BOTTOM-UP HEAT DEMAND MODEL

Lukas Goetzlich*, Richard Heimrath**, Ingrid Schardinger*, Franz Mauthner***, Markus Biberacher*, Martin Santa Maria*

*Research Studios Austria FG, Studio iSPACE

Schillerstraße 25, 5020 Salzburg, Austria

Phone: +43 662 / 90 85 85

E-Mail: lukas.goetzlich@researchstudio.at

** Technische Universität Graz

Rechbauerstraße 12, 8010 Graz, Austria

*** AEE – Institute for Sustainable Technologies (AEE INTEC)

Feldgasse 19, 8200 Gleisdorf, Austria

1 SUMMARY

The paper presents a harmonised bottom-up heat demand modelling approach, based on area-wide available data and therefore appropriate for a nation-wide implementation. Effective spatial energy planning depends on the availability of up-to-date energy related data and information in high spatial resolution and quality, especially to enable heat demand models on building level. The heat demand model includes necessary attributes and indicators of building use, envelope quality, building dimensions and heating/cooling systems. Input data on building footprint level is combined with data on address level. Additionally, a detailed analysis on energy consumption indicators (ECI) is performed. It considers the calibration and influences of the building characteristics on ECIs. The input data is specified in a data concept, as a general framework with regional adaptations, which considers the needs and situations of the participating regions (federal state Salzburg, selected Styrian communities, city of Vienna). Finally, the results of the heat demand model and its validation are presented.

2 INTRODUCTION

Reliable fundamentals are crucial for SEP and the respective decision processes. Spatial information has high relevance on the analysis of energy demand, renewable energy resource (RES) potentials and existing infrastructure, e.g.high heat demand density is a main indicator for district heating options. Existing heat demand modelling approaches on European and national level are often top-down approaches (e.g., Abart-Heriszt, Stoeglehner 2019, Buechele et al. 2015), which make use of a combination of publicly available data and statistics to calculate spatially disaggregated heat demand. These approaches are limited in their spatial resolution and reliability on the local level. 3-D city modelling approaches provide information for planning processes on a detailed level of the individual building (e.g., Nageler 2020). The application of these approaches requires high processing capacities and is therefore restricted to district level or smaller cities. There are also statistical bottom-up approaches like Schneider (2017) which focus on one single database like the national address- and building register and therefore show a high dependency on this data base and its quality. The various approaches cannot be strictly separated and are often used in combination. There are also approaches established between these two extremes that use the building footprints and additional data (e.g., Rehbogen et al. 2017) or detailed statistical data on address or building level (Mauthner 2019). Each approach has different advantages and limitations (e.g., the accuracy versus manageable spatial extension) and fits better to planning processes depending on the desired purpose. For the use in administrative processes, it is important to have detailed reliable information based on a harmonised and area-wide applicable approach. Therefore, the present research focuses on the development of a bottom-up heat demand model based on area-wide available data and applicable for a Austrian-wide implementation. The paper presents the GIS based methodological concept and the results of a bottom-up head demand model based on research conducted in the projects *Spatial Energy Planning for Heat Transition* (waermeplanung.at).

3 DATA

The basis of SEP is up-to-date data in high resolution and quality. An intensive input data analysis process in previous projects and studies (e.g., Götzlich et al. 2021, Rehbogen et al 2017, Schardinger et al. 2019) and especially the comprehensive metadata research in the project Enerspired Cities (https://geoportal.enerspired.city) showed that data quality of the existing energy related data is heterogeneous. There is no single data set that contains all relevant data in high quality. To create a solid information basis of the existing building stock, an extensive data concept was developed to compensate specific weaknesses and to benefit from specific strengths of single input data. A special feature of the framework is that it responds to regional needs and allows for customization in this regard. The data concept provides a broad framework for all indicators of SEP and is also applied to identify and structure (geo-) data for the building model. The data concept includes content-related data, technical specifications and structured answers to the question "What are the recommended data sources for which spatial indicators to provide which kind of user information/application?" Existing public and/or administrative data bases are used to enable efficient update routines. The data concept regards a thematic grouping into modules. In order to cover the requirements for SEP, data representing the usage, the geometries, the envelope quality and the conditioning of buildings were calculated. Table 1 shows the input data and their assignment to the corresponding modules. The building address serves as a key for linking the different data bases.

