MODELING ENERGY DEMAND FOR HEATING AT CITY SCALE

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ABSTRACT

A forecast of the individual heating energy demand of each building can be used for energy planning and management in a district heating network. The goal of this research work is to estimate such a potential for an urban quarter in Ostfildern, Germany. To achieve this goal, a method for the automatic extraction of the building's heating volume via a geo-information system is used. These geometries serve as an interface for the simulation model which calculates the building heating energy demand. The additional publication of the monitored consumption data via a Web Application is done to make residents aware of the sustainable urban development in their city.

INTRODUCTION

The research work presented is part of the European Union research project POLYCITY: "Energy Networks in Sustainable Cities". The purpose of this project is to find a method for facilitating communal energy management by forecasting of individual building heating demand.

Generally, to predict the heating energy demand at city-scale the most developed methods are based on GIS-technology. The easiest method is the method based on typification of districts, where the prediction of the heating energy demand is based on the district type, its size and number of buildings in it. This method, which is described by [Blesl, 2002], does not consider the buildings separately, but the size of the district type in km² as well as the the age of the buildings.

A more detailed method considers each building separately, whereby the heated gross area is estimated by the multiplication of the building ground area with the number of floors. Both methods can be also combined, as described by Blesl, 2002.

A higher precision in determining the building geometry is reached by using laser scanning data. [Blesl, 2010] combines the obtaining building volume with the building typology, to estimate the thermal parameters like heat transfer coefficients (U values). To verify the estimated U values for the appropriate building type, simultaneously taken infrared images of the city quarter are used. The data are then used to calculate the heating energy demand according to the European Directive DIN 12831. Assumptions are made for the window area. The user behaviour is not taken into account and for heating power calculations, heat-up times are not considered.

Other methods use very simple calculation models to predict the heating energy demand like e.g. the method based on degree-days [Sarak, 2002]. These methods estimate the heating energy demand using as inputs the difference between a constant room temperature and ambient temperature and as parameters the overall heat transfer coefficient [Jaffal, 2009].

More detailed methods use building simulation models, which require a large amount of data input [Mavrogianni, 2009]. Regarding the forecast of the heating energy demand at city scale a problem of data availability for the building simulation models can occur. Therefore, a very important aspect is to find a solution to forecast the heating energy demand of the buildings with the least input parameters possible, but giving reliable results.

Furthermore, as a consequence of the improved quality of thermal properties of buildings due to energy regulations, overall energy use associated with building characteristics is decreasing, making the role of the occupants more important [Santin, 2009]. Studies have shown that occupant behavior might play a prominent role in the variation in energy consumption in different households [Branco, 2004]. There is still a lack of studies regarding the impact of consumer behavior.

The method presented in this paper uses laser scanner data to determine the 3D geometry. The thermal building characteristics like heat transfer coefficient are taken from the building specification certificates for a few representative buildings for the whole analyzed area. As the buildings were all constructed within a short time period, where the same legal requirements applied for thermal standards, the thermal building characteristics are almost equal for all buildings.

Therefore, the parameters of the representative buildings for each building group could also be used for other buildings of the appropriate building group.

A Geographic Information System (GIS) together with an Access database are then used for the acquisition of building specific data, like e.g. outer building surface. Here, a special algorithm is developed, which enables an automatic extraction of the building's heating volume via a geo-information system. The so prepared geometries serve as an interface for the models which calculate the building heating energy demand with different levels of detail.

The modeling methods are first tested on one case study building and then used for other buildings to finally forecast the heating energy demand of the whole residential sector of the analyzed area. Measured consumption data were available to compare calculation results with real consumption of each building.

CASE STUDY AREA

Scharnhauser Park (SHP) is a residential area, which is located at the southern border of Stuttgart, Germany. This area is a former military area where working places, residential areas and green park sections are integrated to result in a harmonious living and transportation environment with high comfort and low energy consumption. The area of Scharnhauser Park has 178.000 m² and the population of SHP is almost 10.000 inhabitants.

About 80% of the heating energy demand of the whole area of SHP is supplied by renewable energies. The main heating and electrical energy is delivered to the buildings of SHP from the 8 MW_{th} wood fired co-generation plant.

