COMPARISON OF DIFFERENT ENERGY DEMAND CALCULATION MODELS ON URBAN SCALE

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ABSTRACT

Performing building life cycle assessment at city quarter level is a necessary step towards developing and implementing strategies for sustainable urban development. This paper compares energy demand calculation results of two established building simulation tools and a calculation according to the German Energy Saving Ordinance with those of an own developed tool. This tool is called *urbi+* and calculates the life cycle based energy demand of residential buildings at city quarter level. It is shown that the simplified method for energy demand calculation of the building's use stage delivers resilient results on building as well as on city quarter level.

INTRODUCTION

Introduction of the Overall Topic

One of the main challenges of the upcoming decades will be the creation of a climate-neutral building stock until 2050 (European Commission 2018). Technical facilities are already available and must be placed into a reasonable context (Jarek Kurnitski 2013). The aim is to reduce the energy demand of the existing building stock by increasing the energetic demands on the building envelope and the efficiency of technical building services by integrating renewable energy technologies (Chwieduk 2003).

Nowadays the simulation-based energetic analysis of buildings already takes an essential role in the planning of energy-efficient and sustainable buildings (Shoubi et al. 2015; Sousa 2012). Building simulations can therefore be used to show up a way on how to realize climate-neutral buildings, which can be reflected from already existing studies (Marszal et al. 2011; Nguyen, Reiter, and Rigo 2014).

However, these studies usually refer only to individual buildings or building complexes and to the energy demand of the use stage of the building (Ramesh, Prakash, and Shukla 2010; Reinhart and Cerezo Davila 2016). Nevertheless, in order to develop recommendations for action that point the way to a climate-neutral building stock, it is necessary to develop and carry out life cycle based energy and emission related analyses, evaluations and assessments of large building stocks. Although individual building-related pilot projects can demonstrate the concrete feasibility of climate-neutral buildings, the application and impact of the measures used to accomplish climate-neutral buildings must be calculated and evaluated on a large scale. But simulations on building and larger level(s) are mostly very time-intensive and error-prone (Remmen et al. 2018). The challenges of an assessment approach on urban scale are caused by different variables. For example, the heterogeneous building structure, where buildings of different building age classes can be present, or the data availability and quality (Peyramale and Wetzel 2017).

Therefore, the approach is to develop a tool (*urbi+*) that can provide a quick, automized and reliable calculation of the building's life cycle energy demand, to enable *urb*an *i*mprovement concerning sustainable development. Since the energy demand of the current building stocks use stage accounts for the largest share of energy demand along the whole life cycle of buildings (Assiego De Larriva et al. 2014), we are first focusing on developing a method for an reliable and quick calculation of the energy demand of the buildings use stage and to transfer it on a district, city or regional level.

Introduction of our Approach

We are using 3D city models, based on the open data model *CityGML* (Kolbe 2009), as one input-source for *urbi+* and as data exchange facility. A 3D city models contains different objects, in our case buildings, with specific information describing these buildings. This allows us to use and facilitate the exchange of information of large building stocks for the calculations. *Urbi+* additionally asks for a few input-parameters (see *Simulation* section) via a GUI. Having all the information together, calculating the energy demand for heating and domestic hot water (DHW) on the level of specific buildings and whole city quarters (depending on the number of building objects stored in the 3D city model and the specific selection of these) is the next step.

In this study, the methodical procedure for a fast and efficient calculation of the energy demand for heating and DHW at building and city quarter level is discussed. The results on specific building level will be compared with common and verified procedures of well-established building and urban simulation tools.

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Additionally, first extrapolations are carried out at the district level.

After the *Introduction* section a condensed summary of the *State of the Art* is presented in which a selection of well-known studies in this field are briefly described. Followed by this, the methodological approach of the study is presented in the *Methodology* section. This section provides a short description of the approaches and tools used in the scope of the study. Additionally, an overview of the methodological approach of *urbi+* and the considered case study are presented in this section. The *Methodology* section is followed by the *Simulation* section where the boundary conditions of the conducted simulations are presented. The following *Results* section summarizes the calculation results and provides conclusions with regard to the calculated values. The *Conclusion* and *Future Work* sections summarize the overall findings of the study and provide an outlook on what is coming next, regarding the further development of *urbi+*.