Table 1: Input data of the specific modules applied for the province of Salzburg

Modules / Data Basis	**Identi-fication**	**Usage**	**Quality of Envelope**	**Measures**	**Condi-tioning**	**Energy Consumption Indicators**
Register of addresses	x					
Digital cadastre data	x			x		
Buildings of orthophotos	x					
AGWR community data		x	x	x	x	
Open government data (OGD) of SAGIS concerning building's usages (e.g., hospitals, schools, retail etc)		x				
ZEUS energy certificates			x		x	x
Protected buildings			x			
Townscape protection zones			x	x		
Historic city protection zones			x	x		
Digital elevation model (DEM)				x		
Digital surface model (DSM)				x		
Zoning plan Land Salzburg				x		
District heating network					x	
Subsidised photovoltaics					x	
Subsidised solar collectors, biomass heatings, district heating, heat pumps					x	
Gas network					x	
Heating data base					x	
Water-water heat pump data					x	
Area of permanent settlement						x
Temperature data						x

4 METHODOLOGICAL CONCEPTS

4.1 Building Indicators

For each of the five modules, the output was defined according to the needs of information on building level for SEP. The first module consists of the linkage between address points and building polygons because there is no such database and it facilitates the assignment of secondary attributes. These attributes come from external data sources and can often be linked via address code or their spatial building footprint (polygon). Statistical information is available on address level, e.g. building use information is provided on address level by different sources (e.g. ddress related building and housing register -AGWR or open government data -OGD). In the second module, this information is joined to the identified buildings and 22 different use classes are assigned to the buildings. The building use is determined in detail, which means that every use that appears at the building, is considered. The third module deals with the envelope quality of the building. Herefore, the construction years serves as an important indicator. Unfortunately, there is a lack of detailed area-wide information about the quality of the buildings' envelope and its renovation state, because energy certificates cover the existing building stock only partly. Data analysis of AGWR has shown that data quality and completeness is heterogeneous especially for the building dimensions. For this reason, the fourth module models the dimensions (gross floor area, volume, envelope area, ridge height) based on the building footprint and the difference between the digital elevation model (DEM) and the digital surface model (DSM) following the approach of Spitzer et al (2021).. The building polygons provided by the GIS-Services of the province administrations are used as the data source for the footprints. In the final module, information from various sources about the conditioning system of buildings is collected and processed by complex algorithms. For example: Data on district heating and gas grids are used by identifying their endpoints and matching them with the closest building. For more detailed information on the assignment of building indicators look at Götzlich et al. (2021), Building Model for Spatial Energy Planning.

4.2 Detection and Calibration of Energy consumption Indicators (ECI)

ECIs are required to estimate the buildings' heat demand. The ECIs in this study are based on measured values of defined building archetypes. Measured heat consumption data is provided by the billed consumption values of around 500 biomass heating plant operators from all over Austria (anonymised), who are obliged to submit corresponding information to the funding agency annually as proof within the framework of the funded climate programme "QM Heizwerke". After cleaning the input data, a total of 42,578 measured values and building information from 8,780 supplied objects are available for the period 2010 to 2019, which are used for the evaluation. The evaluated consumption data correspond to the billed annual consumption values from the district heating transfer station at the customer's place. To determine the area-related heat consumption per building (q_{del} in kWh/m²GFA), the absolute consumption data (q_{del} in kWh/a) is divided by the conditioned gross floor area of the building (GFA_{kond} in m²) (equation 1). For the determination of the reference heat demand figures, the area-related heat consumption per building is climate-adjusted and statistically evaluated for different building archetypes. The present evaluation includes a total of 150 building archetypes, which result from the differentiation according to ten construction periods and 22 usage categories. The climate adjustment is required to determine the archetypal reference heat demand indicators q_{del} . For this purpose, a correction is made using the heating degree days (HDD) 22/14 according to ÖNORM B 8110-5 2019. For the HDD adjustment, each heat supply area was georeferenced using a unique object address and the consumption values were converted to the reference climate for each measurement year and each location. A climate data set from the Central Institute for Meteorology (ZAMG) with a resolution of 1km*1km served as the data basis. Thereby, these climate-adjusted reference heat demand figures can be converted to any climate in Austria. By multiplying the ECI (q_{del}) with the respective gross floor area, the heat demand (space heating and hot water) of every single building can be modelled. To determine the area-related heat consumption per building qdel in kWh/m²GFA, the absolute consumption data Qdel in kWh/a are divided by the conditioned gross floor area of the building (GFA_{kond} in m²) (equation 1).

$$q_{del}\left[\frac{kWh}{m^2_{GFA}.a}\right] = \frac{Q_{del}\left[\frac{kWh}{a}\right]}{GFA_{kond}\ [m^2_{GFA}]} \qquad \text{Equation 1}$$

Descriptive statistics and explorative data analysis methods were used to evaluate the area-related heat demand figures. The following evaluations and analyses were carried out for each building archetype:

a. Population characteristics
b. Histograms
c. Boxplots
d. Outlier analysis (threshold: 1.5 times interquartile range in boxplot)
e. Approximate test for normal distribution

As a result, a statistical evaluation for climate-adjusted area-related reference heat demand figures is available for each building archetype.Table 2 lists the archetypal heat demand figures of one- and two-family houses per construction period (where n: sample size as number of buildings; Q1: first quartile / quarter value; Mean (q_{del}): mean value of the measured energy in kWh/m²GFA-a; Q3: third quartile / three-quarter value; ØGFA: average gross floor area of the sample; ± SE: ± standard error of the mean value).

