, which is produced regeneratively with the help of PV systems (currently approx. 350 MWh/a).

2. Analysis of energy consumption since 1998

If one examines the development of land consumption over the past 20 years, one initially sees a fairly moderate increase in the main usable area of the university of about 36 % (Fig. 3). It must be taken into account here that in the wake of the political turnaround in 1990, various restructuring of academic departments and partial realignments took place. A more detailed analysis reveals a disproportionately strong increase in highly technical areas (laboratory, server room and technical areas) by approx. 70 %. In the recent past in particular, there has been a flurry of new construction activity. In particular, buildings were constructed for institutes of the natural sciences with a high level of technical equipment and numerous laboratories. In return, rented buildings were handed over and older buildings were partially demolished.

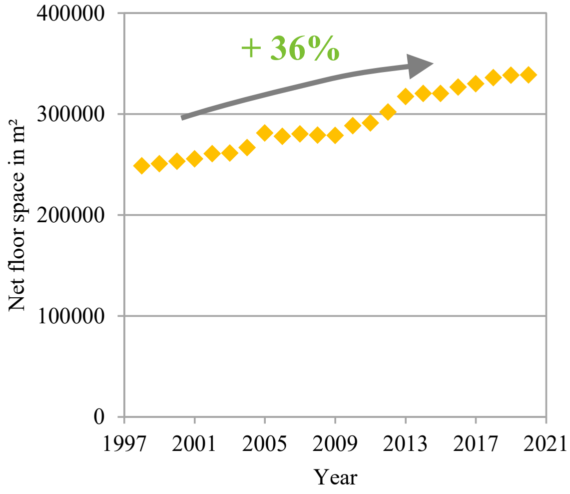

Fig. 3: Net floor space in m² without medical school (CAMPER, 2015 and CAMPER-MOVE, 2019)

The university is aware of its pioneering role and ecological responsibility and regularly initiates energy efficiency measures in its existing buildings. Newly constructed buildings have a high level of structural thermal insulation. Despite the increase in space, the heat consumption of the university campus has thus been kept at an almost constant level over the years. A slight increase has only been recorded since 2016 (Fig. 4). Due to the fact that the campus buildings are predominantly supplied with district heating from Sachsen Energie, with a high CHP share from a highly efficient combined cycle power plant (CCPP), the heat consumption also has a lower impact on the greenhouse gas (GHG) balance. Nevertheless, heat demand is highly relevant, as it generates significant energy costs and causes significantly higher emissions in other neighborhoods (with less efficient heat supply).

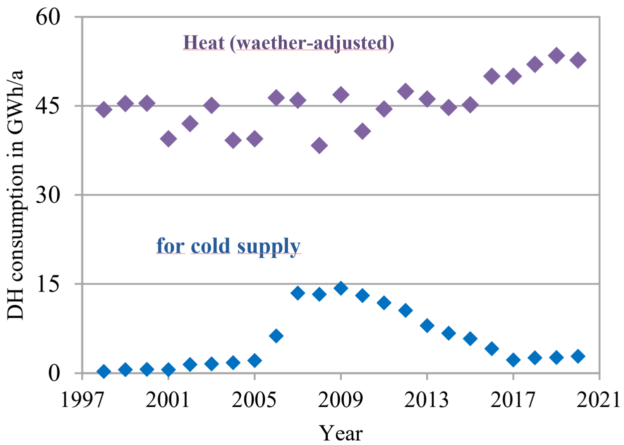

Fig. 4: DH consumption in GWh/a without medical school and weather-adjusted (CAMPER, 2015 and CAMPER-MOVE, 2019)

If we look at district heating consumption differentiated by building, we see large individual differences. The bandwidth of the area-specific heat consumption ranges from approx. 30 to 400 kWh/(m²a), in individual cases even up to 700 kWh/(m²a). Taking into account the varying use and equipment of the buildings (depending on the assigned departments and shares of use/technology areas according to DIN 277-1 (2016)). Buildings with large laboratory and test areas, as well as the sports halls and the botanical garden (many greenhouses) have the highest area-specific heat consumption. In the case of completely or partially renovated buildings, the consumption of district heating decreases on average by 30 to 40%, which is partly due to the relocation or decommissioning of large-scale consumers (such as the refectory, test stands). On average, reductions and increases in building consumption offset each other. The area-specific DH consumption of the entire campus has been consistently in the range of approx. 100...120 kWh/(m²a) over the last 20 years, which corresponds to energy efficiency class C to D according to EnEV (2015). In view of the age and condition of the campus buildings, this represents a rather low consumption value.

