Proceedings of the REHVA Annual Meeting Conference
Low Carbon Technologies in HVAC
23 April 2018, Brussels, Belgium

https://www.rehvam2018atic.eu/

ENERGY PERFORMANCE OF SHOPPING CENTERS IN GERMANY

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ABSTRACT

In recent years, the number of shopping centers has increased continuously in many countries. Due to the high air ventilation rate and heat load in the shop areas, shopping centers tend to have high energy demand, which shows a large energy saving potential. In order to establish an overview of the energy performance in shopping centers, 13 German shopping centers built from 1964 to 2011 were investigated through energy benchmarking. Aiming for a detailed analysis of the energy use behavior of shopping centers, in addition to benchmarking, energy monitoring was carried out in two shopping centers. The results show a wide deviation of energy use intensity in different shopping centers. This represents a significant potential for energy efficiency improvements in this type of building. Furthermore, the impact of various variables, such as technologies for heating, ventilation, and air conditioning (HVAC); floor area; year of construction and supply air flow rate, on energy performance of shopping centers is also discussed in this paper.

KEY WORDS: energy performance, shopping center, energy benchmarking, energy monitoring, HVAC system

1. INTRODUCTION

Shopping centers are building complexes containing several business units of different sizes and types. With increasing number of buildings of this type, a better understanding and improvement of the energy performance of shopping centers are becoming more important. In 2015 the total gross leasable area in shopping centers in Europe reached 156 million m^2 with an annual increase of 4.6 million m^2 [1]. Between 2000 and 2017 in total 200 new shopping centers with a leasable area above 10,000 m^2 have been constructed in Germany [2].

A comparison of energy performance in seven Swedish shopping centers and 34 Norwegian shopping centers [3] shows that the total energy use intensity in individual shopping centers, which includes both building electricity and thermal energy use, varies widely between 162 and 545 kWh/(m^2·a). This deviation indicates a large energy optimization potential in this type of building. In another study, the total energy used in 5,209 shopping centers, situated in 28 European countries, Norway and Switzerland, is calculated by multiplying the total gross leasable area of the shopping centers by a respective total energy use intensity depending on the shopping center size [4]. The calculated average energy use intensity in 500 German shopping centers, based on the gross leasable area of the buildings, is 265 kWh/(m^2·a) [4]. However, the determinants of energy performance of shopping centers cannot be identified in these two studies because of the complexity of the buildings and the data limitations.

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To provide a better understanding of energy performance of existing shopping centers in Germany, we conducted extensive energy benchmarking in this study. Energy benchmarking, as it is referred to here, is a process of determining the energy performance of a building and comparing it with the energy performance of similar types of buildings [3] [5] [6]. This process provides an overview of energy performance of existing buildings and assesses the opportunities of energy optimization without detailed evaluation. Furthermore, the determinants of energy performance of shopping centers can also be analyzed. In addition to energy benchmarking, energy monitoring was carried out in two shopping centers. Energy monitoring is a process of recording, storing, visualizing and analyzing of information on energy use of buildings and building services systems [7]. In the framework of this study, data measured through energy monitoring facilitate the determination of energy use for different functions and zones in the buildings.

This paper presents an overview of technical installation systems as well as energy use in existing shopping centers situated in Germany. Furthermore, the impact of different variables on energy performance of shopping centers is discussed.

2. METHODS

Energy benchmarking was performed in this study as follows:

Step 1 A questionnaire was developed for the purpose of gathering information about shopping centers such as their location, year of construction, net floor area, total ventilation flow rate, technologies for heating, ventilation, and air conditioning (HVAC) and total annual energy use for the years 2012 to 2014.

Step 2 The energy performance and building characteristic data of shopping centers were collected through the questionnaire and personal communication with owners, managers and service staff. The collected data were verified to ensure the information is reasonable and evaluable. In this study useful responses to the questionnaire were obtained from 11 shopping centers. Besides data collected from the 11 shopping centers through questionnaire, energy performance data of two other shopping centers were measured through energy monitoring. In total, 13 shopping centers were investigated in this study.