Table 2: Statistical evaluation of heat consumption data one- and two family houses

Construction Period	**n**	**Q1 [kWh/m2*a]**	**Mean (q_{del}) [kWh/m2*a]**	**Q3 [kWh/m2*a]**	**ØGFA [m²]**	**± SE**
bis 1918	154	84.9	128.3	165.8	188	4.8
1919-1944	145	74.4	122.3	155.7	174	5.6
1945-1960	498	83.9	129.6	166.3	175	3
1961-1970	498	76.9	117.8	151.6	183	2.7
1971-1980	556	77.7	115.2	143.2	186	2.3
1981-1990	363	76.3	113.7	145.5	184	2.9
1991-2000	326	76.7	109.2	136.9	181	2.7
2001-2010	385	61.4	94.1	117.0	174	2.6
2011-2019	251	56.5	84.5	102.7	169	2.6

4.3 Assignment of ECI

In the present approach, the buildings of the study area are assessed based on their energy characteristics. For this purpose, the following attributes are central to the energy behaviour of a building: The assessment of the building location, carried out in the module building identification, provides information about the climatic conditions under which heating and cooling take place (Figure 1, right). The use of a building is considered as every use has different effects on the energy demand (Figure 1, left). The building envelope quality is determined by the year of construction and the current relevant renovation status. 4) Furthermore, the compactness of the heat-emitting outer envelope is very relevant because it impacts the selection of suitable ECIs.

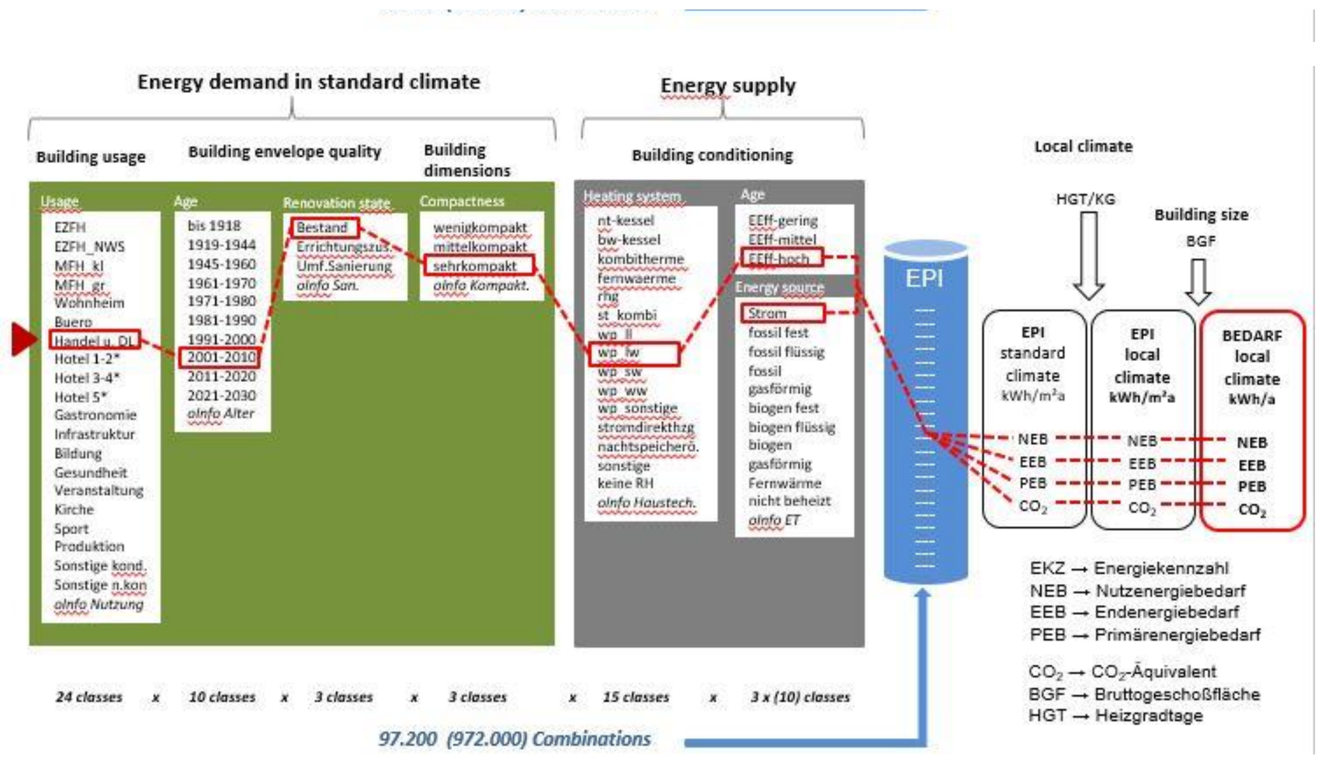


Figure 1: Schematic overview of the structure of the energy performance indicators - Characterisation of the building types and their heating systems based on the essential properties

Based on these indicators the heat demand on the level of delivered energy (q_{del}) is modelled for all buildings.