STATE OF THE ART

Large properties have a high potential for energy saving. However, the heterogeneous building stock, data availability and quality, etc. is a great challenge (Peyramale and Wetzel 2017). There are already models and tools available and there is also research in this field running, which allows the evaluation of existing buildings in regard to their energetic performance as well as considering possible refurbishment concepts, according to the state of the art.

Within the *HoEff-CIM* project, which was carried out at the Technical University of Munich, a tool was developed that provides an easy and cost-effective data collection of existing buildings. The so-called *QuickCheckTool* determines the energy demand based on the building age class and the actual condition of the building and proposes renovation concepts for the property. Based on an university campus, an energy master plan was developed which identifies the most energy-intensive buildings and provides recommendations for energy-saving measures. The refurbishment measures are evaluated with regard to energy, economic and ecological aspects. However, this tool only considers individual properties and a great deal of effort must be put into data collection and processing. (Dotzler et al. 2018)

An already existing tool which operates on 3D city models (CityGML) is *SimStadt*. *SimStadt* got developed at the *Centre for Renewable Energy Technology (zafh.net)* at the *University of Applied Sciences Stuttgart*. *SimStadt* is an urban energy simulations platform to calculate energy transition at urban scale. Within the first version, a solar and PV potential analysis as well as the calculation of the energy demand of buildings can be carried out. In addition, CO_2-emissions can be displayed and simulations of refurbishment measures can be performed (Nouvel et al. 2015).

City Building Energy Saver (CityBES) is a project located at the *Lawrence Berkeley National Laboratory*. It also uses the open data standard CityGML to support efficiency programs at district or city-scale. The web-based tool allows quick energy modeling and analysis of large building stocks. Energetic simulations are executed on an EnergyPlus calculation kernel. Furthermore, the PV potential is estimated and analyses for building refurbishment are proposed to support retrofit decisions (Chen, Hong, and Piette 2017).

Urban modelling interface (umi) is a Rhinoceros-based urban modeling design tool for observing and simulating entire neighborhoods. It consists of an integrated operational energy module based on EnergyPlus, a daylighting module based on Radiance/Daysim, an embodied energy and carbon calculation module and a walkability analysis of neighborhoods. The three-dimensional visualization of the city quarter allows a quick identification of the most energy-intensive buildings by colored marking (Reinhart et al. 2013).

The state of the art shows that there are already several models and tools existing, which allow to determine and visualize the energy demand at building and district level. In general, these models and tools are, however, focusing mainly on simulating the energy demand of a building's, or of all buildings in city quarter's use stage as accurate as possible. But comprehensive approaches of assessing the life cycle based energy demand of the structural building elements and technical building services is missing.

It should also be mentioned here that building simulation is still facing the problem of integrating proper user behavior models. That is one of the reasons why there is very often a large energy performance gap between the simulated energy demand during the design phase of buildings and the measured energy consumption during building use (Moeller et al. 2020).

Urbi+ is therefore focusing more on assessing the life cycle based energy demand of buildings, then on specifically calculating the energy demand of the building's use stage. However, since the use stage of the already existing buildings accounts for the largest relative share in total energy demand and environmental impact, considering all life cycle phases, *urbi+* first focuses on the specific assessment of the buildings use stage. Therefore, the following chapter describes a methodology to quickly calculate resilient and usable energy demand calculation results on building and city quarter level.

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METHODOLOGY

Methodical Approach of the Study

Within the study, four approaches/tools to determine the buildings energy demand are considered on the basis of a real existing reference building, which is used as a case study. The calculation results of *urbi+* are compared with the two different already established building simulation tools as well as a calculation according to the *Germany Energy Saving Ordinance (EnEV)* to prove that the simplified method, which is implemented in *urbi+*, delivers usable and reliable results.