With the development of the local cooling supply, the district heating consumption increased temporarily due to the use of absorption chillers from 2006 to 2015 (Fig. 5). In the meantime, however, most of the systems have been converted to electrically driven compression chillers, so that the growing demand for cooling has since been reflected primarily in electrical energy consumption. In the past, there was an almost linear increase in electrical energy consumption (Fig. 6), which has more than doubled in the last 20 years. This development is driven by the growth in computing capacities (the first high-performance data center went into operation in 2006) and laboratory facilities, new buildings with a high proportion of glass (solar loads), and increased occupational health and safety regulations, which result in higher requirements for cooling and ventilation of these usable areas and thus additional electrical energy requirements. The reduction in the consumption of electric power due to the onset of the COVID pandemic can be seen (highlighted in red).

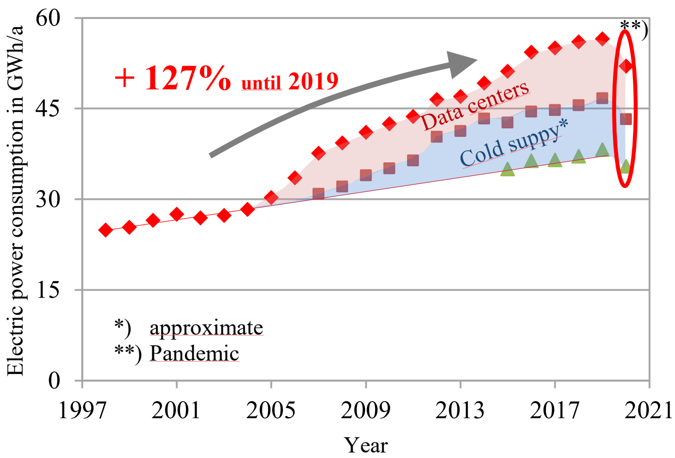

Fig. 5: Electric power consumption in GWh/a without medical school (CAMPER, 2015 and CAMPER-MOVE, 2019)

In light of these findings, consumers of, in particular, electrical energy were examined in more detail (Fig. 6). In this regard, laboratories, cooling generators and data centers are the main consumers. The increase in the distribution of technical equipment in university buildings (with laboratory and computer technology), in conjunction with stricter safety and comfort requirements in the faculties of natural sciences and engineering, creates a growing demand for cooling and ventilation.

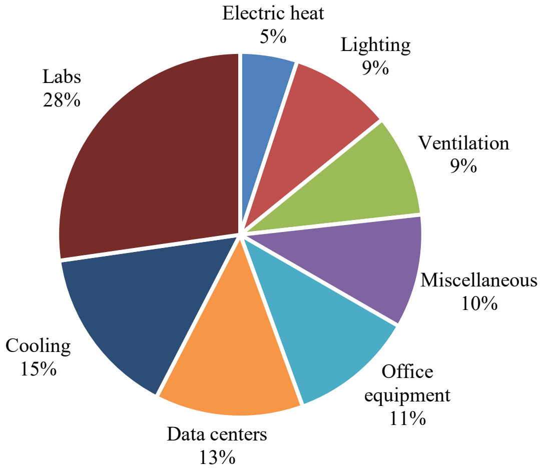

Fig. 6: Electricity consumption by use (CAMPER-MOVE, 2019)

3.1. Current data from 2019 and 2020

Figure 7 shows the currently verified final energies. On the left side the values from 2019 and on the right side those from 2020 are plotted. Furthermore, the gasoline equivalent of the mobility is also plotted to have a comparison. The first influences of the COVID pandemic can be seen. Due to the use of mobile working, the consumption of electrical energy has slightly increased, while the heat consumption has remained almost constant. The share of self-generated electric energy in the years was about 0.57% which corresponds to an energy of about 360 MWh per year.

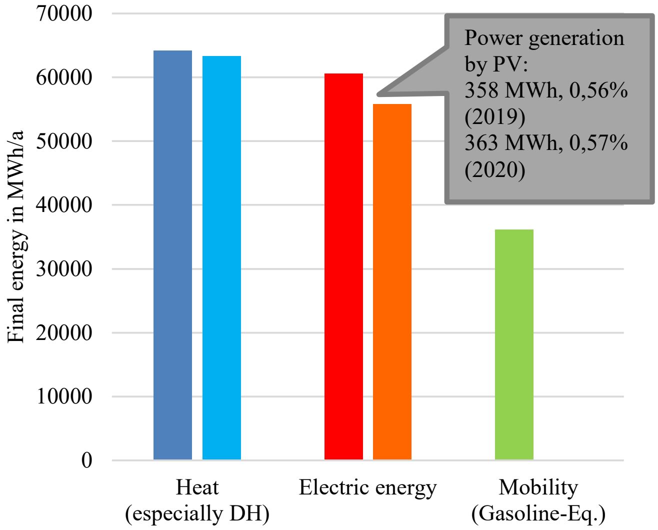

Fig. 7: Final energy in GWh/a without medical school (left: 2019; right: 2020) (CAMPER-MOVE, 2019 and Richter, *et al.*, 2017)

For comparison with Fig. 7, the GHG emissions are plotted in Fig. 8. A clear difference can be seen here. While the final energies were at a similar level, the GHG emissions are different. Electricity consumption causes significantly more emissions than heat consumption and attempts by far the highest emissions. Heating energy (mainly from district heating) is ecologically less harmful. Mobility causes many times more emissions than heating. The differences between the two years are due to changes in the respective GHG factors.