Delivered energy *is the amount of energy consumed at the point of sale (e.g., that enters the home, building, or establishment) without adjustment for any energy loss in the generation, transmission, and distribution of that energy. As such, it is the sum of fossil and renewable fuels (e.g., biomass or fuel wood) and purchased electricity. Delivered energy is sometimes referred to as "site" energy (Office of Energy Efficiency and Renewable Energy 2021).*

In this study, the heating energy demand (HEB_{DE}) is defined as the amount of energy required by the building for space heating and hot water production including the losses of the heating system. As the district heating transfer station has only about 1-3 % losses, this energy system is chosen to determine the HEB_{DE}. The development of the HEB_{DE} is based on a range of different literature references and additional calculations based on the simulation software IDA-ICE. The most important external sources were the master's thesis by Franz Mauthner (2020), the dissertation by Andreas Müller (2015), OIB-Guideline 6 (2019) and ÖNORM B 8110-5:2019 (2019). The following graphs show the heating energy demand (HEB_{DE}) of one- and two-family houses.

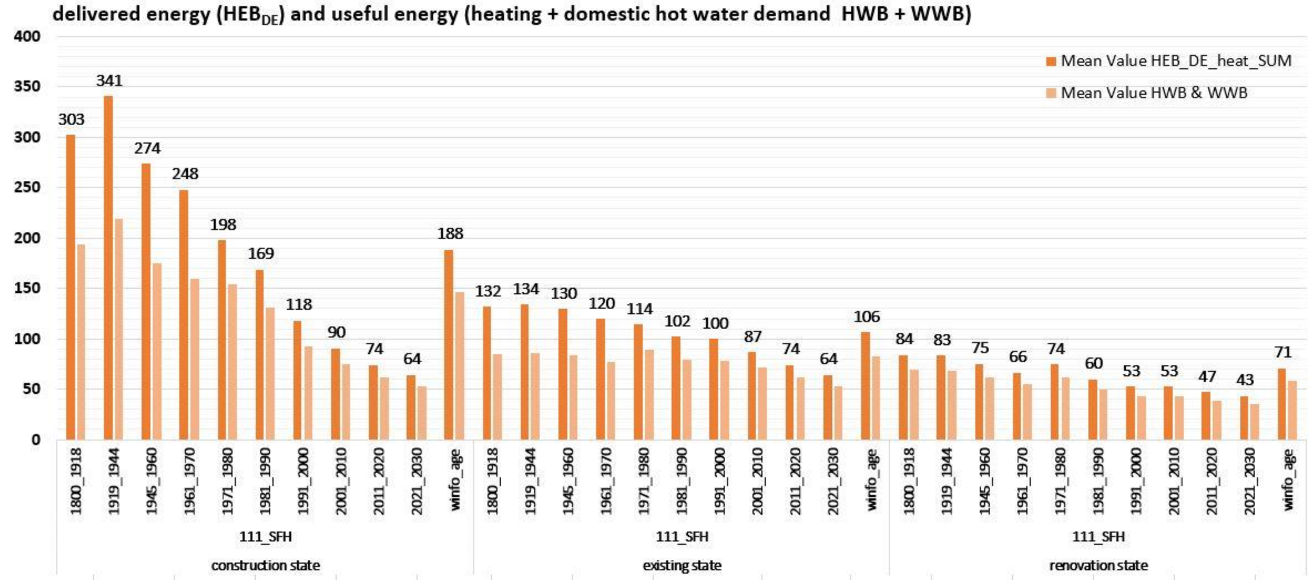


Figure 2: Heating energy demand (delivered energy) for single family houses (111) and second residence houses (112) (construction, existing and renovation state)

