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Computing Residential Heat Demand in Urban Space using QGIS. A Case Study for Shumen, Bulgaria

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1 ABSTRACT

Smart Cities need Smart Energy Planning. This requires knowledge about the spatial configuration of building heat demand, to facilitate circumspect decisions about where and how to renovate the building stock and what type of heating supply technology to implement. This paper presents a tool for static heat demand computation for residential buildings within the open-source Geographical Information System QGIS. It comes in the form of a Python script that analyses building geometries, accounting for walls shared with neighbouring buildings and computing heat demand according to the German norm DIN-4108-6. The novelty of the approach presented here, compared to standard procedures to compute urban heat demand which rely on building typologies, lies in the individualized computation for each building which allows for the inclusion of building specific characteristics not accounted for in standard building typologies.

2 INTRODUCTION

2.1 Smart Cities Need Smart Energy Planning

Smart cities make use of smart technology in service provision, governance and planning. Energy provision is no exception, in fact it is one of the drivers of the development of „smart" urban technology. Climate protection demands an increased effort towards energy efficiency and smart energy planning.

This requires the development of new tools, in particular, for modelling and simulation of heat demand in the building sector. The efficiency of heat provision has an important spatial component, since heat transport, much more so than electricity transport, gives rise to losses. Providing heat for the building sector (space heating, space cooling and hot water) accounts for a large share of urban primary energy consumption and associated CO2 emissions.

While thermal building simulation has been performed for decades at the individual building level, it is only in the last few years that it begins to be performed in an urban context with explicit spatial reference.

2.2 Accounting for the spatial context of heat demand

The spatial distribution of building heat demand within a city is relevant for several policy and planning questions: "Where to implement energy-efficiency measures?" and "what type of heating system is best suited to meet sustainability and climate protection needs?", possibly also "where to demolish old construction, and where place new one?". The answer to these questions (from an energy-efficiency and reducing CO2-emissions perspective) requires information at a spatial scale finer than the entire city.

Ideally, information on the heat energy needs of a building should be available at the building (or even dwelling unit) level. From there, the figures can be aggregated straightforwardly to different, coarser levels, appropriate for the purpose of the analysis. One approach to obtain a spatial reference is to use a digital building cadastre and based on building characteristics to assign a building heat demand type from a residential building heat demand typology (usually in the form of a KWh/m2*annum value). This yields a spatially referenced building stock with values for heat demand per square meter of floor area which can easily be transformed into total heat demand for a given building by multiplying with the floor area of the building according to the digital cadastre or into a heat demand density for hectare of urban space.

2.3 Organization of the paper

This paper begins with an overview of current approaches to estimating the heat demand of residential buildings at large scales, in particular, various building typologies. Then, the need for increased flexibility is explained and a different approach is proposed. This approach is implemented in the form of a software tool, which is then applied in a case study for the city of Shumen, Bulgaria. Residential heat demand for the entire city is computed and resulting spatial patterns are discussed. Finally, a measure of the usefulness of increased flexibility and the potential gain of heat demand estimation precision are presented.

3 ASSESSING URBAN HEAT DEMAND WITH BUILDING TYPOLOGIES: STATUS QUO

Until a few years ago, the spatial referencing of heat demand was achieved (in Germany) through the use of urban space typologies, offering urban space types ("Stadtraumtypen") with average heat (or heat and electricity) densities (i.e. in the form of a KWh/m2*annum value). These urban space typologies were derived from specific case studies of urban areas; city maps were then partitioned into different areas which were assigned an urban space type. (F.ex., see (Everding, 2007) – a recent example of this method is the Energieatlas Wilhelmsburg 2010 (IBA Hamburg Gmbh et al, 2010).

With the advent and availability of digital cadastres (in the mid-2000s), it became possible to carry out this classification into energy demand types at the building level. An electronic cadastre is more than a map of a city. It contains information on geo-referenced individual buildings.

This allowed combining "building typologies" with digital cadastres. Building typologies have been developed in Germany since the early 1990, for policy studies addressing the building stock – back then without the intent, or the possibility, to apply them in a spatial context (Institut Wohnen und Umwelt, 2005).

Numerous such typologies have been created since then – building typology for the State of Schleswig-Holstein (Arbeitsgemeinschaft für zeitgemäßes Bauen e.V, 2012); for Germany (Blesl, 2002); for the city of Hamburg; (Ecofys Germany Gmbh, 2011). The most prominent example is the TABULA project (Episcope/Intelligent Energy Europe, 2009-2012), as part of which national building typologies for 20 countries were developed. These include Germany (Institut Wohnen und Umwelt, 2011), Austria, Great Britain, Serbia, Bulgaria and many others.

Although they differ in some respects, all of these building typologies use the construction type of a building (e.g. single-family house, row house, prefabricated block of flats etc.) together with the construction epoch (e.g. built between 1960-1969) in order to evaluate its thermal properties and assign a value for the heat demand per square meter floor area per year (KWh/m2*annum). Some typologies also include calculations for heat demand for warm water, which however is not addressed in this paper.