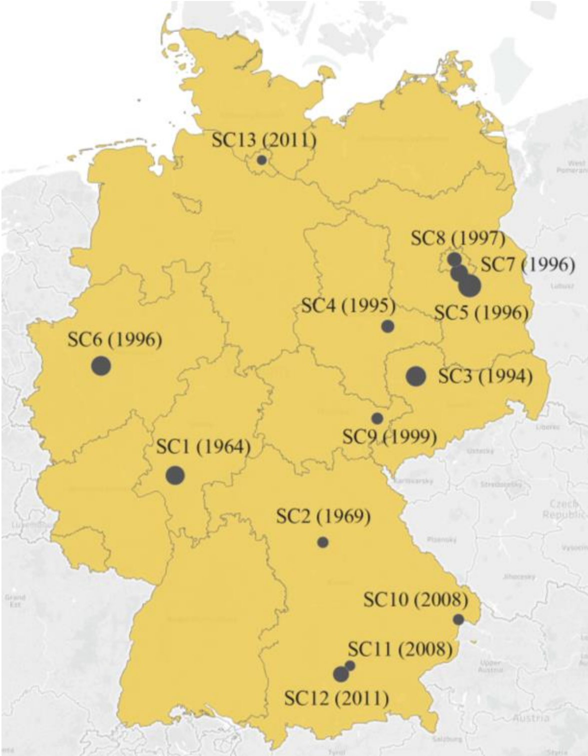
Step 3 The average annual end and primary energy use intensities (EUIs) from 2012 to 2014, expressed as kWh/($m^2 \cdot a$), were used as indicators of energy performance of an individual building in this study. Buildings with high energy performance are intended to have low EUI. Annual primary energy use was calculated with the end energy use of electricity and heating energy as well as the appropriate primary energy factors according to the German Energy Saving Ordinance (EnEV) 2013. Heating energy use was normalized for weather differences by multiplying it with climate factors from the German Weather Service [8]. Weather normalizing ensures comparability of the energy use from different periods or places with different weather conditions [8]. The EUI of a shopping center was calculated as the energy use divided by the net floor area of the building. For this calculation the energy use and the floor area of parking areas and residential areas in the building were excluded.

Step 4 Statistical relations were examined between the EUIs and several characteristic variables of the shopping centers. The linear correlation coefficient r was established to describe the strength and the direction of a linear relationship between the variables and the energy use intensities of the shopping centers.

Energy monitoring was performed on the basis of the existing comprehensive measurement systems in two shopping centers. The measurement systems were installed during the construction phase by the owners for the purpose of monitoring the monthly electricity and thermal energy use for different functions and zones. The monthly data of energy use since 2011 were provided by the building owners for evaluation.

3. RESULTS AND DISCUSSION

3.1 Overview of the HVAC systems Fig. 1 shows the 13 shopping centers investigated in this study on a map as well as their year of construction and net floor area. These shopping centers were built between 1964 and 2011, and their net floor areas range from 30,000 to 159,884 m^2.



Name	Net Floor Area [m^2]
SC1	110,240
SC2	38,762
SC3	124,353
SC4	52,546
SC5	159,884
SC6	118,000
SC7	96,901
SC8	61,339
SC9	43,121
SC10	37,458
SC11	34,846
SC12	63,398
SC13	30,000

Fig. 1 Net floor area excluding parking area and residential area (size of marks) and year of construction (label of marks) of the investigated shopping centers (SC) in Germany.

Indoor air quality and thermal comfort in the shopping centers is conditioned primarily by supply air. The heat and cooling load in the shop areas, which cannot be met with supply air, is covered by individual air conditioners installed by the tenants. The result of energy benchmarking shows that 12 of the 13 investigated shopping centers are equipped with central HVAC systems, and a distributed HVAC system is applied for one shopping center (SC6). The air handling systems of the central HVAC systems can be characterized as all-air systems and air-water systems. All-air systems are applied for nine centers (SC1-5 and SC7-10). Outside air is conditioned centrally in the air handling units (AHUs) and supplied directly to the shops via air distribution systems. The air-water systems are utilized in three shopping centers (SC11-13). The conditioned air is supplied to terminals of the shops for further treatment using hot or chilled water, so that every shop can adjust the supply air condition individually. The supply air flow rate is constant in ten shopping centers (SC1-3, SC6 and SC8-13). For three shopping centers with variable supply air flow rate (SC4-5 and SC7) the design supply air flow rate is taken into account for evaluation.