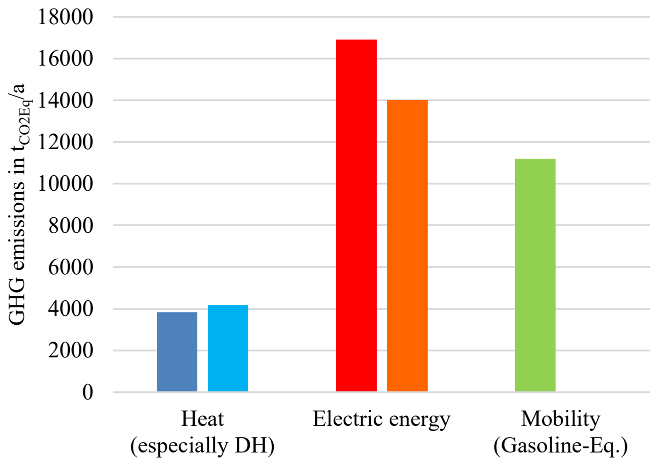

Fig. 8: GHG emissions in t_{CO_2Eq}/a without medical school (left: 2019; right: 2020) (CAMPER-MOVE, 2019 and Richter, *et al.*, 2017)

Fig. 9 shows the energy costs for heat and electricity. The cost of electrical energy in 2020 was 13.8 million euros and the total annual cost of energy was 18.5 million euros.

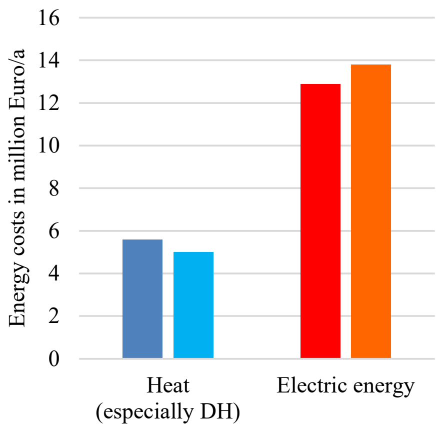

Fig. 9: Energy costs in million Euro/a without medical school (left: 2019; right: 2020) (CAMPER-MOVE, 2019)

3. GHG emissions and mobility

Figure 10 documents the percentages of the different energy sources in the final energy consumption and GHG emissions. The respective percentages in regard to the supply of heat (with district heating or natural gas/oil) and of electricity were similar, i.e. just below 40% of the total. Approximately 22% of the final energy consumption can be attributed to the mobility (gasoline equivalent) of employees and students (commuting, business trips, vehicle fleet). Looking at the GHG balance, a different picture emerges: With 63%, electrical energy consumption accounts for by far the largest share of GHG emissions. Mobility accounts for 26% of the emissions, and only about 11% is linked to the supply of heat. In total, emissions of approx. 44 000 t CO_2 equivalents were reached.

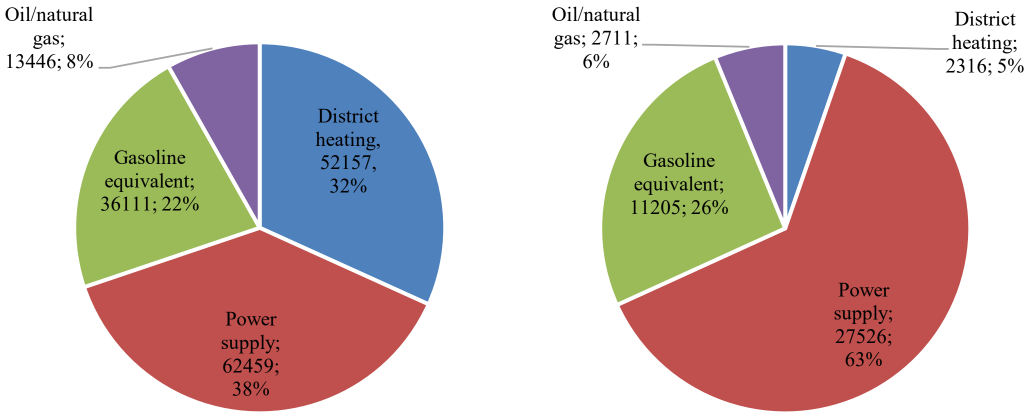

Fig. 10: Final energy consumption in MWh/a (left) and GHG emissions in t_{CO_2Eq}/a (right) (CAMPER-MOVE, 2019 and Richter, *et al.*, 2017)

