CITYGML-BASED 3D CITY MODEL FOR ENERGY DIAGNOSTICS AND URBAN ENERGY POLICY SUPPORT

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ABSTRACT

This paper aims to evaluate the accuracy and strength of a new approach that automatically calculates the heating demand of whole district areas, modelled in 3D with the open standard CityGML. For this purpose, two residential districts in Ludwigsburg and Karlsruhe have been chosen as case studies. To evaluate the accuracy of the model, the simulation results were compared to real measured consumption data and the model uncertainties were analysed. The mean deviations found between simulated and real district heating consumption are 7% and 21% for the two cases.

Beside the thermal diagnostics of the existing building stock, the paper shows how 3D city models could play a central role in the development of urban strategies for renewable energy supply and energy efficiency measures on both district and city levels.

INTRODUCTION

Accountable for around 80% of the oil, gas and coal world consumption, urban metropolises are the lead contributors of greenhouse gas production, a main driver of climate change, despite covering only 2% of the Earth's surface. A rapid transition of urban areas towards energy efficiency and adaption to challenges created by climate change are highly required.

In this context, 3D city modelling can be an essential tool for energy planners and municipal managers, enabling them to perform accurate diagnostics of the existing building stock, and to plan low-carbon urban energy strategies. These strategies consist of coordinating the decrease of building energy demand, the extension of sustainable energy supply concepts using a high renewable fraction, and the development of strategies for sustainable transport.

Every 3D city model approach that aims to simulate the energy demand of existing building stocks faces three main challenges. First, the variety of the building data availability and levels of detail in existing urban areas must be taken into account with a flexible data set standard. Second, a data pre-processing must address gaps in information by estimating the missing data and transforming the available ones. Last, a heating demand calculation must be found that is adapted for the city-scale purpose, while offering a good compromise between short computation time and high accuracy results given a limited input requirement.

To address these issues, two departments of the Hochschule für Technik Stuttgart, Energy and Geo-informatics, have jointly developed an integrated heating demand calculation process that is based on a CityGML city model.

In this paper, we first describe this integrated process in detail, and then test it on two case studies representing two different levels of data availability and detail. The results and uncertainties are analysed and discussed. Finally, we present further applications of this 3D city model, which aim to support cities to define their refurbishment priorities and long-term urban energy policies.

DESCRIPTION OF THE INTEGRATED PROCESS

3D city model with CityGML

The OGC Standard CityGML (Groeger et al., 2012) has been chosen for the modelling of 3D building data in our integrated process.

CityGML is an open, multifunctional model that can be used for geospatial transactions, data storage, and database modelling. It provides a basis for 3D geospatial visualization, analysing, simulation and exploration tools. Thus, it offers the possibilities for numerous and varied spatial analyses such as noise mapping, urban wind flow studies, photovoltaic potential, district network connections and extensions, heating demand calculations, simulation of refurbishment scenarios, and the integration of new buildings into an urban surrounding.

A considerable advantage of CityGML in comparison to other 3D city model formats is its spatio-semantic model, which specifies object modelling in different levels of detail. Due to this, it is an excellent database for heating demand analysis of existing building stocks, since the level of building parameter availability can be reflected in the Levels of Detail of CityGML (see Figure 1).

The most simple geometric representation of a building for a heating demand evaluation consists of a simple rectangular block. This block model consists of the "Level of Detail 1" (LoD1) of CityGML. The

Level of Detail 2 (LoD2) adds the roof form to the building level, Level of Detail 3 (LoD3) adds in the positioning of the façade windows, and Level of Detail 4 (LoD4) incorporates the modelling of the indoor space.