Heating energy use of seven shopping centers (SC2-4, SC7 and SC9-11) is completely supplied by district heating. Four shopping centers (SC1, SC5, SC8 and SC13) use gas boilers to generate hot water as heating medium. In the other two centers (SC6 and SC12) hot water supplied to AHUs is provided primarily by heat pumps using ambient energy. The peak load in the AHUs and other heating energy use in these two shopping centers are covered by district heating.

In nine shopping centers (SC3-9, SC11 and SC13) outside air is cooled by the cooling coils in the AHUs using chilled water as cooling medium. In the other two shopping centers (SC1 and SC12) outside air is cooled down partly by the direct evaporative cooling and partly by the water cooling coils in the AHUs. Compared to chilled water cooling, direct evaporative cooling can be more attractive for large buildings like shopping centers because of less space requirement and especially less distribution losses. One shopping center (SC10) has only AHUs using direct evaporative cooling, and the AHUs of the other shopping center (SC2) has no cooling function. In this center (SC2) the shop areas are cooled, if at all, with the air conditioners installed by the tenants. Besides the AHUs, the terminals in the shopping centers with air-water systems (SC11-13) are also supplied by chilled water. Chilled water is provided by chillers in nine shopping centers (SC1, SC3-9 and SC13). In SC11 and SC12 the chilled water is cooled by multi-level energy supply systems benefiting from renewable energy sources such as ambient air and near-surface geothermal energy.

3.2 Annual electricity use The electricity use of the investigated shopping centers is supplied by the public power grid and measured by the energy suppliers. According to the responses to the questionnaire, the electricity use in shop areas is unknown for the shopping center owners, since the tenants have their own contract with the energy supplier. Therefore, the comparison of energy performance in this study is executed on the basis of the landlord electricity of the shopping centers. Fig. 2 presents a comparison of the landlord electricity use intensity (EUI_{el}) in the 13 shopping centers on average for 2012 to 2014. The average annual EUI_{el} of all shopping centers is 56 kWh/(m^2·a), while the average annual EUI_{el} of individual shopping centers ranges from 25 to 89 kWh/(m^2·a). The two shopping centers investigated through energy monitoring (SC11 and SC12) have the two highest EUI_{el}. As discussed in section 3.1 landlord electricity used in the three shopping centers with air-water-systems (SC 6, SC11 and SC12) covers the total electricity use of HVAC systems; however, the electricity use of HVAC systems in other shopping centers is covered partly by tenant electricity depending on the ownership of the installation and the tenant agreement.

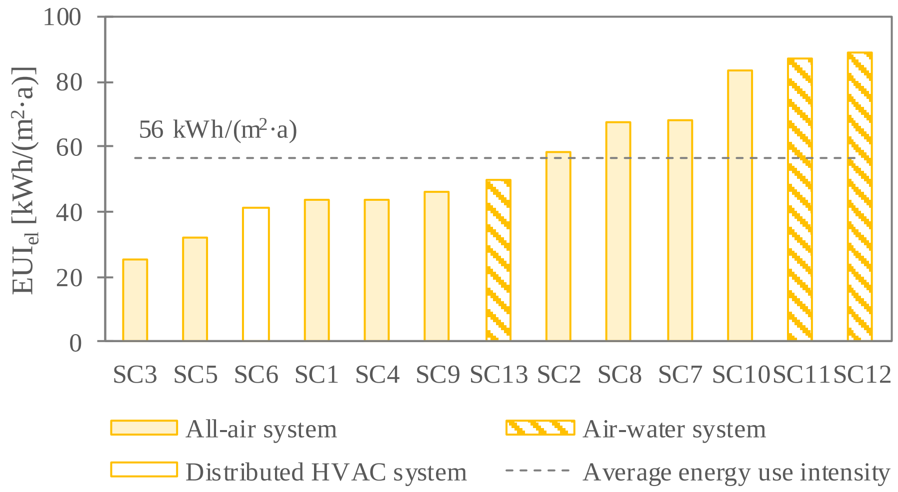


Fig. 2 Average annual electricity use intensity (EUI_{el}) of the shopping centers from 2012 and 2014.