Established building simulation tools:
1) *IDA Indoor Climate and Energy (ICE)*: *IDA ICE* is a building simulation tool developed by *EQUA Simulation AB*. *IDA ICE* allows a very accurate and precise dynamic simulations on the level of single buildings and building blocks. (EQUA Solutions AG n.d.)
2) *umi* (also see *State of the Art* section): The tool is used to evaluate, amongst others, the environmental performance, regarding the operational and embodied energy use, on urban scale.
3) Calculation according to EnEV and BEC: The *BEC* is based on the *German Energy Saving Ordinance (EnEV)*, and refers to the DIN-norms *DIN V 4108-6* (Thermal protection and energy economy in buildings – Part 6: Calculation of annual heat and energy use) (DIN V 4108-6:2003-06 2003) and *DIN V 4701-10* (Energy efficiency of heating and ventilation systems in buildings – Part 10: heating, domestic hot water supply, ventilation) (DIN V 4701-10:2003-08 2003) for the energy demand calculation. The BEC is an official and verified document that provides information on the energy performance of buildings in Germany.
4) *urbi+*: At the *Institute of Energy Efficient and Sustainable Design and Building* of the *Technical University of Munich*, *urbi+ is developed* for calculating the life cycle based energy and emission related performance (embodied/grey and operational energy and emissions) of large building stocks (based on *Java* programming language). More information to *urbi+* is provided in the following subsection *Methodological Approach of urbi+*.

To verify the results of *urbi+*, its calculation results are compared with the results of *IDA ICE*, *umi* and *BEC*. All results are based on one specific building, which is used as case study in a first step. The building is assessed in a refurbished and non-refurbished status. In total this leads to six calculation processes, which are compared with each other. In a following step the whole city quarter, in which the specific building is located, is assessed by using *urbi+*.

Methodical Approach of urbi+

The methodological approach of *urbi+* allows a quick and sufficiently accurate approach to determine the building's energy demand of the use stage, based on 3D city models (see Fig. 1). This process works iterative for all residential buildings in the 3D city model, which are chosen to be considered in the assessment. The summary of the results of all residential buildings under consideration provides the energy balance of the building stock to be assessed.

Assumptions
Before explaining the different methodological steps, its underlying assumptions are explained in a first step:
1) The calculation of the energy demand of the building's use stage is based on a single zone model.
2) There is no floor plan or specific zoning used for the calculation since this information is generally not available in 3D city models on large scale
3) Since also the information on the refurbished standard of buildings is not available, we assume that the condition of the constructional elements and the energetic standard of the building (e.g. u-values) refers to its year of construction.
4) All calculations refer to the regulations of the *German Energy Saving Ordinance* and therefore to *DIN V 4108-6* and *DIN V 4701-10*. The *heating period*

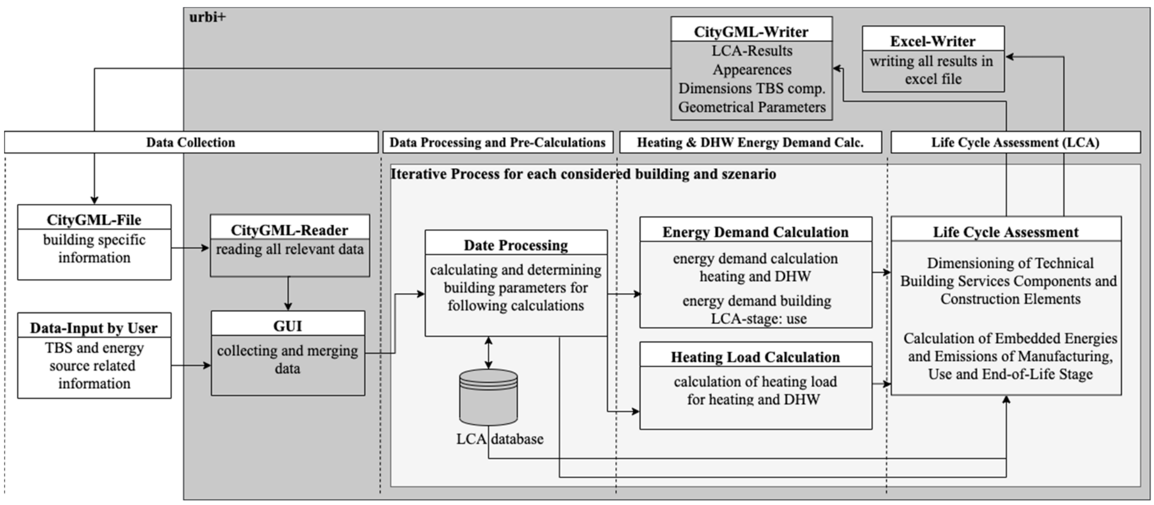

Figure 1: Overview Methodological Approach urbi+

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procedure is chosen as an approach within the norms. The length of this period is set to 185 days.