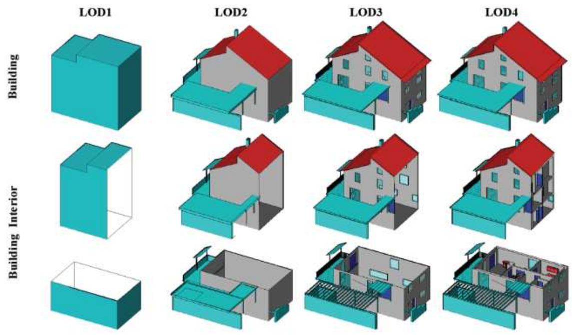

Figure 1 – The four Levels of Detail of CityGML (Groeger et al., 2012, page 72, Source: Karlsruhe Institute of Technology (KIT))

3D city model can be generated, either by stereo air photo, digital cadastre combined with building information (height, roof type), or laser scanning. In particular, the latter technique allows for an automatic generation of a CityGML model of whole cities in a short time. By 2013, the complete building stock of Germany will be modelled with CityGML – LoD1. Some regions like Saxony have already completed their 3D city model with LoD2 (Baltrusch et al. 2011).
For the analysis of the CityGML-based 3D city model, the specific Java-based software CAT3D has been developed at the Hochschule für Technik Stuttgart, extracting relevant information like volumes, envelope surfaces and orientation, adjacent walls and buildings etc.. Furthermore, given the diverse qualities of the 3D city models, the healing module "CityDoctor" has been integrated into the process, which allows for the control and enhancement of the geometrical quality of the 3D model by closing polygons and volumes or separating buildings with common adjacent walls (Coors et al., 2011).

Data pre-processing and enhancement

Systematic and automatic data pre-processing has been integrated in the process, allowing for the calculation of heating demands for different Levels of Detail and data availabilities. In many cases, only a set of building attributes are available (for example, building usage, building type and building age). Each additional set of building information data (number of storeys, date of full refurbishment, window proportion per façade, (non)heated attic/cellar story etc.) refines the urban thermal model and improves the result accuracy.

As the building's thermal properties such as heat loss coefficients (U values) are rarely known and the collection of this information is time-consuming, some implemented algorithms can be used to assess them by means of default values from building typology libraries (in Germany: IWU, 2003). Depending on the availability of additional information, these values can be updated, particularly in regard to refurbishment measures.

Such building typology libraries are essential to address districts with several hundred or thousands of buildings. These libraries can exist at a national level (e.g. Project Tabula, 2012), for certain regions (e.g. the states of Bavaria and Schleswig Holstein in Germany), or for specific city quarters with exemplary monitoring projects (e.g. Karlsruhe Rintheim). Generally, the more locally and accurately these building libraries are defined, the higher the accuracy of the on-site construction characteristics. As a result, this data pre-processing supplies formatted inputs to the heating demand calculation module.

Heating demand calculation

Regarding heating demand calculation, customary building performance simulation software tools are mostly not appropriate for a city-scale calculation. Namely, they require overly complex input thermal data, are not designed to use geometry input from city models, and have a programming and computation time that is much too long. Moreover, a thermal dynamic building simulation coupled with a detailed radiation model may not be a meaningful calculation choice if the window surfaces and their position per façade or the air change rates are not known, or when the heating data for building zones (e.g. attic, basement, staircase…) is uncertain or not available.

On the other hand, a purely statistical model, consisting of the multiplication of specific consumption ratios by the living area, does not benefit from the potential of 3D city modelling.

One compromising solution is the use of a simplified dynamical model based on an electrical analogy. Such a model has already been integrated in some urban energy simulators, in particular CitySim (Robinson et al., 2009). Stochastic human models, as well as a simplified radiosity algorithm (Robinson et al., 2005), were developed in parallel to the heating demand algorithm, answering the specific requirements of dynamical simulation at the urban scale. The accuracy of the simulated hourly heating demand is not easily verifiable. As far as we know, no confirmation with actual measures at urban scale and hourly basis has been carried out.

Another solution is the quasi-static monthly energy balance (standardised in the ISO 13790). This simpler but reliable algorithm has been selected in this integrated process. Its limited input requirements are compatible with a 3D city model, while its robust and reasonably accurate algorithm is used worldwide by energy standard organisations. Moreover, the computing time of this heating demand calculation is well suited to generate and compare long-term urban energy scenarios for districts with thousands of buildings.