Fig. 3 shows the EUI_{el} as a function of the net floor area, the year of construction and the specific supply air flow rate of individual shopping centers. The strong correlation between the EUI_{el} and the net floor area provides a linear correlation coefficient of -0.60, which indicates that shopping centers with larger floor area tend to have lower EUI_{el}. The newly built shopping centers tend to have higher EUI_{el} than older ones. The shopping center with the lowest EUI_{el} was built in the 90´s. Furthermore, the strong correlation between the EUI_{el} and the specific supply air flow rate (r = 0.81) indicates that the EUI_{el} tends to increase as the specific supply air flow rate of the shopping center increases. Worth mentioning here is that the specific supply air flow rate is not based on the shop area but calculated as the total supply air flow rate divided by the total net floor area excluding the parking area and the residential area in the shopping centers.

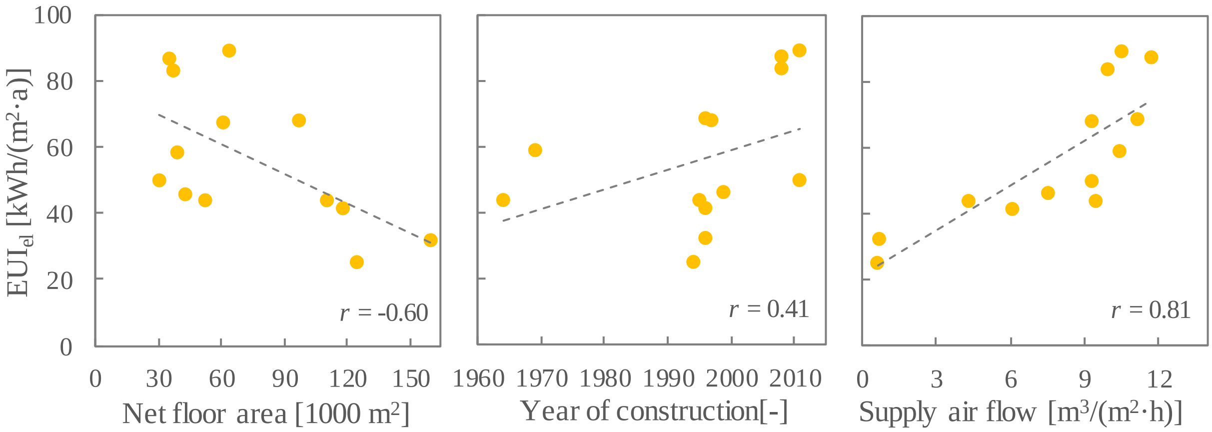


Fig. 3 Electricity use intensity (EUI_{el}) of shopping centers as related to the net floor area (left), the year of construction (middle) and the specific supply air flow rate (right).

Based on the data measured through energy monitoring, the total electricity use of the two buildings as well as the electricity use for different functions can be determined. The total delivered electricity for SC11 is 207 kWh/(m^2·a) on average for the years 2012 to 2014; and for SC12 it equals 205 kWh/(m^2·a). As shown in Fig. 4 the tenant electricity use constitutes on average 58 percent of the total electricity use in SC11 and 57 percent of the total electricity use in SC12. The average tenant electricity use intensity is 120 kWh/(m^2·a) in SC11 and 116 kWh/(m^2·a) in SC12. These values refer to the total floor area of the shopping centers excluding parking area and residential area. In comparison, the average tenant electricity use intensity based on the total shop area is approximately 211 kWh/(m^2·a) in SC11 and 187 kWh/(m^2·a) in SC12. Electricity used for the HVAC system accounts for 29 percent of the total electricity use in SC11 and 28 percent of total electricity use in SC12. The HVAC system has an average electricity use of 60 kWh/(m^2·a) in SC11 and 57 kWh/(m^2·a) in SC12.