In the case of mobility, the high personal final energy consumption results primarily from employees' private motorized transport including business trips by air (Fig. 11). In absolute terms, students' final energy consumption for their commute to and from work is at a similarly high level. Yet, with approx. 36 000 students compared to approx. 8 000 employees and approx. 4 300 air travelers, this relates to a larger group of persons. Overall, the mobility behavior of students may be assessed quite positively already at this point. Thanks to the mandatory semester ticket, which is valid throughout the state, students rarely resort to private motor vehicles. However, also as a result of the semester ticket, proportionately fewer students than employees use bicycles or walk for their commute - despite short distances for these ways. In combination with the high number of students, this leads to a considerable final energy consumption for public transport. The fuel consumption of buses and cars is particularly problematic in terms of the local air pollution caused. Air traffic, on the other hand, has a strong impact on the global greenhouse effect.

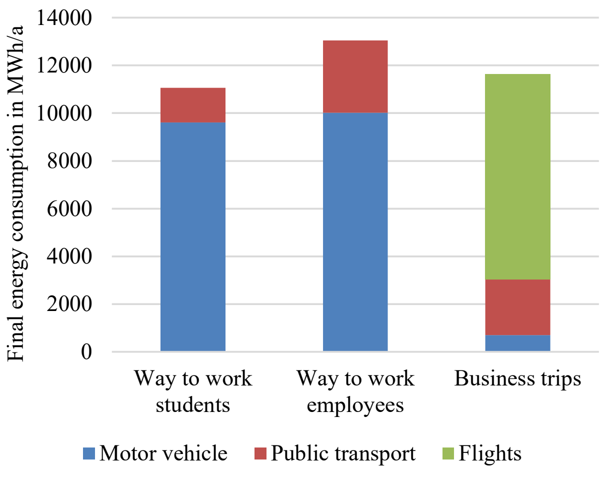

Fig. 11: Final energy consumption via mobility in MWh/a (Richter, *et al.*, 2017)]

4. Energy supply strategies

A significant number of remedying measures were identified for the university campus. If implemented in a consistent manner, these measures could lead to a significant long-term reduction in final energy consumption and greenhouse gas (GHG) emissions without impairing teaching and research. The analysis of the campus revealed serious differences in the development of consumption and the resulting environmental impact of the various energy sources (heat, electricity, mobility). Therefore, the research project will focus on the practical implementation of measures to effectively contribute to reducing the final energy consumptions and GHG emissions. The following main topics are considered:

1. reducing the energy consumption of cooling supply
2. increasing autonomous power supply through solar energy and sector coupling (power-to-cool, power-to-mobility)
3. enhancing the utilization of local, district and waste heat supplies at low-temperature levels (LowEx)
5. furthering the development of the university energy management
4. supporting an efficient user behavior (incl. mobility)
6. monitoring and updating of development planning

5. Summery

With consistent implementation of a wide range of individual measures to reduce the useful energy demand in conjunction with an optimized, increasingly regenerative energy supply (centralized and decentralized), significant energy and GHG savings can be achieved for the TU Dresden campus. However, this requires significantly stronger efforts than before. In particular, a trend reversal must be brought about in electrical energy consumption. This can be achieved by the use of energy-saving computer technology and laboratory equipment as well as a demand-oriented operation of the equipment, the reduction of the cooling energy demand (e.g. through improved summer heat protection) as well as an efficient cooling generation, an increased solar power supply of the campus and an extended energy controlling / energy management. The reduction of the absolute heating energy demand can be achieved in spite of planned campus expansions, if existing and, if necessary, expanded campus-internal heating networks are put to extended use and process-related heat sources are consistently included. The mobility-related energy consumption and emissions caused by employees' commutes and business trips should not be neglected. New mobility concepts with appropriate incentives for ecologically advantageous user behavior are needed here.

6. Outlook

The next steps in the project processing are to analyze the data of all business trips of the TU Dresden from 2017 until now. Here, the influence of the pandemic is particularly interesting and whether the behavior of business travel is gradually changing from less business travel by plane to more by train and the replacement of travel by using web meetings.

Additionally, a further investigation will be started with the approach to check whether the introduction of modern radiator controllers can make a significant and minimal-investment contribution to the reduction of heating energy at the TU Dresden.

7. Acknowledgments

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