From the standard ISO 13790, some simplifications and adaptations have been made. For example, every building is modelled with a single thermal zone, since their internal structure is not detailed for CityGML model LOD1 and LOD2. In the special case of multi-usage building, set-point temperatures, internal gains and air change rates have been averaged according to the respective used area.. Moreover, internal gains or air change rates are of a fixed ratio relative to living area, depending only on the building usage and building age.

Finally, an empirical "user-factor" has been introduced in the standard algorithm, aiming to adjust the standardised heating demand results closer to the on-site reality. This user-factor was developed by the *Institut für Wohnung und Umwelt* (Born, 2002), after observing that high energy bills often induce the tenant to only partially heat, or to reduce temperature set points and thus, save energy. Effectively, this factor modulates the heat losses, from 0.85 for old buildings, to 1.1 for PassivHaus, depending on the mean U-value of the building envelope.

The meteorological data used for the simulation are standardised regional monthly mean irradiances per façade orientation, as well as the monthly outside dry bulb temperature (DIN V 4108-6, annex A). The calculation algorithms are implemented in the software Insel 8.

Localization of energy saving potentials and definition of refurbishment priorities

Additionally to the heating demand diagnostics of the existing building stocks, refurbishment scenarios can be simulated with different building energy standards that are equivalent to different envelope thermal efficiencies (e.g. U-Values of the building elements, airtightness, thermal bridges). Energy saving potentials and refurbishment investment costs are then calculated, taking into account the targeted building energy standards, the actual building thermal efficiency, and the building element areas from the 3D city model. These energy and economical indices will assist energy planners and municipal managers in the definition of refurbishment priorities, as well as the development of a long-term urban energy strategy.

HEATING DEMAND DIAGNOSTICS

This method has been already tested over several districts in Germany (Eicker et al., 2012) and the Netherlands. This paper focuses on two case studies, the districts of Grünbühl in Ludwigsburg and Rintheim in Karlsruhe.

Case study Grünbühl in Ludwigsburg

Grünbühl is a residential district southeastern Ludwigsburg, Germany, with a total living area of 77.000 m² on a ground area of 15 ha. Most of the buildings were built in the decade after World War II, others later in the 80's. The majority of the building stock is still in the original state, although around 1% of the total living area has been refurbished per year (780 m²) since 1990. This value corresponds exactly to the national refurbishment mean rate, staying far from the European recommendation (2% / yr).

During the project EnEff:Stadt Ludwigsburg, a 3D city model was built using Level of Detail 1 (Building block model).

Necessary geometrical data, such as ground floor area and mean building heights measured by a laser scanning in 2002, and building attribute information, such as building usage, types, construction and refurbishment years) were provided by the municipality of Ludwigsburg. Thermal characteristics such as U-values were taken from the national building typologies classification (IWU, 2003). Additional relevant data were collected onsite (e.g. window proportion per façade, thickness of outside insulation for refurbished buildings, basement configuration etc.).

Based on this 3D city model, heating demands per building block were simulated. They are presented in kilowatt-hours per square meter per year, normalized by the reference heated area according to DIN V 18599-2, 2005. The simulated heating demand per building in Grünbühl varied from 30 kWh/m².yr for fully refurbished buildings in 2007, up to almost 200 kWh/m².yr for post-war building blocks in poor condition (e.g. cracked walls, humidity damage, non-airtight roofs and windows). The mean heating demand in this residential post-war district reached 106 kWh/m².yr.

Figure 2 – Simulated yearly heating demand, visualised in the 3D city model Grünbühl

To evaluate the accuracy of the model, simulated and real yearly heating demands were compared per building block and for the whole district. The municipal energy company Stadtwerke Ludwigsburg, which supplies natural gas to the majority of the buildings of Grünbühl, provided the mean gas consumption for the last five years for the different building blocks, adjusted with the degree-day method. From these data, the real heating demands were calculated assuming a gas boiler efficiency of 85% (Loga et al., 1997) and a domestic hot water (DHW) demand of 20 kWh/m²a. As information concerning the heating systems inside the buildings was difficult to obtain, particularly from the private owners, these assumptions of boiler efficiency and DHW demand must be considered with caution. For instance, it was at times unclear if some apartments use electric or gas boilers for the DHW preparation.