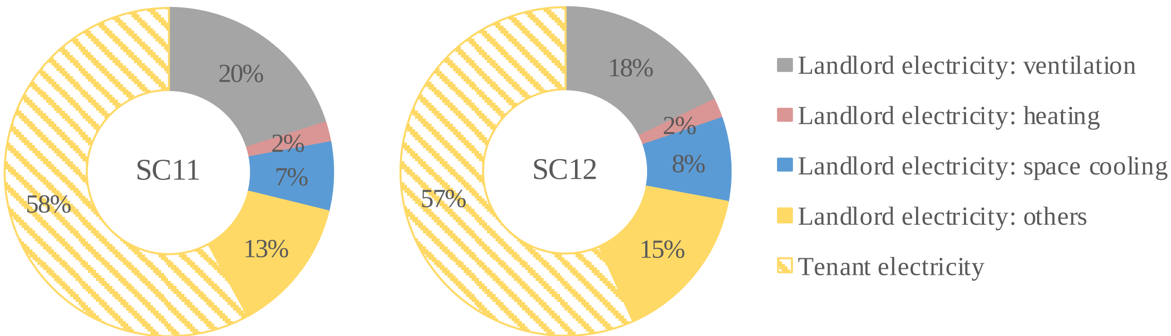


Fig. 4 Breakdown of the total electricity use in SC11 (left) and SC12 (right) based on the measured data from 2012 to 2014.

3.3 Annual heating energy use Besides the electricity supply, the district heat supply and the fuel gas supply are also measured by the energy suppliers. Fig. 5 shows the weather-normalized annual heating energy use intensity (EUI_{heat}) of the investigated shopping centers on average for the years 2012 to 2014. The average EUI_{heat} of individual shopping centers varies between 25 and 128 kWh/(m^2·a). The average value of all shopping centers is 56 kWh/(m^2·a). The EUI_{heat} in SC6 with a distributed HVAC system is above the average value, although the heating energy demand in this center is covered partly by heat pumps. Shopping centers with air-water systems have below-average EUI_{heat}, while the three most energy-inefficient shopping centers are all equipped with all-air systems. SC12 with heat pumps using near-surface geothermal energy and air-water system has the lowest heating energy use intensity.

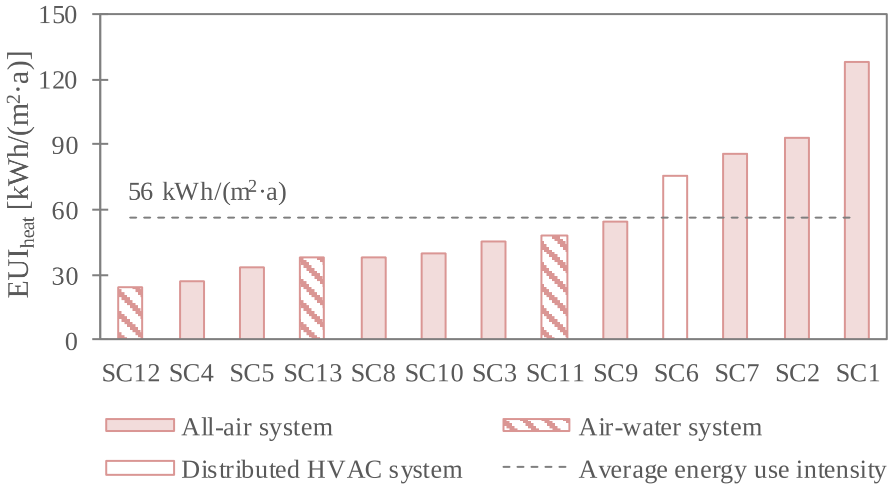


Fig. 5 Average annual heating energy use intensity (EUI_{heat}) of the shopping centers from 2012 to 2014.

Fig. 6 illustrates the correlations between the EUI_{heat} and the net floor area, the year of construction as well as the specific supply air flow rate of the shopping centers. Compared to the strong negative correlation between the EUI_{el} and the floor area, there is a positive but negligible correlation between the EUI_{heat} and the floor area. The determined value of -0.81 for the correlation between the EUI_{heat} and the year of construction indicates that more recently built shopping centers are more energy efficient than older ones, as expected. Worth mentioning here is that this analysis considers exclusively the year of construction and the past renovations of the buildings are not taken into account. Between the EUI_{heat} and the specific supply air flow rate no linear relationship can be assumed.