Figure 1: Area of Scharnhauser Park [Source: SWE]

DATA ACQUISITION

Geometries via GIS

GeoMedia Professional is geo-information software, which enables the extraction of the following information:

- the building footprint area and building type from the Automated Real Estate Map (ALK-map)
- average building height from laser scanner data

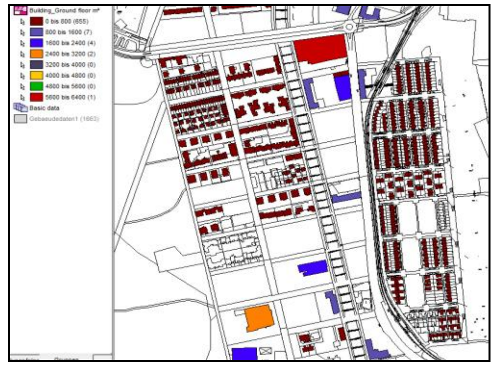

Figure 2: Thematic map with building footprints

Measured heating energy consumption data

The annual heating energy consumption data of all buildings of SHP originate from the archive of the municipal utility company Esslingen am Neckar GmbH. The data is delivered in form of Excel or paper sheets. In order to organize these data, a data model was developed and implemented in an Access database.

Thermal building characteristics

The only thermal characteristics of the buildings needed for the simulation model are the heat transfer coefficients (U-values). As the residential buildings were all constructed within a short time period, where the same legal requirements applied for thermal standards, the thermal characteristics needed for the simulation model are almost equal for all buildings. Therefore these values have been taken from the thermal insulation specifications available for two building groups (row houses and multi-family houses). The average U-values are shown in the table below:

Table 1 Average U-values for the buildings constructed between 2000 -2008.

Building category	**R OW HOUSES**			
Building element	**Outer wall**	**Roof**	**Floor**	**Window**
Avg U-Value [W/m²K]	0.22	0.165	0.21	1.3
Building category	**MULTI-FAMILY HOUSES**			
Building element	**Outer wall**	**Roof**	**Floor**	**Window**
Avg U-Value [W/m²K]	0.241	0.214	0.556	1.2

Weather data

Air temperature and global radiation data was provided for the whole year 2008 and 2009 from the weather station placed in the analyzed residential area Scharnhauser Park.

METHOD

The paper presents a method to forecast the heating energy demand at city-scale. For this we used an algorithm to extract the building geometries and developed a GIS-interface for the simulation model. We used the INSEL simulation software to implement two simple models to predict the heating energy demand of the residential buildings (www.insel.eu). We first tested both models on a case study building of the analyzed area and then used this method for other buildings of the analyzed area. The results have been validated by the measured annual heating energy consumption values.

GIS-interface as an input for simulation model

The given building footprints together with the measured building height are used to generate a topologically consistent 3D city model (Ledoux and Meijers, 2009).

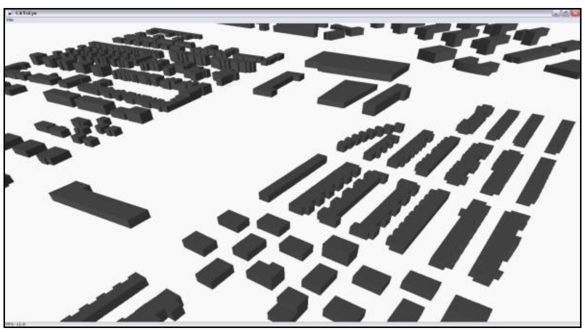

Figure 3: Topologically consistent 3D urban model of SHP

Topologically consistent here means that the geometry of a wall that separates two buildings, appears only once in the model. The two buildings sharing this wall reference its geometry in their boundary representation as proposed in the CityGMl standard (Gröger et al., 2008). The advantage of this model is that it is fairly easy to distinguish separate building elements like outer walls, walls between two buildings (mainly by row houses), roof area and floor area.