The mean deviation between the simulated and real heating demands for the whole district reached 21%, with a standard deviation of 11%.

Detailed at a building block level, most of the individual simulated heating demands overestimated the real demand derived from measured consumption between 5 and 30%.

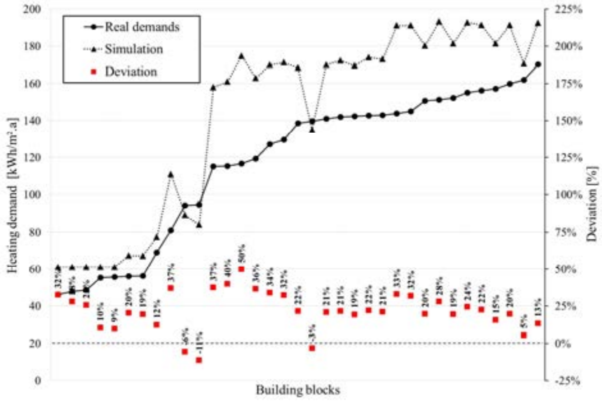

Figure 3 – Comparison simulated and real heating demand per building block in district Grünbühl

Case study Rintheim in Karlsruhe

In the residential district "Rintheimer Feld", the public housing society "Volkswohnung GmbH Karlsruhe" owns 30 buildings, with a total living area of 65.000 m². The buildings were built in two phases: 22 multi-family houses in the middle 1950's and eight tower buildings in the early 1970's. Between 1998 and 2008, 11 buildings were fully refurbished, the remaining 2/3 are either only partially or non-refurbished. A few years ago, a detailed energy audit was carried out for this building stock. The buildings were classified as follows into six different types, according to their energy efficiency:

- Type 1: non-refurbished multifamily-houses, built in 1954-1956
- Type 2: non-refurbished tower buildings, built in 1974
- Type 3: multifamily-houses, built in 1974, partially refurbished (façade in 1975, roof in 2003)
- Type 4: multifamily-houses, built in 1954, fully refurbished in 1998
- Type 5: multifamily-houses, built in 1954, fully refurbished in 2000
- Type 6: multifamily-houses and tower buildings, fully refurbished in 2007

The detailed information collected during this audit (e.g. U-values assessment, thermal bridges, heating system) was integrated in the 3D city model "Level of Detail 2" of the city Karlsruhe as building semantic information.

The heating demand was simulated per building block, and then summed for each of the six building types.

To compare the simulated heating demand with the real gas consumptions, the following assumptions were taken: a constant gas boiler efficiency of 88% and a DHW demand of 22 kWh/m².yr (data from the energy audit).

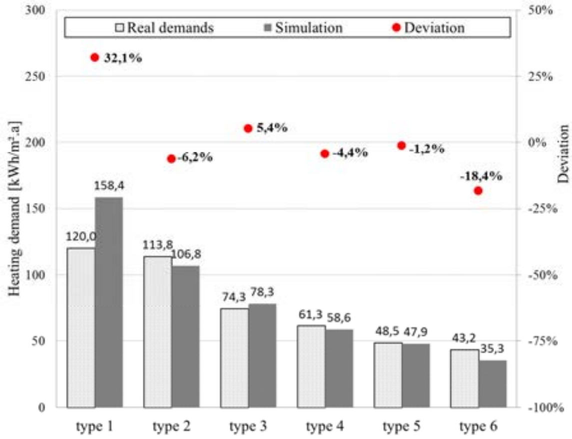

Figure 4 – Comparison of simulated and real heating demand per building type in district Rintheim

The mean deviation between the simulated and real district heating demand was +6.7%, with a standard deviation of 18%. The deviations for the four "middle-efficiency" building types laid between -6% and +5%, whereas the deviation was higher for the high energy consumers with an overestimation of the simulated demand of 32% (Type 1) and the high efficiency buildings with an 18% underestimation (Type 6).