5) The used building model is available in level of detail 2 (LOD). This means, that the cubature of the building, including the roof shape, is available, but no windows or internal walls, etc.
6) The focus is set on residential buildings, since these account for 22% of the global final energy consumption (UN Environment and the International Energy Agency 2017).

Step1: Data collection
The methodological procedure for calculating the building's energy demand starts with data collection.
Building data for each considered building is specifically sourced from the 3D city model. The following information, mandatory for the calculation, must be available from each considered building in the 3D city model:

- Building geometry of wall, roof and ground surfaces, described by polygons.
- The building function or usage (e.g. residential, public, office building)
- The buildings year of construction
- The building's roof type
- Number of storeys above and below ground

Since building specific information concerning the building usage and the energy system are in general not available in 3D city models, this information must be provided for the calculation via the graphical user interface (GUI) of *urbi+*. The following necessary information has to be defined:

- Definition of thermal zone of the building (heated top floors and basements)
- Location of the building (for definition of average external temperature)
- Energy systems for heating and domestic hot water

Step 2: Data processing and first pre-calculations
With the information about the function or usage of the building, the residential buildings, which are to be considered, can be selected. In the next step the area of all building parts (walls, roof, ground) is calculated by using the provided polygons. With the definition of the thermal zones, the roof type and the general measures of the building, the building's net volume can be calculated. The living area is calculated by multiplying the number of heated storeys with the ground floor area and the factor of 0.89 (see Eq. 1) (Bogenstätter 2007).

$$A_L = A_g * n_S * 0.89 \quad (1)$$

A_L = living area [m^2]; A_g = ground floor area [m^2]; n_S = number of storeys [-].

Using the *SharedWallSurface* calculation tool, developed by Sindram for Kaden (Kaden 2014), the area of all walls that are 'shared' between building, e.g. for row houses, are calculated.
With the building's year of construction, the building can be sorted into a specific *building age class.* According to the *German building typologies*, worked out in the TABULA project (Loga et al. 2015), specific u-values and g-values are defined for all considered building parts of each building age classe*s*. In addition to that, *urbi+* allows an own definition of u-values and g-values for each building age class via the GUI, if required. The method of calculating window areas is based on an age-class related estimation of window areas in relation to the square meters of living space of a building, according to Heinrich (Heinrich 2018), based on Diefenbach et al. (Diefenbach et al. 2010) and Loga et al. (Loga et al. 2005), the window area is distributed evenly over all external walls that are not shared between buildings.

Step 3: Calculation of heating and DHW energy demand
The energy demand calculation for heating and DHW is conducted according to the simplified *heating period procedure* defined in the already mentioned norms *DIN V 4108-6* and *DIN V 4701-10*. The following main parameters are considered for calculating the energy demand for heating in a first step (see Eq. 2):

$$Q_h = Q_l - \eta_P (Q_S + Q_i) \quad (2)$$

Q_h = useful energy demand [kWh]; Q_l = heat losses (transmission + infiltration) [kWh]; Q_S = solar gains [kWh]; Q_i = internal gains [kWh]; η_P = utilization factor [-].

For calculating the *heat losses from transmission,* the defined u-values and calculated areas of all building components, according to the defined thermal zone of the building, are used. For the calculation of the *heat losses from infiltration* the calculated building volume is used as basis and multiplied with a constant factor, defined in *DIN V 4108-6*. The *solar gains* are calculated by using the calculated window area, their distribution over all non-shared walls and generic radiation values for Germany, defined in *DIN V 4108-6*. The *internal gains* are calculated by multiplying the calculated building volume with a generic factor, also defined in *DIN V 4108-6*.
The sum of *solar and internal gains* is multiplied with a *utilization factor* and then subtracted from the sum of *transmission and infiltration losses*, which results in the building's *useful energy demand*. The *utilization factor* thereby varies according to the average external temperature).
Additionally, the heat losses during and auxiliary energies for the transfer of heat into the room and for heat storage and distribution are added to the *useful energy demand*. The resulting sum is then multiplied

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with the product of the *heat generator expenditure figure* and the *cover ratio for heating,* both defined in *DIN V 4701-10*. This finally results in the building's *final energy demand*.