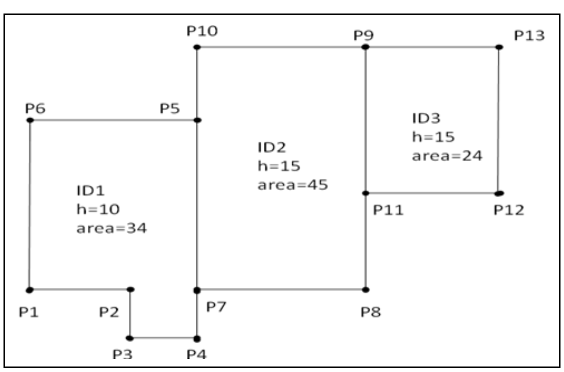

Figure 4: Example of the extraction of the building data

Based on this topologically correct 3D city model, the total area of outer walls, walls between buildings, ground floor and roof can be calculated per building as shown in Table 2 for the above example.

Table 2 Example of data calculation

Building ID	Ground Floor Area	Internal Wall Area	Outer Wall Area	Roof Area
	m²	m²	m²	m²
ID1	34	60	200	34
ID2	45	150	270	45
ID3	24	90	210	24

The window area was calculated as a fixed part of the outer wall area: 12% for row houses and 20% for multi-family houses.

The so prepared geometry data for each building was put in one data file and serves as a GIS-interface for the simulation model.

Calculation models

The GIS-interface, which includes building geometries, was finally fed into the Building Simulation Model by using the software INSEL (www.insel.eu). Two versions of models have been tested. The first one (Model 1) calculated the heating energy demand by taking into consideration only the transmission losses through the outer envelope of the building. This model corresponds to the degree day method. The second model (Model 2) considers the whole energy balance with transmission and ventilation losses as well as solar and internal gains following the calculation procedure from European standard DIN V 18599.

There are many parameters, which can be explored at the city-scale. In our case, parameters regarding building structure, insulation, etc. are not analyzed in detail, because the residential area of Scharnhauser Park is an area with similar low energy buildings standards. Regarding the user related parameters, our models gives a possibility to explore the following user influences:

1) Model 1 – heating set-point temperature and duration of heating
2) Model 2 – heating set-point temperature, internal heat gains, solar gains (different shadow effects), air change rate and duration of heating can be investigated.

In case of Model 1 the heating set-point temperature is set to a constant value of 20°C (without night time reduction). Model 2 has the following settings: set-point temperature of 20°C, air change rate of 0,5 1/h and internal heat gains of 5 W/m².
The accuracy of both models was checked by the comparison between daily measured and calculated data as well as a comparison between the annual values for one case study building.

Finally, the models were used for the calculation of the annual heating energy consumption for all residential buildings in Scharnhauser Park. The models output was then compared to the measured annual household heating energy consumption. The structure of this process is shown in the figure below:

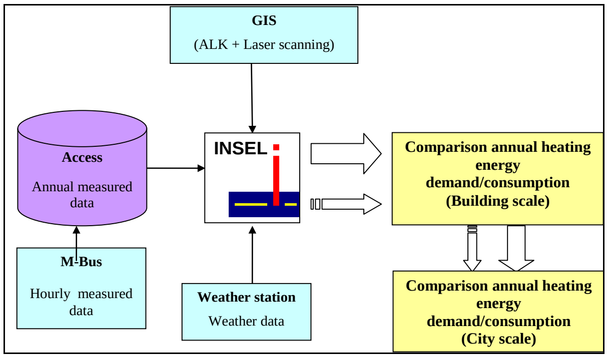

Figure 5 Overview of the method used

RESULTS AND DISCUSSION

Case study multi-family house

The case study building is a multi-family house with 12 flats with a heating gross area of 1688 m². The annual heating energy consumption for the year 2009 is 54,3 kWh/m²a. The deviation between this value and the calculated demand using the degree day method (model 1) is 6% when using the real geometry and thermal properties of the building taken from the building certificate. When the geometry determination is simplified or when average U-Values are taken, the error increases by 10 to 13 percentage points.

Table 3: *Errors in demand calculation as a function of geometry and U-value precision*

Nr	Calculation procedure	Deviation in %
1	Real geometries and real U-values	6
2	Real geometries and average U-values	16
3	Geometries from laser scanning and real U-values	19
4	Geometries from laser scanning and average U-values	29

The table shows how the precision of geometry or thermal properties influences the annual heating energy demand calculation. Due to the fact that all buildings are based on the calculation procedure 4 (geometries from laser scanning and average U-values) a deviation of 30% can be expected.