In the building Type 1, single room gas furnaces supply heating, individually controlled by the tenants. This may explain the relatively low consumption observed in this building category, in which tenants might adopt energy conservation behaviour in order to lower their energy bills.

DISCUSSION ON THE MODEL UNCERTAINTIES

District heating demand deviation

In both presented case studies, the total simulated heating demand overestimated the real heating demand, by 21% and 7%. These deviations are acceptable from the perspective of a city-scale heating demand diagnostics when compared to the typical 20% oversizing of the energy supply systems.

In comparison with Grünbühl, the 3D city model of Rintheim showed simulation results closer to the real demand. The higher accuracy can mainly be explained by the higher Level of Detail (LOD2 versus LOD1) and the more accurate and detailed building thermal data.

By analysing in detail the single building results, we found the highest deviations (40% and more) occurred among the buildings with a lack of important information. Indeed, the accuracy of the simulated heating demand is directly correlated with the building data availability and uncertainty. For most buildings in the district Grünbühl, the simulation results overestimate the real heating demand between 5 and 30%.
Uncertainty regarding the installed heating systems must be mentioned as an important factor contributing to the deviation in results. Although heating systems do not affect the heating demand simulation directly, they are taken into account in the calculation of the "real" heating demand from the measured gas consumption, and therefore, relevant in the comparison between the simulated and real heating demand.

Other model uncertainties directly impacting the simulation accuracy can be grouped into the following categories:

- geometric uncertainties
- thermal uncertainties, including the physical building model itself
- uncertainties linked to the building tenants' profiles and behaviour

Geometrical uncertainties

The heated volumes and areas are often higher in the calculation than in the reality, since information on basement floor height, staircase and other unheated zones are not available in most cases. Moreover, a 3D city model LoD1 does not correctly consider the attic story in the case of pitched roof buildings. For buildings with only a few storeys, this can strongly affect the simulation results.

Another piece of geometric information often missing in 3D models of existing urban areas (at least LoD1 and LoD2) is the window to façade ratios. For the Grünbühl case study, the rations have been roughly determined for each building during a laborious two-day on-site survey. For city models where on-site survey would be too costly and time-consuming (wherein thousands of buildings are involved) or simply impossible, a general assumption, such as the 20% that was used for the case study Rintheim, or a building typology-dependent ratio is recommended for use.

In the case of 3D city models with façade textures, the determination of the window to façade ratios can be automatized with image segmentation algorithms (Felzenszwalb et al., 2004).

Uncertainties about the window to façade ratios may lead to errors in solar gain as well as heat transmission loss calculations, and therefore, affect the heating demand. Figure 5 represents the heating demand deviation relative to the window to façade ratio error for the Grünbühl district. The considered interval of window to façade ratio corresponds to the typical range for residential buildings: 10% - 30%. The results of this sensitivity study were detailed for the refurbished buildings, the oldest buildings and the whole district. For each of these building groups, the heating demand deviations were calculated relative to the mean value of real window to façade ratios: 17% for the refurbished buildings, 18% for the oldest buildings and 20.3% for the whole district.

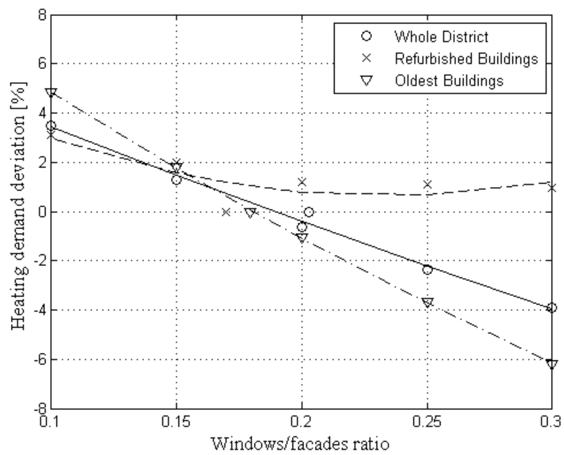

Figure 5 – Sensitivity study on window size

In the case of Grünbühl, the uncertainty on the window to façade ratio led to a deviation smaller than +/-5% on the total heating demand.