Given a building typology and a digital cadastre, the task is then to assign these usually around 30-40 building types to the individual buildings contained in the cadastre and thus generating the heat demand value for each building. For a discussion of how to assign types from a typology to buildings in a cadastre see (Muñoz Hidalgo & Peters, 2015). For a practical example of the construction of a building heat demand typology and using it to develop a heat demand atlas see (Ecofys Germany Gmbh, 2011).

A project developed at the TU Darmstadt (Hegger, et al., 2014) resulted in a tool which differentiates between urban types (Stadtraumtypen - e.g. a territory with predominantly single-family houses, built between 1960 and 1969), that, however, uses the same underlying logic of creating a typology with heat demand values and assigning it to real objects using a cadastre of some sort.

An important point to mention is that three of the mentioned typologies (IWU Typology for Germany, Schleswig-Holstein Typology and the Stadtraumtypen) use a third criterion to differentiate buildings – the renovation level. For example, according to the IWU typology a single-family house in Germany built between 1958 and 1968 could have a heat demand of 211 KWh/m2*annum for a "baseline" condition, 97 KWh/m2*annum with "renovation package 1" or 52.1 KWh/m2*annum with "renovation package 2" (Institut Wohnen und Unwelt, 2011, p.77-79).

A somewhat different approach was undertaken for the SimStadt tool (Hochschule für Technik Stuttgart, M.O.S.S., GEF Ingenieur AG, 2015). This tool uses building typologies and 3D building data to assign materials and characteristics rather than heat demand values to buildings and then uses the DIN-18599 calculation procedure to compute heat demand. This method is more flexible than the assignment of heat demand values. The tool presented in this paper is in a similar spirit.

4 PURPOSE AND APPROACH OF PROPOSED TOOL

4.1 The need to make existing methods more flexible

The issue addressed in this paper is the lack of flexibility of the approaches described above (with the exception of the SimStadt approach). There is a need to account for building-specific parameters – beyond bulding types – in assessing heat demand. To illustrate why that is so, the standard procedure for calculating heat demand is briefly sketched in the following paragraph:

Computing heat demand of a building follows well-defined principles. Basically, heat demand is computed as the sum of heat transmission losses through the areas of the building shell. Heat transmission losses are greatly influenced by material and thickness of the building shell; this is reflected in the heat transmission coefficients (captured by so called “U values”) associated with particular areas of the building shell. A number of parameters are also important for the calculation: Indoor air temperature, air exchange rate, and indoor heat gains, for example. For computing heat demand to suffice legal requirements or energy planning, normed values for these parameters are assumed.

Building typologies cointain (implicitly or explicitly) information on the heat transmittivity of the building shell. They are based on knowledge and experience of materials and construction typology for buildings of different construction types and epochs.

In recent years, it has become obvious that actual heat consumption of buildings greatly differs from heat demand calculations as described above (Arbeitsgemeinschaft für zeitgemäßes Bauen e.V, 2009, p.5). Reasons for these discrepancies could be numerous - from wrong assumptions of building characteristics and user behaviour to inaccurate assigning of building types to buildings. Whatever the reasons may be – the possibility to account for building specific information would offer an improvement over methods using standard building information. This is what the method and the tool proposed in this paper is about.

The following example serves as illustration. When using a predefined typology as described above, an analyst differentiates buildings according to the three criteria as mentioned: construction type, construction epoch and (in some cases) renovation level, in combination with normed values for indoor air temperature, ventilation rate and the like. Now imagine a situation where the heat demand of buildings in neighbourhood A (multifamily buildings, built between 1960 and 1969 and renovated in 2000) differs from the heat demand of the buildings of neighbourhood B (same characteristics) because in neighborhood A, half of the dwelling units are vacant, or the renovations which the buildings in A underwent in 2000 differed from the renovations B underwent, or inhabitants of neighbourhood A tend to keep an average internal temperature of 190C and the inhabitants of B an average temperature of 220C (because of demographic differences). Such variables are usually accounted for during the construction of the typologies by taking averaged values. This approach is rooted in the assumption that user behaviour and other characteristics average themselves out and thus dissappear at aggregated levels. Although this could be the case with respect to some characteristics, others, which are spatially autocorrelated and exhibit spatial clustering could still be present at an aggregated level and if averaged values are assumed, a variance in the spatial pattern of heat demand could be lost.

One other phenomenon which could invalidate standardized heat demand projections is the “patchwork renovation” typical for former East Block countries. This situation occurs when a building receives insulation and energy-efficient windows only on parts of the façade. This occurs frequently in these countries as building ownership is organized as condominiums, a consequence of privatizing former state property of buildings by selling flats to renters. Some apartment owners decide to renovate, while others do not, resulting in a façade which contains patches of insulated and non-insulated shell. Such situations cannot be covered by the normal typology approach unless numerous more types are predefined.