When calculating the energy requirement for DHW, a fixed value of 12.5 kWh/m^{2}a is initially assumed as the useful energy requirement, according to DIN V 4701-10. Analogous to the heating energy demand calculation the heat losses during and auxiliary energies for the transfer of heat into the room and for heat storage and distribution are added to the final energy demand of 12.5 kWh/m^{2}a. The resulting sum is also multiplied with the product of the *heat generator expenditure figure* and the *cover ratio for DHW*, which then results in the final energy demand for DHW.

Single and multi-building calculation

The model distinguishes between the calculation on the level of specific buildings and the calculation of the entire building stock. If individual buildings are selected for the assessment, the energy system can be defined for each building specifically (if information is available). If, however, an entire building stock is to be assessed, the distribution of energy systems over the entire building stock is used for energy demand calculations on individual building level. This means that if 80% of the buildings in a building stock are supplied with heat by a gas boiler and 20% by an oil boiler, then this percentage distribution is assumed for the heating energy demand calculation of each building in the assessed building stock. Each building is therefore supplied with heat by 80% gas and 20% oil boilers. This is due to the fact that the calculation of the energy demand of a whole building stock consists of the sum of all energy demand calculations of all considered buildings, in an iterative process, according to the method described above. However, as there is no building-specific information on the energy system on building stock level, the percentage of energy systems across the entire building stock is used for the iterative calculation process at the level of individual buildings. It is assumed that the resulting error is less than if a gas boiler is arbitrarily assumed for 80% of the buildings and an oil boiler for 20% of the buildings. For a specific, logical allocation of specific energy systems to specific buildings, the necessary data sets are missing. Due to the different building sizes, the resulting areas of the building components and the volumes, large deviations and possibly errors can occur when allocations are carried out arbitrarily.

SIMULATION

The following simulations are once carried out for one specific building, in all four described approaches/tools, and once for the whole city quarter, where the specific building is located in, by using *urbi+*. On the basis of the calculation of the entire city quarter, the transformation of the calculation method to large building stock is demonstrated.

Description of Specific Building

The object of investigation is an existing residential building in the city of Munich (see schematic illustration in Fig. 2) consisting of 72 residential units. The building was constructed between 1959 and 1960. The building and system technology were renewed in 1980. The heat generator was replaced in 2016. The main energy sources for heating and DHW are electricity and gas. The building has a usable area of 4,316m². There are BEC's from before (2009) and after (2017) a refurbishment took place available and used for the comparison.

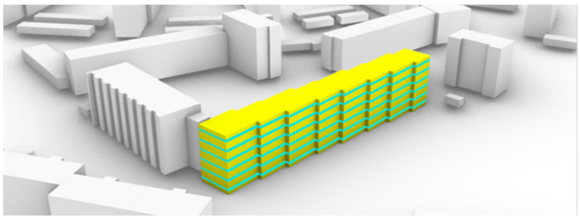

Figure 2: Graphical representation of specific building color marked in umi, Rhinoceros 3D

Description of Whole City Quarter

380 buildings are existing in the considered city quarter located in the city of Munich (see Fig. 3). 213 of these buildings are residential buildings. Around 70% of these buildings are built in the 1960's. The average living area is 664m^2 and the average net building volume 2,265m^3.