Nevertheless, this result cannot be generalized to other case studies, since it is specific to the climate, the main building orientation, and the difference between the wall and the window U-values. For instance, most old buildings of Grünbühl have new windows whose U-values are not so far from those of the walls (respectively 1.6 and 1.4 $W/m^2.K$). When the window size is overestimated, the increase of solar gains overtakes the additional transmission losses, and leads to a lower heating demand. In the Rintheim case study, an opposite effect on resultant heating demand is seen following an increase of the window/wall proportion, although the deviation also remains under +/-5%.

Thermal uncertainties

The two presented case studies illustrate concretely the importance of detailed thermal building information for model accuracy. If such detailed information is available, the total district deviation can be under 10%, as it has been shown for the district Karlsruhe-Rintheim. If no thermal information but only years of construction and occasionally refurbishment are available, the U-values are estimated according to building typology libraries, which leads in the case of Grünbühl to a total deviation around 20%. Besides, if some refurbishment years or refurbishment measures are missing in the model, which unfortunately is often the case for buildings with private owners, the building heating demand will be greatly overestimated. The simulated demand in this case can be up to three or four times greater than the real heating demand for an old fully refurbished building.

Another key parameter in thermal building simulation is the air change rate (sum of air infiltration, natural and mechanical ventilation) that is, impossible to measure at a district scale. The standard DIN 18599 recommends using a constant air change rate of 0.7 1/h (net building volume per hour) for existing buildings. However, experience shows that naturally ventilated buildings have generally lower air change rates than 0.7 1/h, leading to lower ventilation energy losses, and thus lower heating demand.

A study was conducted over 80 individual and collective residential buildings in eastern Germany, mostly older than 30 years old (AnBUS, 2003). It consisted of measuring the natural air change over a whole heating period using the gas tracing method. The results reveal that in 90% of the studied buildings, the mean air change rate over the heating period was below the hygienic threshold of 0.5 1/h recommended in DIN 1946-6, 2009.

Figure 6 represents the heating demand deviation caused by an error in the building air change rate for the case of Grünbühl. The reference air change rates of each building group in this figure correspond to the assumptions taken in the city model: 0.6 1/h for old buildings, 0.5 1/h for refurbished buildings, and around 0.55 1/h for the whole district.

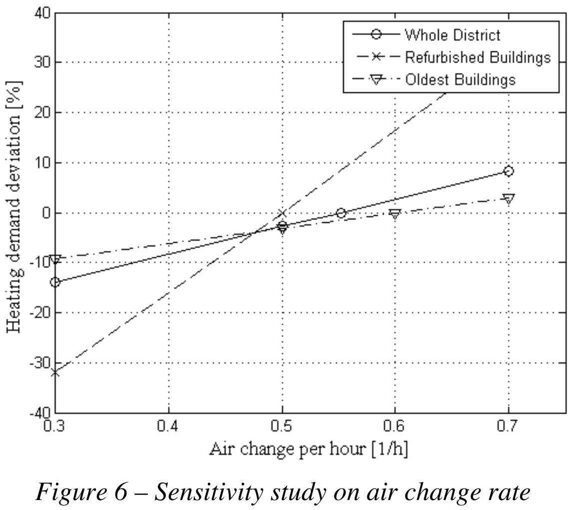

Figure 6 – Sensitivity study on air change rate

The impact of an error in the air change rate is the most important for the refurbished and modern buildings. Indeed, their ventilation losses have a sizeable contribution in the energy balance, comparable with the transmission losses through the building envelope, so that an error of 0.1 1/h in the air change rate assumption can lead to a 17% heating demand deviation. Due to the predictible air change of mechanical ventilation systems installed in most modern buildings, the uncertainty regarding theair change rate is lower than for old buildings.