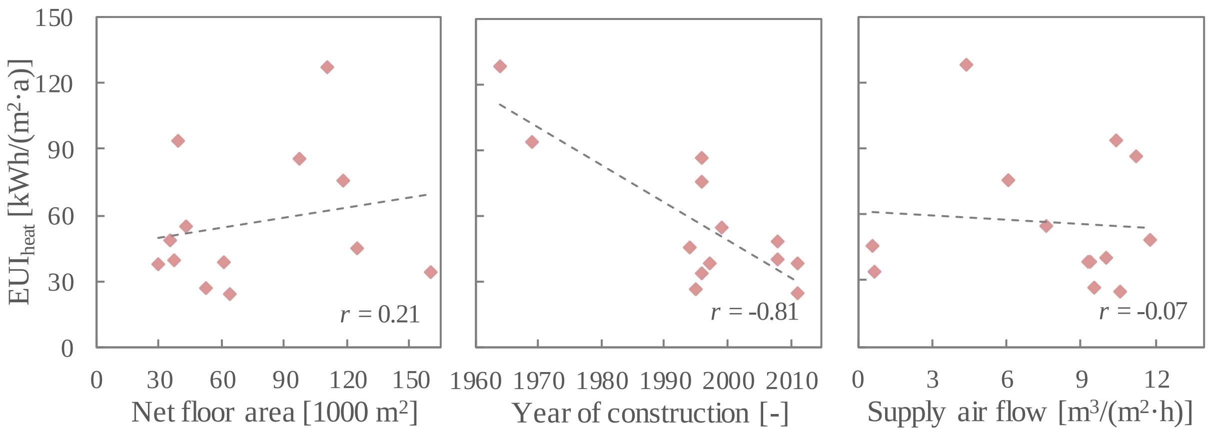


Fig. 6 Heating energy use intensity (EUI_{heat}) of the shopping centers as related to the net floor area (left), the year of construction (middle) and the specific supply air flow rate (right).

3.4 Annual primary energy use Fig. 7 shows the calculated primary energy use intensity ($EUI_{primary}$) of the investigated shopping centers. The deviation in the $EUI_{primary}$ of the 13 shopping centers is between 77 and 219 kWh/(m²·a). The average $EUI_{primary}$ of all shopping centers is 148 kWh/(m²·a). Both shopping centers with the highest and the lowest $EUI_{primary}$ have all-air systems. This indicates a large energy optimization potential in this type of building. The $EUI_{primary}$ of shopping centers with air-water systems varies between 132 and 190 kWh/(m^2·a), while the average value is 166 kWh/(m^2·a). It should be noted that the $EUI_{primary}$ shown in Fig. 7 is only a part of the total primary energy use of the buildings since the tenant electricity use is excluded. According to the result of energy monitoring, the total primary energy use intensity is 406 kWh/(m^2·a) in SC11 and 386 kWh/(m^2·a) in SC12.

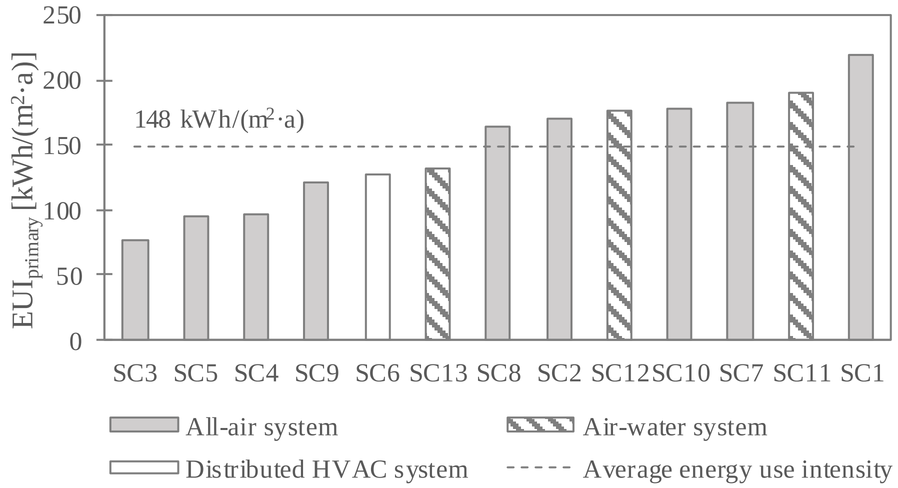


Fig. 7 Average annual primary energy use intensity ($EUI_{primary}$) of the shopping centers from 2012 to 2014.