Figure 3: Graphical representation of city quarter

Definition of Simulation Input-Data

Specific Building: The following listing shows the essential boundary conditions that were assumed for the simulation of the non-refurbished status of the building. These are based on the data sourced from the CityGML model and provided via the GUI (according to information on *BEC* and of on-site inspections). These definitions serve as input parameters for the simulation/calculation of the energy demand for heating and DHW in the four different approaches/tools:

- all levels are heated
- heating: 100 % gas
- DHW: 80% gas, 20% electric flow heaters
- heat transfer system: 100% radiators
- u-values of the building envelope:
  - external wall: 0.4 W/(m²*K)
  - base plate: 1.0 W/(m²*K)

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- roof: 0.3 W/(m²*K)
- windows: 1.8 W/(m²*K)

- g-value window: 0.78
- average temperature (heating period): 7.9 °C
- minimum annual temperature: -16 °C

The following parameters are defined for the calculating a refurbished status of the specific building:

- all levels are heated
- heating: 100 % air-water heat pump
- DHW: 100 % air-water heat pump
- heat transfer system: 100% floor heating
- u-values of the building envelope:
  - external wall: 0.16 W/(m²*K)
  - base plate: 0.3 W/(m²*K)
  - roof: 0.15 W/(m²*K)
  - windows: 1.2 W/(m²*K)
- g-value window: 0.5
- average temperature (heating period): 7.9 °C
- minimum annual temperature: -16 °C

City Quarter: The calculation of the entire urban district is carried out in two runs. In the first run the definitions, applicable to the non-refurbished individual building, are used for the calculation city quarter level. However, it must be taken into account that the u-values and also the g-value automatically adapt and change depending on the age class into which the respective building is divided (see *Step 2* in subchapter *Methodical Approach of urbi+*). In the second run, the following definitions of energy supply systems, which are more realistic for the urban district, is adopted. All other parameters, except the u- and g-values, are remaining the same:

- heating: 30% gas, 10% oil, 10% heat pumps with geothermal probe, 10% electric heaters, 40% district heating
- DHW: 20% gas, 10% oil, 10% gas storage heaters, 20% electric flow heater, 20% solar systems, 20% district heating
- heat transfer system: 50% radiators, 50% floor heating

RESULTS

The final energy demand calculation results are presented for the non-refurbished and refurbished condition of the building. Additionally, two calculations are conducted on city quarter level, both with different definitions of input-parameters. Furthermore, the effect on the specific building calculation of changing parameters on city quarter level is shown.

Specific Building: The results for the non-refurbished status of the building show that *urbi+* calculates the highest (101.3 kWh/m^{2}a) and the *BEC*, with 24% less, the lowest (77.4 kWh/m^{2}a) energy demand (see Fig. 4). The simulation results of IDA ICE and umi both result in 92.3 kWh/m^{2}a. This is 8.9% lower than the result of the developed model and 19.3% more than the calculated value of the BEC. Comparing the results of the non-refurbished status of the building it can be seen that the *BEC* presents the highest energy demand (16.3 kWh/m^{2}a) and *IDA ICE* simulates, with 26% less, the lowest (12.0 kWh/m^{2}a) energy demand. The result of *umi* (12.1 kWh/m^{2}a) is almost the same as the *IDA ICE* result. *Urbi+* calculates a result in between, with 12.9 kWh/m2a. This is 7.5% more than the IDA ICE and umi results and 21% lower than the value from the BEC.

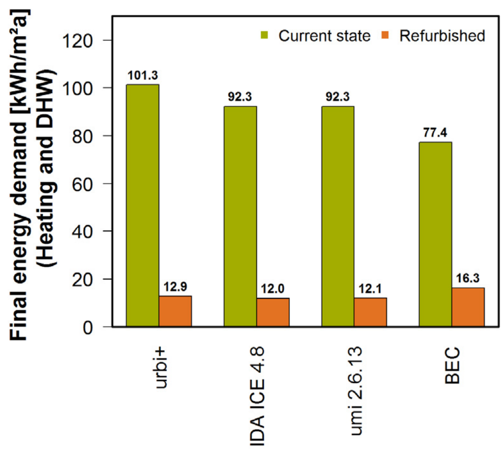

Figure 4: Comparison of final energy demand calculation results of the four different tools