For the oldest buildings, the heating demand calculation is less affected (in relative values) by an error in the air change rate, since the ventilation losses play a secondary role in the energy balance of old non-refurbished buildings that is far smaller than transmissions losses. For the whole district, the uncertainty in the air change could lead to a deviation of -/+10% for the total heating demand.

The use of the heating demand calculation algorithm standardised in the ISO 13790 may also partly explain the deviation due to its simplified physical building model (stationary and single zone) and of its standardised monthly meteorological data. Furthermore, the models do not take into account the influence of urban micro-climate nor the mutual shadowing effects among buildings.

Uncertainty linked with building tenants

The assumption of a fixed and unique heating schedule and set point temperature represents another cause of deviation for the single building heating demand. In the model, daytime full operation is the sweeping hypothesis for all buildings while night-time operation consists of a standardised 7-hour reduced heating operation. The different tenant profiles such as workers, retirees, couples with young children or others are not distinguished in the calculation.

Moreover, in reality, room heating depends on the current tenant activity. For example, sleeping and living rooms are seldom heated simultaneously. Empirical reduction factors for spatial and temporal heating of rooms exist and are part of the heat calculation algorithm. Nevertheless, these fixed factors lead to deviation for the single buildings.

As observed in particularly in the Rintheim case study, old non-insulated buildings often consume less energy than predicted by the simulation, whereas the most efficient buildings consume more. The user-factor developed by the “Institut für Wohnen und Umwelt” aims at reducing this general observed trend by linking with the “economical behaviour” of the users. Nevertheless, such a user-factor does not explain a consumption difference, as high as 20% observed between two identical buildings in Rintheim.

Some municipalities collect detailed information about the tenant profiles. In such cases, a tenant typology library could be developed with such parameters as set point temperatures and heating schedules specific to a tenant category. However, specific tenant models, although relevant to understand the deviation between the real and the simulated consumptions, are not required in the development of urban energy strategies. For such a long-term strategic consideration, given the inevitable fluctuation of the tenant family circumstances and the eventual tenant turnover, it does not seem essential to take into account the effects of a specific tenant profile or behaviour in the building heating demand calculation.

ENERGY SAVING POTENTIALS AND REFURBISHMENT PRIORITIES

In order to support municipal energy policies development, and more precisely to define refurbishment priorities, mapping of the energy savings potential per building is particularly useful.
The energy savings potential is obtained through the comparison of the existing heating demand, with a scenario where the building is refurbished according to a pre-defined energy standard.
In the case of Grünbühl district, this scenario consisted of the refurbishment of all buildings according to the German energy standard KfW-Effizienzhaus-85 (EnEV 2009).
This standard, characterised by the referenced U-values of Table 1, corresponds to a typical complete refurbishment with 10-15cm outside insulation, roof and basement insulation, and new double-glazed window with low emissivity coatings.

Table 1
Reference U-Values of a KfW-Effizienzhaus-85

BUILDING ENVELOPE ELEMENTS	**U-VALUES [W/m².K]**
Walls	0.28
Roof / top ceiling	0.20
Basement floor / ceiling	0.35
Windows	1.3
Thermal bridge	+ 0.05

In this case, the total heating energy saving potential reached 64%. Most buildings achieved a saving potential over 60% and building blocks built in the 1950's reached even saving potentials up to 75%. Buildings with a savings potential under 20% correspond to already refurbished buildings.

Based on these savings potentials, a district-scale refurbishment strategy was simulated for the period 2010 to 2050. The refurbishment rate was set to 2% per year following the recommendation of the German Ministry for Environment. The priority was given to buildings with the highest energy savings potential.