When the time step of the calculation is reduced from a year to a day, the deviation between demand and calculation increases for both the degree day method and the energy balance method (*Figure 6*), even when the correct geometry and U-values are used. This can be mainly attributed to user behavior such as ambient temperature dependent ventilation strategies, use of shading systems etc.

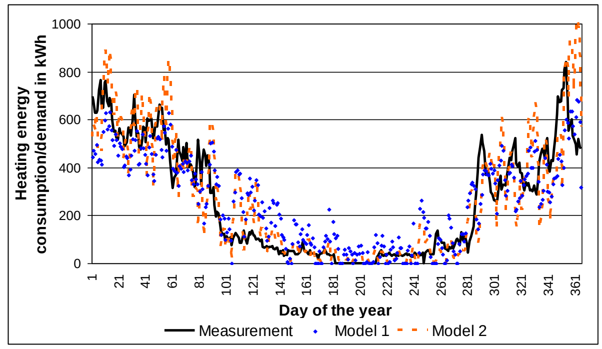

Figure 6 Daily measured and simulated profiles

These deviations will be further investigated in the future. Here, model 2 will give more opportunities to validate different parameters, especially the user behavior related parameters, like set-point temperature, internal heat gains, solar gains (different shadow effects), air change rate and length of heating.

The next diagram shows the heating energy consumption for different flats of the analyzed case study building. Here also the user influence for similar flat constructions is evident.

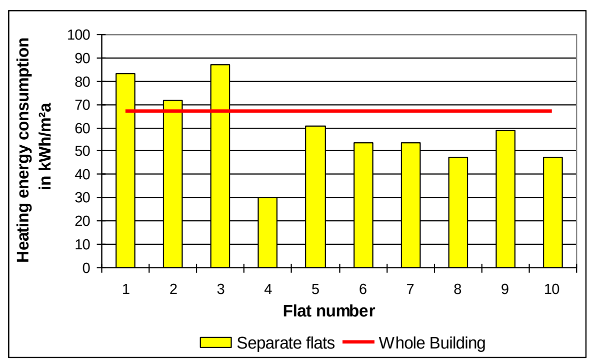

Figure 7: Annual heating energy consumption of similar flats in the apartment building

All multi-family houses

The following figure shows the comparison between the measured and calculated annual values for all multi-family houses for the analyzed area.

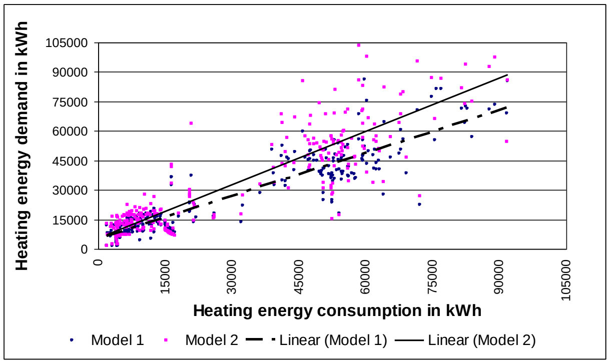

Figure 8: Comparison between calculated and measured data for all multi-family houses

The above comparison indicates a reasonable correlation between measured and simulated values in case of many buildings, but there are some extreme deviations. These deviations account for the quite high average deviation for all multi-family houses, which is 36% for Model 1 and 35% for Model 2. The linear correlation between demand and consumption over the whole range fits better for the energy balance method.

All row houses

The next figure shows the comparison between the measured and simulated annual values for the one- and two-family row houses.

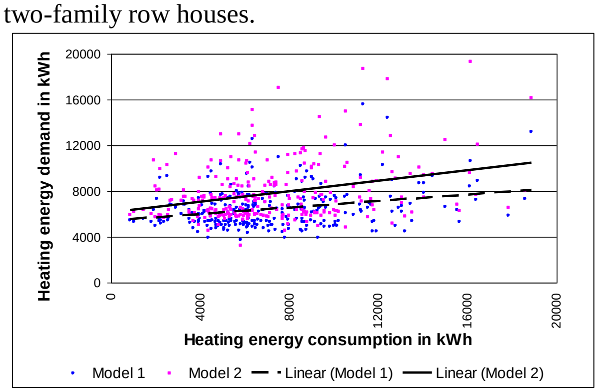

Figure 9: Comparison between measured and calculated values for all row houses

The average deviation between measured and calculated values is 31% (Model 2). The simple calculation Model 1 based only on the transmission losses gives a deviation of 30%. The linear fit does not work well in the low consumption range. User behavior and real occupancy of the buildings (exact time of construction or reduced use of a building) need to be checked more in detail for these buildings. Also the construction types of the row houses are quite different so that the use of one average U-value does not represent the reality well. This can be seen for the comparison of average heating energy consumption data for different types of the row houses with standard deviations up to 30%.