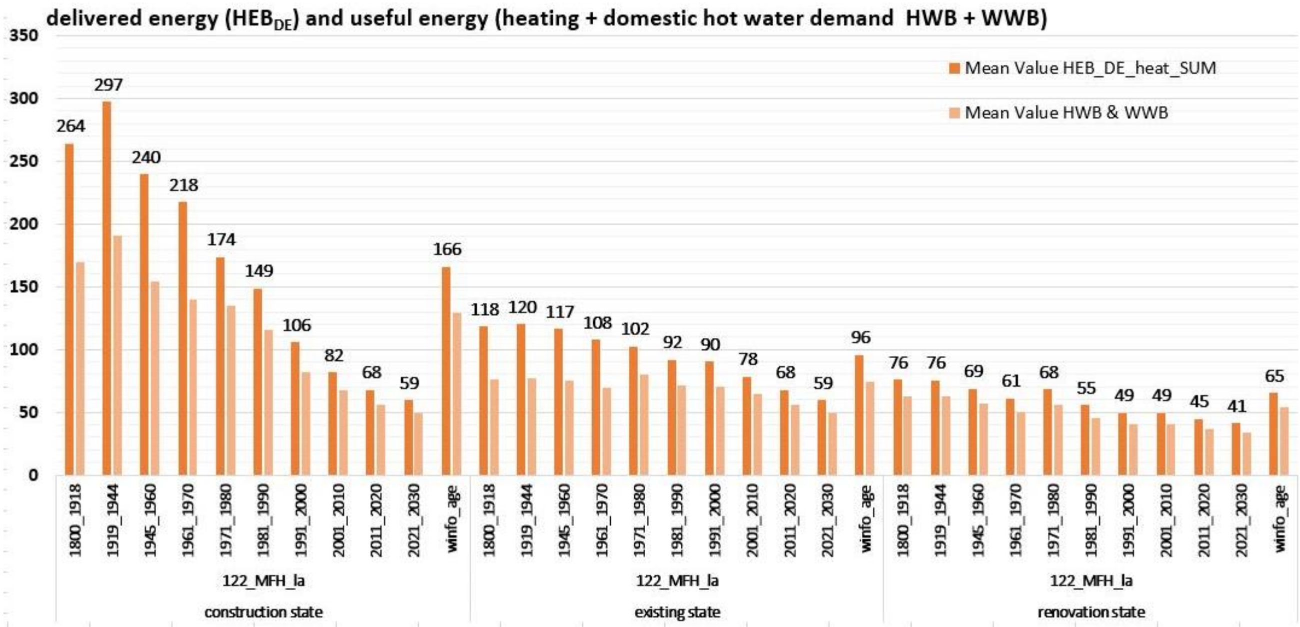


Figure 3: Heating energy demand (delivered energy) for large multi-family houses (122, very compact) (construction, existing and renovation state)

One can see that the renovation state is crucial for the thermal behavior of the buildings. Buildings with a compelte renovation have the lowest ECIs and therefor are more energy efficient than older buildings (see Figure 2 and 3). For further information please look at the Buechele et al. (2022), Spatial Energy Planning for Heat Transition-Deliverable 4.2-Recommendation for Harmonised Standards Methods for SEP (in press).

4.4 Generation of Heatmaps

In order to present the results of the heat demand model cartographically, the heatmap method is used, because it enables geographic clustering of certain phenomena. Hereby, density calculations from point data can be performed and displayed in maps. For further interpretations and evaluations, a smoothing by a spatially discrete weighting of identified demand values was implemented to determine spatially discrete heat demand densities.

Based on previous projects like “Heatmap Salzburg”, “Fernwärmepotenziale im Land Salzburg” and “Heatswap Salzburg”, the smoothing function of Figure 5 was used. It contains a Kernel of 91 x 91 cells of 5 metre = 455 x 455 meters, which is considered as weighing function in the context of a neighbourhood analysis. For example, Figure 4 shows the smoothing function, applied on raster cells. By executing the function, the value of the central cell is calculated out of the sum of its neighbourhood cells. They are weighted according to the Gaussian function displayed in Figure 4. In this way the mean value is calculated and written to the central cell. This method offers a concrete spatial statement about density values, by keeping data protection rules.

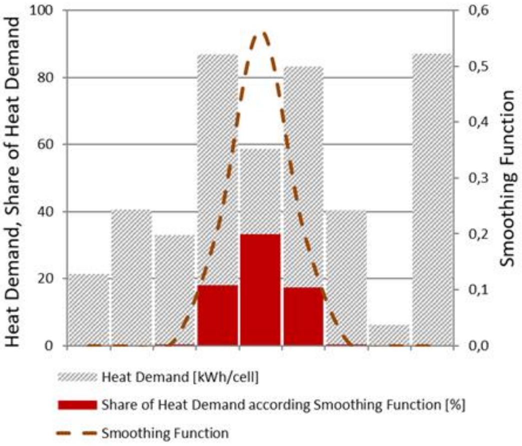


Figure 4: Example of the smoothing method

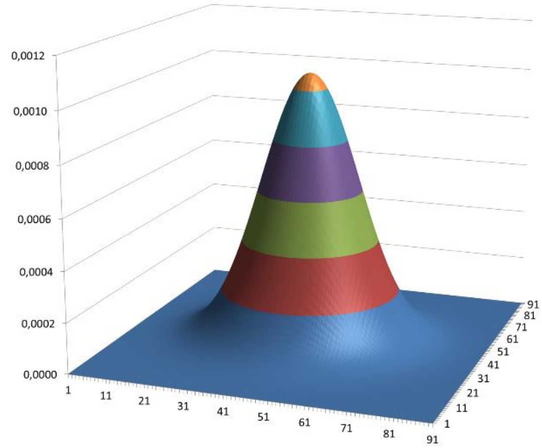


Figure 5: Applied Smoothing Function

5 VALIDATION

To validate the heat demand model, the measured heat consumption data of the “QM Heizwerke” were compared with the modelled data. The reference data set comprises 48 heating networks with in total 4970 buildings of different uses and approximately 12000 measured values over several years. The measurement data were georeferenced to make a comparison at the object level. A climate adjustment was carried out and the measured data was transferred to the reference HGT22/14 of 3824. In addition, incomplete and incorrect data records were eliminated. At building address level, the heat quantities (delivered energy) were compared using a Pearson correlation. The correlation analysis results in a strong linear relationship (r = 0,85) (Figure 6). The sum of the modelled values is 4 % higher than the measured values (Table 3).

