ANALYSIS AND LOCATION OF DEMAND SIDE INTEGRATION POTENTIALS IN URBAN SPACE USING GIS BASED DIGITAL CITY MAPS

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ABSTRACT

An Assessment of the Demand Side Integration Potential from HVAC for whole cities can be achieved through a detailed analysis of the building stock. Using GIS-based digital city maps in combination with usage-based characteristic data on the typical power installed in buildings for HVAC (such as the VDI 3807-4) an automated approach can be defined to achieve building specific data covering a whole city. This paper discusses a feasibility study for such an approach that was carried out at the University of Applied Sciences in collaboration with the Harbour City University both of Hamburg. Out of a total of about 340.000 buildings in Hamburg the study defined 832 buildings of office-like use with a noteworthy DSI potential from HVAC. The same method could be used to automatically analyse the DSI potential of other sectors of building use, the DSI for a whole city and/or be transferred to other cities with similar data bases. Because of the inherent connection to a GIS based data set the results can be easily displayed in maps. The paper gives an introduction into the method, shows some results achieved and discusses the approach and its transferability.

SCOPE AND APPROACH

Scope

The German energy turnaround is based on a massive growth in distributed renewable yet fluctuating electricity generation sources. This calls for a equally growing integration of flexible demand in order to be able to balance demand and generation in the transmission grid as well as in the “last mile” of certain distribution grid sections. In order to achieve this, questions about the Demand Side Integration (DSI) potential of different sectors as well as the precise location of these potentials in urban space are of growing importance.
In this context a method to detect and map the DSI potential of HVAC within the urban space was developed and tested at the Center for Demand Side Integration of the University of Applied Sciences Hamburg in cooperation with the research group for computer-based methods in urban and regional planning at the Harbour City University in Hamburg. It was applied to a selected group of building usages of the tertiary sector and validated against results from a predecessor research project called “e-island” [1] which did a detailed analysis of the DSI potential of the public buildings at medium voltage level in Hamburg. Basis for the identification of the buildings, their basic features like building usage, floor space as well as their precise location was the GIS based digital city map of Hamburg. The digital city map of Hamburg provides a data base which contains detailed information about every single building in Hamburg like the buildings’ ground area, number of floors, building usage, address and geographical location (coordinates). The data is available as an arc coverage file which makes it easy to establish maps for visualization. Since the German federal states all agreed upon a common design for their digital city map data bases (called “**A**mtliches **L**iegenschafts**k**ataster**i**nformations**s**ystem ALKIS®” data) the method described below is just as well applicable to the data sets of other German cities. Its general approach should also be transferable to other digital city maps of other cities outside Germany.

Approach

Types of building usages taken into consideration
The data set of the digital city map covers 339.094 buildings (total of Hamburg) with 128 possible different building usages. Since the DSI potential is highly dependent on the way of use of a building this data set was scaled down to all non-residential buildings from the tertiary sector having an “office-like” use. This limitation was applied because of the fact that for buildings like these distinct results about their DSI potential were available from the predecessor research project “E-Island”.[1]
This selection limited the number of buildings taken into further consideration to 12.461.

Assessment of energy reference areas and resulting energy uptake of the selected buildings
Apart from the “office-like” usage only such buildings where considered that would have a significant energy demand. For the study it was presumed that only buildings with an annual energy demand of more than 100 MWh would have a DSI potential in HVAC that would be worth integrating in a virtual power plant or smart grid.
Lacking the real figures of the energy consumption of the

buildings it is necessary to assess their likely energy uptake using energy performance indicators. In this case these figures were derived from a data base of the German Federal Ministry of Transport, Building and Urban Development called "Rules for energy performance figures for the non-residential bulding stock" ("Regeln für Energieverbrauchswerte und Vergleichswerte im Nichtwohngebäudebestand") [2]. In similar cases comparable data bases might be applicable.

The precondition of a minimum energy uptake of 100 MWh/a and filtering all buildings of not clearly definable multi-usages reduced the data set to a remaining 832 buildings which can be regarded as an important intermediate result of this feasibility study: It was possible to identify the 832 buildings of office-like use in Hamburg for which a significant DSI potential can be expected out of a total data set of 340.000 buildings by using filtering rules that are rather easy to define. The filtering process itself is adjustable so that in other cases other filters can be defined.