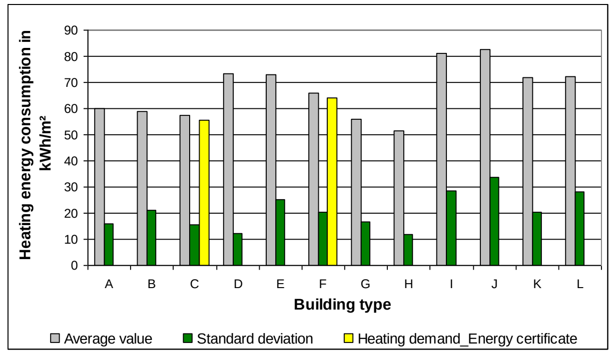

Figure 10: Average heating consumption values for different types of row houses

Other reasons for the discrepancies between measured and calculated values are as follows:

a) The measured heating energy consumption values consist of the heating and warm water consumption. The amount of the heating energy consumption for warm water is not known and therefore assumed as 12.5 kWh per m² heating gross area.

b) In some cases the heating energy consumption value is measured not for one building but for a group of buildings, what reduces the accuracy for individual buildings in this group.

c) The building heights were extracted from laser scanner data. For buildings built after the year 2002, laser scanner data are not available. For these buildings the height value is assumed as 7,5 m.

d) The U-Values used in the model are average values for all multi-family houses or row houses. Some of the buildings are older and have other U-values.

By summing up the simulation results for row houses and multi-family houses, the total energy consumption for the residential sector in Scharnhauser Park can be estimated. The result is compared with measured heating energy consumption values. On a city scale the energy balance model gives quite accurate annual demand forecasts.

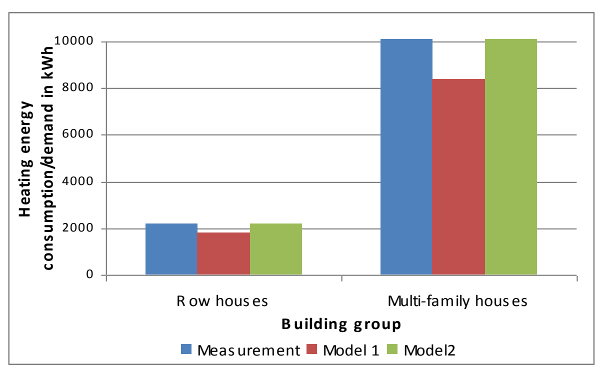

Figure 11: Overall annual comparison of measurement and demand for two building groups

CONCLUSIONS

This paper presents a method for the forecast of heating energy demand at city-scale. The aim of the paper is to apply simple heat balance methods to a large number of buildings and compare the measured consumption with demand calculations. For this an algorithm was developed to extract the building geometries from a GIS system and transfer them to the simulation tool. A degree day and heat balance method were used and validated for one case study building in the analyzed area, for which detailed daily and even hourly heating energy consumption data are available. The error of geometry and U-value simplification on demand calculations was determined for this building and was about 10 percentage points each. With accurate geometry and U-values, demand and consumption deviated by 6% only. If the whole city quarter is considered on an annual basis, the energy balance methods gives very good results with errors less than 5%.

If the time step of calculation is shortened or if individual flat consumption data are considered, the fluctuations are much higher. Here user behavior needs to be integrated into the models to reduce the discrepancy between demand prediction and consumption monitoring. As a conclusion, energy balance methods with simplified geometry data from laser scanning and average U-values and window fractions are capable of predicting well annual energy demand values. For shorter time steps or higher spatial resolution more detailed models including user behavior are required.

The results of the heating energy consumption are already published via Web Application as a GIS-map of Scharnhauser Park. It is also planned to publish the saving potential regarding the heating energy consumption to make the residents aware of the sustainable urban development in their city.

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