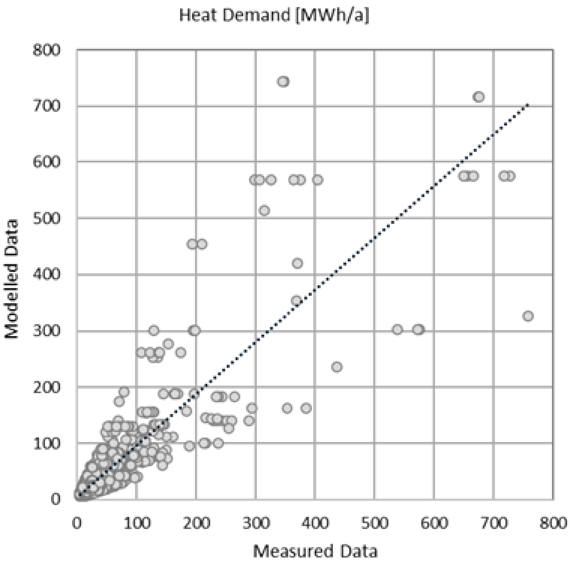


Table 3: Statistics of the measured and modelled heat values for correlation analysis

Sample size [n]	11124
Measured heat consumption sum [GWh/a]	516
Modelled heat demand sum [GWh/a]	538
Deviation of modelled heat demand [%]	+ 4
Correlation coefficient [r]	0.85

Figure 6: Graph of the correlation analysis of the measured and modelled values

Approximately 60% of the validated buildings have a residential purpose, with one- and two-family houses predominating. Therefore, this building category was additionally validated (Table 4). On average, the modelled value exceeds the measured value by 0.4 %. Figure 7 visualises the total heat quantities per construction period. Overall, the comparative values are of similar magnitude, whereby a slight overestimation of the older building stock is visible.

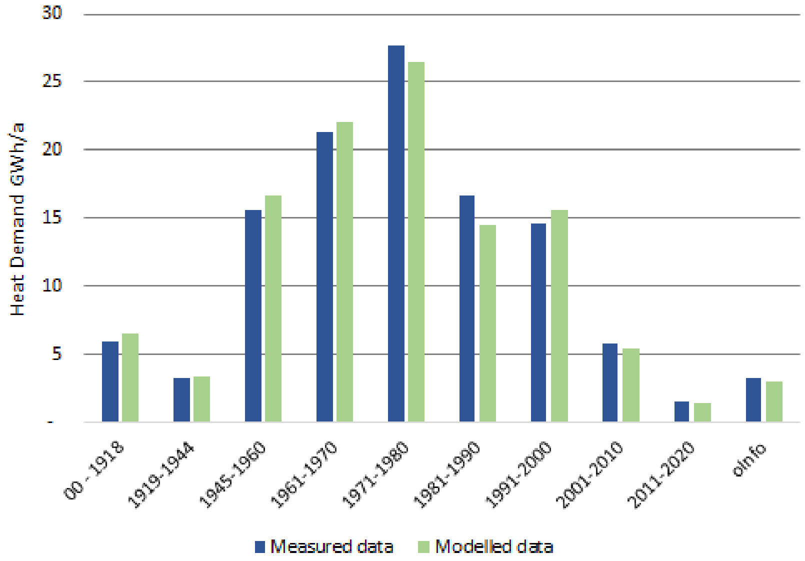
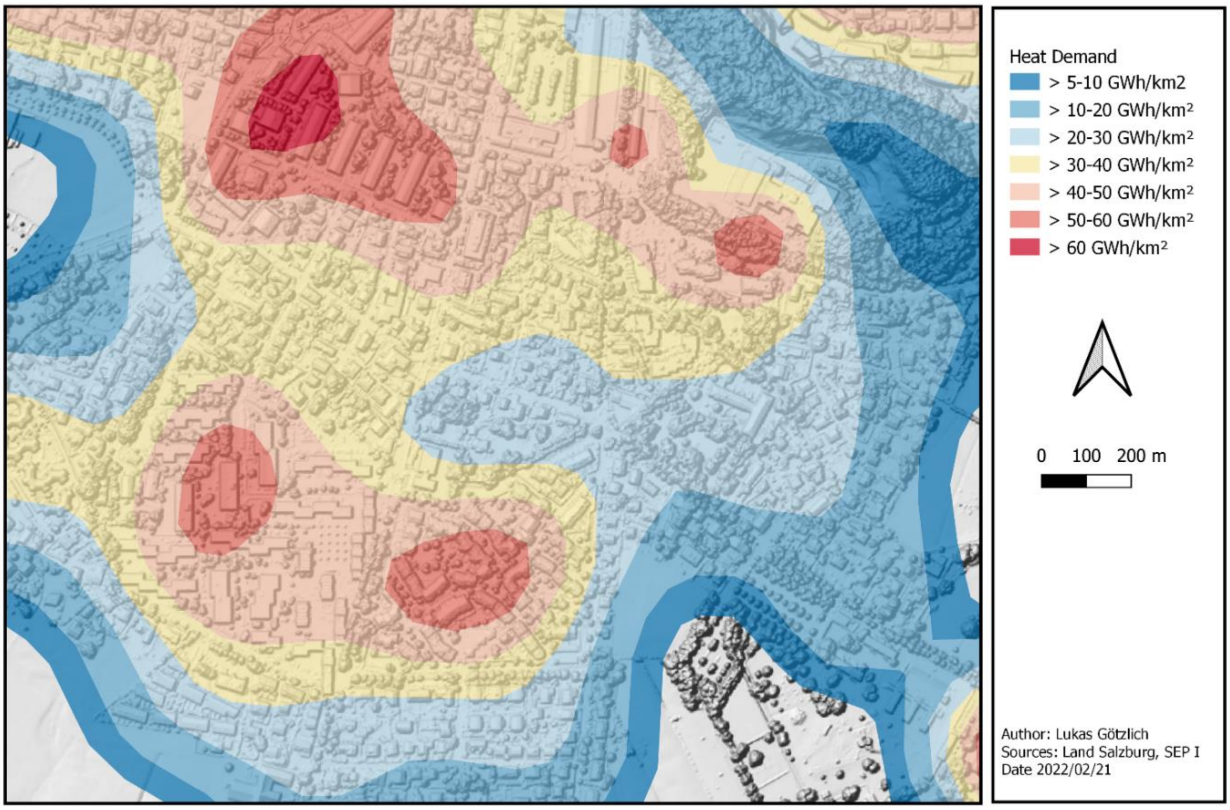