The following reductions are thereby achieved: *urbi+* 87.3%, IDA ICE 87.0%, umi 86.9% and BEC 78.9%. The difference between the result of the developed model and the BEC is, however worth discussing, especially because both calculations are mainly based on the same ordinance and DIN-norms. The difference result from the fact that two different calculation approaches were selected within DIN V 4108-6. Firstly, the heating period procedure in *urbi+* and secondly the monthly balance sheet method, which is used for BEC according to EnEV. The heating period procedure is thereby a much more simplified and conservative approach. That is why the calculation result of the BEC is 24% lower than the one of the developed model. In the case of the refurbishment the changing parameters seem to have a much higher impact on the heating period procedure than on the monthly balance sheet method. one reason for this could be the significantly smaller dimension and complexity of calculation steps in the heating period procedure. This results in more dependencies within the method steps in the monthly balance sheet method and above all on specific parameters that are adapted within the method by changing the input parameters to depict a renovated condition of the building.Overall it can be stated, that *urbi+* calculates, when referring to the specific building, meaningful and reliable results.

The calculation can thus be put to use in the course of extrapolations at city quarter level.

City Quarter: The calculation time of the energy demand calculation (including all steps of the *data processing and first pre-calculations*) of all 213 residential buildings on a conventional laptop,

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excluding the definition of the CityGML-file and all specifications in the GUI, was seven seconds (no parallelization in code). The results show (see Tab. 1) that the yearly absolute final energy demand for heating and DHW of all 213 residential buildings account for 29.6GWh, which results in an average specific yearly final energy demand of 220.0kWh/m^{2}a. These values represent reasonable results in view of the building structure of the city quarter. The following change to a more realistic spread of energy system on city quarter level (second calculation) results in a reduction of 13% in the absolute and 12% in the specific final energy demand (see definition of energy systems in *Simulation* chapter and Tab. 1). This is also a logical result and, besides other, mainly due to the fact that in the second calculation more efficient renewable energy technologies are included in the percentage distribution of energy systems across the city quarter.

Table 1:
Calculation results of urbi+ on city quarter level

	first calculation	second calculation
absolute final energy demand [GWh/a]	29.6	26.1
∅ specific final energy demand [kWh/m^{2}a]	220.0	194.2

Specific Building vs. City Quarter: In a next step it is interesting to see how this change of the percentage distribution of energy systems across the city quarter (seconds calculation) affects the energy demand calculation on *specific building* level. The specific final energy demand of the non-refurbished status of the *specific building* is here presented (see Tab. 2).

Table 2:
Calculation results of urbi+ of refurbished and non-refurbished status of specific building

	first calculation	second calculation
∅ specific final energy demand [kWh/m^{2}a]	101.3	70.5

Looking at the results of Table 2 it can be seen, that a reduction of 30% appears from changing the energy systems from the first to the second calculation. The effect is even significantly higher than with the calculation at *city quarter* level.

This leads to the conclusion, which has not been further examined, that when assessing a whole city quarter, the energy demand calculation on specific building level should not necessarily be consider for further examinations. But that the overall result of the final energy demand at city quarter level represents a reliable and sufficiently accurate value for further studies and calculations.

CONCLUSION

This study has shown that our developed model provides reliable results on specific building and city quarter level and can be used as a basis for further studies. However, there must be a clear distinction between the assessment at a specific building level and the city quarter level. Otherwise, this can lead to misinterpretations of the results. With the validation of the calculation result of the use stage of the building, the first step towards a simulation tool (*urbi+)* to calculate the life cycle based energy and emission related performance of buildings is set.

FUTURE WORK

In the future, the developed procedure is to be supplemented by the aspects of Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) both for the building construction and for the building services.
The present state of work provides an excellent basis for this and above all, the already useful results for the final energy demand calculation of the use stage of the buildings under consideration (specific buildings and whole city quarters). In Addition, uncertainty and sensitivity analysis has to be carried out to get information about the possible error which could result based on the comparison of all different possible ways of input parameter definitions. This could also lead to optimization procedures, that provide an optimal usage of renewable energies. Also comparing calculation results on city quarter level with monitoring data, including building specific information to the energy system, would be helpful to evaluate the calculation results on specific buildings as well as the city quarter level. Additionally, the energy performance gap could be further assessed in the scope of such a study. In the meanwhile, *urbi+* is tested on a building stock of more than 115,000 residential buildings.

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