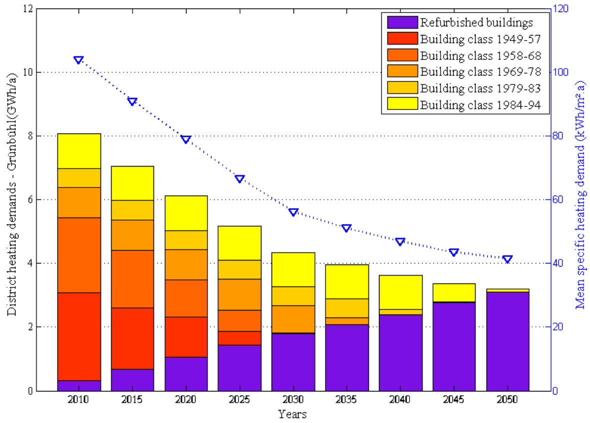

Figure 7 – Refurbishment scenario in Grünbühl over the period 2010-2050

With such an urban refurbishment policy, the total heating demand of the residential Grünbühl district would be cut in half after 25 years, and would reach nearly 40 kWh/m².yr by 2050 when compared to more than 100 kWh/m².yr demand in 2010.

Besides these heating demand calculations, a 3D city model allows also the planning of (renewable) district heating system extensions, the calculation of the district carbon footprint, as well as detailed economic studies. In order to calculate the refurbishment investment costs required to bring the building efficiency to the level of a targeted energy standard, a catalog of refurbishment measures has been developed. This catalog lists different insulation levels, such as a light inside insulation (e.g. 6 cm glass wool), thick outside insulation (e.g. 20 cm polyurethane), window standards, ventilation systems etc., and their corresponding physical (e.g. resistances and U-values) and economical characteristics (e.g. material costs, installation costs). The 3D city model provides the different building envelope element areas, which are multiplied by the unit price (€/m²) of the different refurbishment measures necessary to reach the energy standard pre-defined by the user.

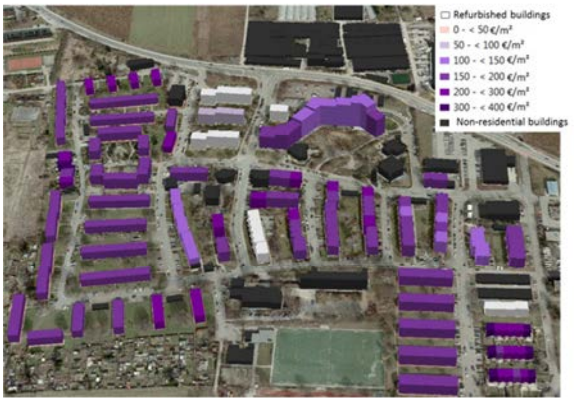

Figure 8 – Refurbishment costs, visualised in the 3D city model Grünbühl

These assessed refurbishment costs could be used as criteria for the definition of the refurbishment operation priorities. Alternatively they could be integrated in hybrid indexes combining physical and economical calculations, such as for instance "CO2 saving per invested euro".

CONCLUSION

3D city models offer an excellent dataset for automatized and reliable heating demand diagnostics.

If detailed thermal building information is available and accurate, the error for simulating the total district heating demand may lie under 10% like in the case of the district model Karlsruhe-Rintheim. If the building data availability and quality are low, the use of local building typology libraries relative to building/refurbishment years allow a reasonable district heating demand error of around 20% to be maintained, but can lead to high uncertainties for single buildings.

Accurate data collection that is applicable at the city-scale without being overly time-consuming, represents the major challenge for the generalization of 3D city model use. For this purpose, crowd sourcing could be an interesting path. Private owners could provide essential building data like construction standards, window areas and types, refurbishment measures undertaken and type of heating systems on a web server. The task consists of setting incentives to provide this data, as well as to control the data quality. Another option consists of geo-localised infrared thermographies, which allow for the automatic extraction of window areas, as well as refurbishment status and thermal properties using image segmentation algorithms. This is one of the goals of the new project SimStadt (SimStadt, 2013), which aims at providing cities and energy suppliers a useable simulation environment in the next three years.

In addition to heating demand diagnostics, which serves as a calibration phase, 3D city models offer opportunities to simulate energy scenarios, supporting city planners and municipal managers in the development of long-term urban energy strategies. 3D city models could also directly adress the building owners or tenants and allow them to calculate their energy savings potential and the investment costs of required refurbishment. Whatever the application, 3D city models have the potential to facilitate and support a wholistic city energy strategy and thereby, become a keystone of the energy transition.

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