Assessment of installed load for HVAC based on building usage and energy reference area

For the final determination of the building-specific DSI potential form the installed HVAC existing performance indicators were used again. Code 3807 "Characteristic values of energy and water consumption of buildings – Section 4: Characteristic values for electric energy" by the German society of engineers (Verein Deutscher Ingenieure VDI) was applied for this step. In chapter 6 it provides typical values for installed electric ventilation and cooling load demands. [3]

The main purpose of the code is to give orientation when evaluating the electrical demand of a building in order to be able to determine reduction potentials in the different usage sectors like lighting, heating, cooling etc. For this feasibility study these performance indicators were used to asses installed loads of HVAC in the data set following the simple approach of

$$P_x = e_x \cdot A_x \; (W)$$

with:

e_x energy performance indicator for ventilation [e_V] or cooling [e_C] (W/m$^2_{EFS}$)

A_x energy related floor space (m$^2_{EFS}$).

The performance indicators in code 3807 sect.7 are differentiated into 31 different usage zones and give information about typical installed loads (W/m$^2_{EFS}$), full use hours (h/a) and resulting energy demand (kWh/m$^2_{EFS}$). Five categories of demand are distinguished: "Very high", "high", "medium", "low" and "very low". The two latter categories only apply to new and energy efficient buildings thus serving as target values to define possible saving potentials within the existing building stock.

A rather serious mistake could be made by generally assuming that the total floor space of a building was applicable as the energy related floor space. [4] shows that some usage zones in generally ventilated and air conditioned buildings are neither ventilated nor air conditioned at all. In order to be able to apply the described method the "true" energy related floor space (EFS), in this case the air conditioned and/or ventilated floor space, needs to be defined. A source for this is [5] where on the basis of statistical analysis average percentage values for ventilated and air conditioned building areas for different usages can be found.

RESULTS

The electricity demand of the selected 832 buildings was estimated to be approx. 430 GWh/a. Their installed power for ventilation was determined to lie in between 5.5 MW (low projection) and 22.7 MW (high projection) with 13 MW for a medium projection.

The total installed power for cooling was approximated between 20 MW (low projection) and 84 MW (high projection) and a medium projection of 61.5 MW. A more distinctive result than the overall sum of the installed capacity though is the frequency distribution of the installed load.

Frequency distribution of the load

When applying a frequency analysis to the results obtained it becomes apparent that the largest share of the buildings selected has only a limited amount of power installed for HVAC. Only a few buildings have a high capacity of HVAC installed. This implies that the method tested is suitable to identify and select those buildings within the building stock that can be connected to a smart grid / virtual power plant from the perspective that their load shifting potential would presumably be able to deliver the expected return on investment.

Figures 1 and 2 display the Pareto-like frequency distribution of the installed load.

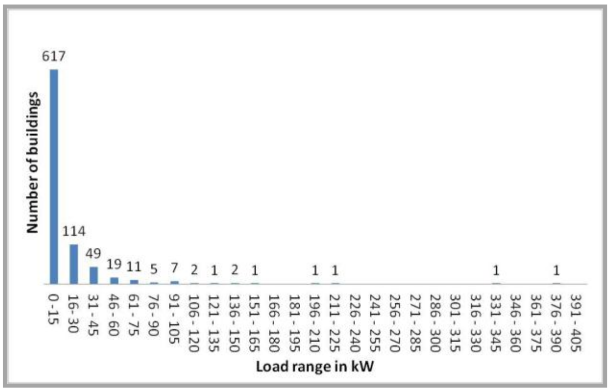

Figure 1: Distribution of the installed load for ventilation in the 832 buildings selected.

The time length for shifting or shutting off these loads varies by the DSI approach that the load is integrated into. Results from the research project "e-Island" suggest that a repetitive daily reduction of about 1/3 of the power can be applied in most cases without affecting the comfort of the building users. Feasibility studies undertaken by the utility company of the city of Hannover suggest that for limited periods the total load for HVAC can be shut off without the building users noticing this [6].

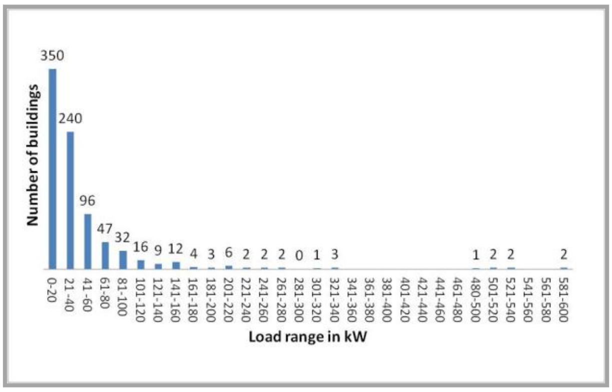

Figure 2: Distribution of the installed load for air conditioning in the 832 buildings selected.

Daily and yearly load profiles

To obtain conclusions about the dynamics of the DSI potential a graphical analysis was done displaying hours of HVAC operation for the buildings during each hour of a year. Hours of normal operation on working days were displayed as well as weekends and holidays with a reduced operation. For HVAC operation outdoor temperatures considered likewise. The results obtained are exemplified in figure 3 displaying the dynamics of the electrical load for cooling purposes in relation to weather data for Hamburg for the year 2010.