Figure 7: Heat demand per building period of one- and two-family houses

6 RESULTS

The methodological concept and the specified data concept were implemented as a prototype in the state of Salzburg, the city of Vienna and in regions of Styria. The concept and input data proved suitable to meet the information level needed for a bottom-up heat demand model in order to provide a substantial basis for spatial energy planning. All the results present the heat demand for the local climate of the buildings and include energy used for space heating and hot water. Figure 8 presents the heatmap calculated within the building model using the approach presented in 4.4. In comparison, figure 9 shows the heat demand on the building level. Based on the available measurement data of single and multi-family houses, figure 8 and 9 display a region consisting of a similar building composition. The highest heat density is found in the northern and the southern part in figure 8. A lower heat density exists in the eastern regions. More than 60 GWh/km² pear year is consumed in regions with a high heat demand. This raises the interest on the buildings in these regions, which are shown in figure 9. The multi-family houses in the south-west consume most of the heat and less energy is used by single family houses. This observation goes along with the pattern in the other regions. Altogether up to 800 MWh/m² of energy per year are demanded by residential buildings.



230 Figure 8: Heat Map of the study area

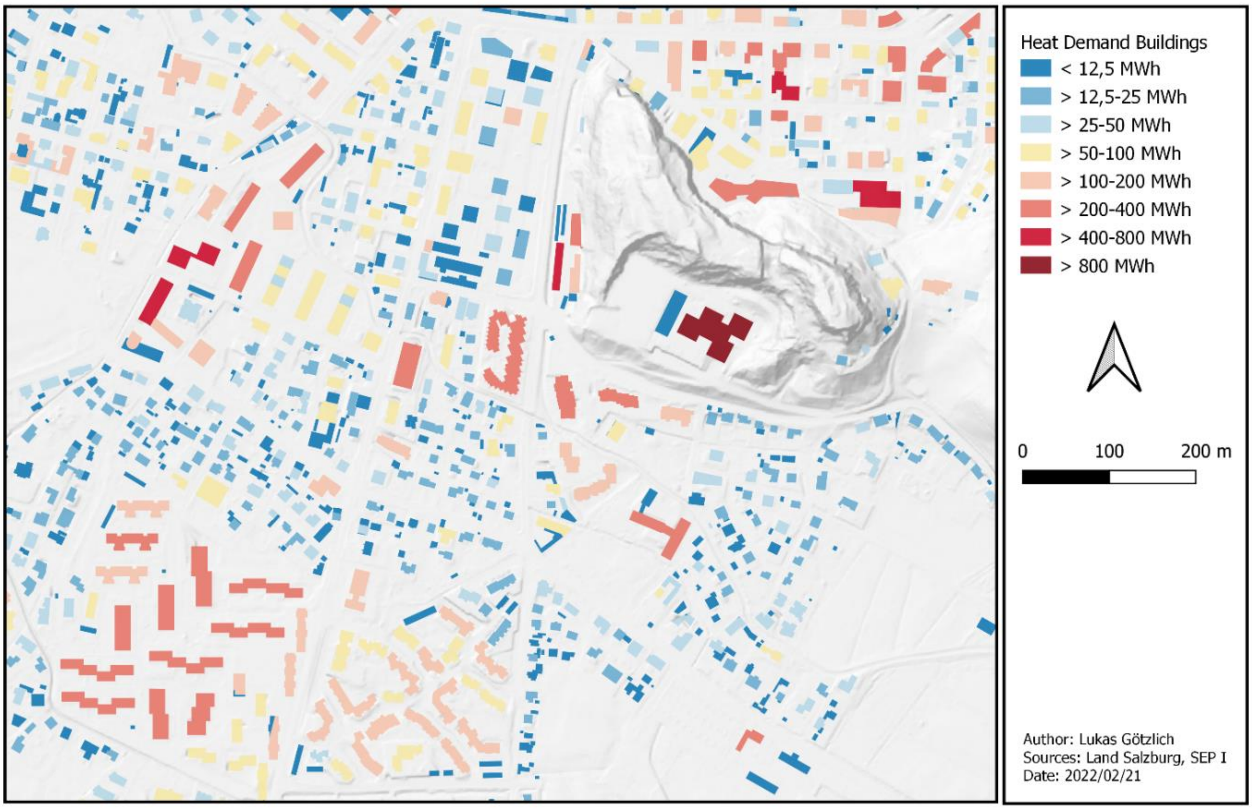


Figure 9: Heat Demand of the Buildings in the study are

Based on the developed heat demand model, further analyses on building use and building period were conducted for the federal state Salzburg. A total heat demand of 5.944 GWh/a of delivered energy was calculated for the federal state of Salzburg (Table 4 and Table 5).

Table 4: Heat demand and building usage

Usage Category	**Heat Demand [GWh/a]**
One- and two-family house	1676
Second residence house	259
Small multifamily house	916
Big multifamily house	466
Residential home	84
Non-residential sector	2543
Sum	**5944**

Table 3 also provides an overview of the distribution of the heat demand across usage categories. The largest share of heat is consumed by the non-residential sector (2543 GWh/a). Due to the high amount of one- and two-family houses in the study area 1676 GWh/a are demanded by this building category, followed by small (916 GWh/a) and big-family houses (466 GWh/a). Second residence houses only consume 259 GWh/a because the number of buildings in this category is smaller. The heat demand of residential homes is estimated at 84 GWh/a because of their small number in the investigated regions.

Table 5: Heat demand and construction periods of the buildings

Construction Period	**Heat Demand [GWh/a]**
until 1918	890
1919-1944	337
1945-1960	672
1961-1970	817
1971-1980	1052
1981-1990	818
1991-2000	504
2001-2010	472
2011-2020	240
No information	142
Sum	**5944**