The $EUI_{primary}$ in relation to the net floor air, the year of construction as well as the specific supply air flow rate are plotted in Fig. 8. The $EUI_{primary}$ tends to decrease as the net floor area of the shopping centers increases, but this correlation is not significant providing a linear correlation coefficient of -0.32. Also a negative but negligible correlation is indicated between the $EUI_{primary}$ and the year of construction. The $EUI_{primary}$ tends to increase as the specific supply air flow rate increases, but this correlation is not as strong as it between the EUI_{el} and the specific supply air flow rate.

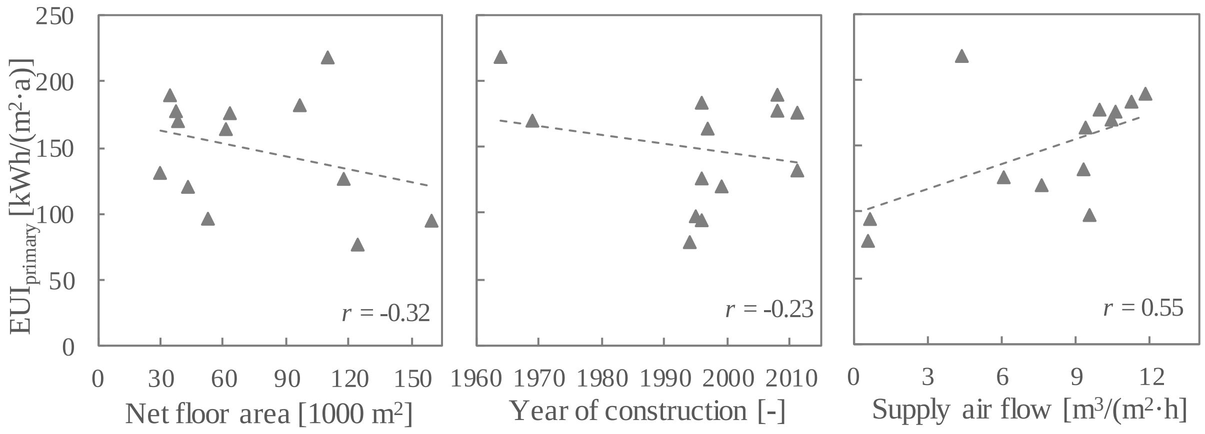


Fig. 8 Primary energy use intensity ($EUI_{primary}$) of the shopping centers as related to the net floor area (left), the year of construction (middle) and the specific supply air flow rate (right).

4. CONCLUSIONS

Twelve of the 13 investigated shopping centers have central HVAC systems, while the three most recently built shopping centers are equipped with air-water systems. There is a wide deviation between the energy use in different shopping centers, which indicates a large potential for energy efficiency improvements in this type of building. Electricity use intensity in individual shopping centers, ranging from 25 to 89 kWh/(m^2·a), shows a strong correlation with the specific supply air flow rate. Shopping centers with small floor area tend to have a higher electricity use intensity compared to larger ones. The heating energy use, ranging from 25 to 128 kWh/(m^2·a), has a strong correlation with the year of construction. More recent buildings have better energy performance than older ones. Shopping centers with air-water systems have below-average heating energy use intensity. Primary energy use of the shopping centers varies between 77 and 219 kWh/(m^2·a) and has a significant positive correlation with the specific supply air flow rate. Because the electricity use of the tenants is not available for 11 of the investigated shopping centers, it is excluded from the comparison of energy performance. Since the tenant electricity, according to the result of energy monitoring, constitutes approximately 60 percent of the total electricity use of the buildings, this exclusion affects the comparison of energy performance between different buildings significantly. To achieve better energy performance in shopping centers, more information and energy use data, such as tenant electricity use and occupant behaviors, are needed for further studies.

ACKNOWLEDGMENT

The authors gratefully acknowledge the German Federal Ministry of Economic Affairs and Energy for providing financial support (promotional reference: 03ET1092A& 03ET1502A).

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