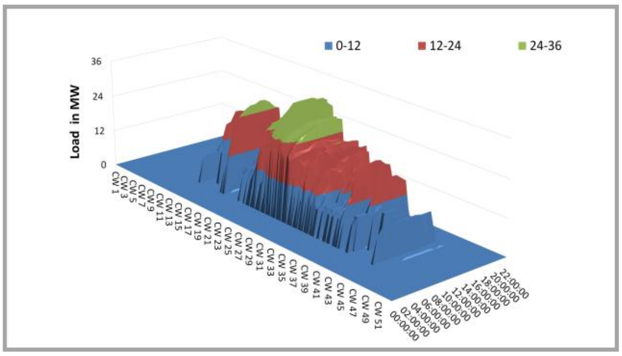

Figure 3: Hourly load shapes of the electrical demand for cooling for the 832 buildings resulting from climate data of 2010 (medium projection).

Similar projections have been obtained for the ventilation loads using operation hours for the standard DIN 18599-10. [7].

Mapping the DSM potential

A vital benefit of the method tested is the opportunity to directly display the results obtained in maps. Due to the lay-out restrictions connected to a conference paper this feature cannot be displayed here to a proper degree. The following figure 4 may give an impression though. It shows a map section of Hamburg city centre displaying the DSI potential of several buildings using a colour index from dark green (low potential) to bright red (very high potential).

Figure 4: Map of Hamburg city centre displaying the DSI potential for HVAC in office like buildings.

VALIDATION

For validation purposes the results obtained in the feasibility study were compared to the previously obtained results of the "e-Island" research project. In "e-Island" the DSI potential of the 20 most load intensive public properties of Hamburg were examined in detail doing site inspections.
For a number of these buildings the DSI potential was estimated in the feasibility study as well thus offering the opportunity to compare field data to the results obtained by the approach of the concept discussed in this paper.
Ii doing so it became obvious that the estimated load values for ventilation tend to be too low. This is especially so for buildings of the usage type "university". So even the high projection for the estimation of ventilation loads was (though only slightly) too low compared to real values.
In contrast to this the medium projection for installed air conditioning loads was found to be quite accurately displaying the "e-Island" findings.
Figure 5 displays the findings.

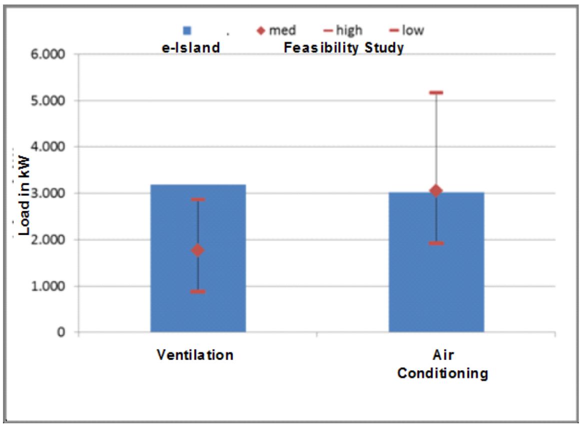

Figure 5: Comparison of the total load installed for ventilation and air conditioning of selected buildings analysed in both the "e-Island" research project and the feasibility study.

DISCUSSION AND OUTLOOK

Summarizing it can be stated that the method described in this paper provides a simple procedure to analyse and locate the DSI potential of a city. Validating the results to a building sample which was also analysed in detail in the research project "e-island" it was found that the data matches (for air conditioning) or almost matches (ventilation) the installed load values.

Comparing the data obtained to first results from the "active customer demand control" project of Vattenfall Hamburg suggests that the scale is reasonable: Vattenfall claims to have gathered 14 MW of shiftable load in 14 buildings of the usage category "trade, hotels and restaurants" and estimates the overall DSI potential of the city of Hamburg to lie in between 200 – 300 MW. [8]

Further research by the authors was carried out on an analysis of the retail sector using this method. Results suggests that about 22MW shiftable load from ventilation alone could be found in this sector.

Furthermore it can be stated that low projections of the installed loads for ventilation and air conditioning seem to be practically irrelevant. A medium to high projection of installed electrical loads seem to be applicable. New buildings might be an exception to this finding.

An important advantage of the method described is its extensibility. Using the method described it becomes possible to cover practically every building usage if

a) applicable energy performance figures are at hand,
b) existing rules for the application of such figures are known and respected and
c) due care is exercised in determining the correct energy related floor spaces.

Further research would enable an overall analysis of the DSI potential of all 340.000 buildings of Hamburg including the residential buildings.

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