Additionally, the construction periods of the entire building stock are regarded in context to the heat demand. Most heat is consumed by buildings constructed between 1961-1990 with a peak in the period of 1971-1980 of 1052 GWh/a. The heat demand for facilities constructed in the period until 1918 is at the same level than for the categories explained before. A reason might be the thermal characteristics of old buildings, which are not very efficient. There might be the opposite case for new buildings, so their heat demand is low 240 (GWh/a for buildings from the category 2011-2020).

7 CONCLUSION

The comprehensive model for the estimation of heat demand at building level has been validated as sufficiently realistic, especially for residential buildings, to provide a solid basis for SEP. Both, the linear correlation and the total sum suggest sufficient quality of the model. The integration of a broad range of relevant data allowed the high quality and completeness of the results. By using measured consumption data to determine the ECI, the heat quantities include a mean user behaviour. In discussions with energy suppliers and other experts, this result level proved to be adequate in order to determine district heating network potentials. Thus, the results of the building model are used as input for the estimation of the district heat potential areas, which were calculated in the same research project following the approach presented in Schardinger et al. (2019). Since the comprehensive spatially high-resolution model provide area-wide building and heat demand information and enables flexible aggregations, the results are of interest for a variety of applications. The results of the model will be displayed in a heat atlas, hosted by the GIS department of the federal state of the respective study area. The presented approach provides also essential information for the inventory analysis "Energy in the Spatial Development Concept", which the Salzburg Provincial Government makes available to all municipalities in the province. This inventory analysis serves as substantial basis to address the energy sector in the spatial development concept. The model is implemented in Salzburg Province, Vienna and regions of Styria and rollouts to other federal states are currently under discussion. Further applications using of model results are currently being worked on e.g., the District Report of the Municipality of Vienna and Local Development Concepts in Styria and strategic and monitoring purposes of the Province Administration.

However, the validation process also showed a need for further research in the non-residential sector. This is subject to ongoing research within the follow-up project GEL S/E/P II. Plausibility checks and more validations are also ongoing. The presented model provides the necessary indicators for the heat demand on building level and serves as a basis for electricity and mobility demand models in the ongoing project GEL S/E/P II.

8 ACKNOWLEDGEMENT

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10 CONFERENCE TOPIC

Spatial Energy Planning with Focus on Renewable Energies