The tool presented in this paper can account for such specific building (and occupant) characteristics where they are known – something that the standard building typology approach does not allow.

4.2 Approach: Individualizing heat demand computations

The approach of the tool presented here is the following: Rather than assigning heat demand values which were calculated- or empirically sampled - for representative buildings in a typology, the analyst assignes all heat demand-related variables to the buildings using a typology and then calculates heat demand for each building in the building stock separately. In this way, the analyst has the opportunity to modify characteristics for individual buildings or groups of buildings and is not bound to the three criteria that the typologies are based on. Using the example of neighbourhoods A and B, which have buildings of the same construction type, construction epoch and renovation level – using a more flexible tool, the analyst first assigns an average internal temperature of 200C from a typology but then he is able to modify it for individual buildings or groups of buildings, if it is suspected that the user behaviour is different. With the example of the “patchwork renovation”, this problem can be tackled by being able to assign different U values (thermal transmittance) to different parts of a building façade.

5 IMPLEMENTATION OF PROPOSED TOOL

5.1 Software

The software environment chosen for the tool, was that of the open-source QGIS. Using a GIS environment for large-scale heat demand calculations is benefitial, because it provides tools for spatial analysis and visualization. The tool designed is in the form of a script in the python programming language and is executed directly from the QGIS python console. It is still in a beta phase – it is complete, operatable, but still undergoing computing optimizations and upgrades. It can be viewed on Github at: https://github.com/ivandochev/QGIS-Heat-Demand.git

5.2 Building Specific Variables

The workflow begins with a building dataset (in the form of a shapefile, database or similar) which, based on an adopted (or designed) building typology, digital cadastre and assumptions/estimations, inherits building characteristics. These characteristics can then be modified for each individual building, or for groups of buildings in accordance with the needs of the analysis.

Table 1. summarizes these characteristics and presents the sources/assumptions behind the computations in the test case study presented in chapter 6. Many of the assumptions are taken from the TABULA project, in order to ensure comparable results.

Script Variable	**Example Schema for Input Shapefile**	**Explanation // Source in example case study**
City level Data		
Average Temperature per month	Not taken from Shapefile, added manually in script as a list of values	Climate data in such form is, in many cases in the EU, provided in energy-efficiency legislation. // Bulgarian Ordinance 16 (Bulgarian Ministry of Economics, Energy and Tourism, 2009)
Solar radiation		
Building level Data		
OBJECTID	OBJECTID	Unique identifier of building // Cadastral ID
Height	HEIGHT	Height in meters // Simplified = floors * 3
Floors	Floors	Number of floors // Cadastral Data
Area	BuildArea	Area of footprint // Cadastral Data
Perimeter	BuildPerim	Building perimeter // Cadastral Data
RoofType	RoofType	Used to differentiate the heating losses to unheated space. If value 'hip', then it is assumed that the last floor is under unheated space with average temperature of 10^0C // Satellite Imagery
WinWallRatio	WinWallPer	The ratio between openings (windows) and walls. // A uniform ratio for all walls is used in beta version of script, equalling 2:8 (20%), based on empirical data.
HeatStorCapacity	HeatSCap	Effective heat storage capacity of building – simplified - 50 Wh/(m³K) – heavy building, 15 Wh/(m³K) – light building. All buildings were categorized as heavy. // DIN 4108-6.
WallU	Walls	Transmission coefficient for Walls // Building Typology
WindowU	Windows	Transmission coefficient for Windows // Building Typology
RoofU	Roofs	Transmission coefficient for Windows // Building Typology
BaseU	Base	Transmission coefficient for Windows // Building Typology
EnEfWallsU	Walls_Reno	Transmission coefficient for renovated walls. If insulation is present for the entire building – modify 'WallU' variable and leave blank here. If "patchwork renovation" is observed, provide U value for the insulated part of the façade. // 0.5 (SOFENA, 2012. p.8)
EnEfWindowsU	Windows_Re	Same as EnEfWallsU // 1.7 (Bulgarian Ministry of Economics, Energy and Tourism, 2009, p.23)
PerIns	PerIns	Could be given as percent of façade area with insulation. Alternatively, the ratio of renovated to non-renovated dwelling units can be used. // Census

		Data
PerEnEfWin	PerEnEfWin	Same as above. // Census Data
Temperature	InsideTemp	Average Internal Temperature // A standard 20^0C was assumed (Episcope, n.d.)
AirChangeRate	AirChR	Air change rate // A standard 0.6 was assumed (Episcope, n.d.). This is a highly debatable value which is precisely why it is important to be able to account for it. For the purposes of the case study a uniform value was taken, acknowledging the possibility that these could vary a lot in reality.
HeatedVolumeCoef	HtVolCoef	Ratio between building volume and heated volume. // 0.8 was assumed roughly equals an average floor height of 3 meters and clear height of 2.5 meters (Episcope, n.d.)
InternalGainsPerSq Meter	IntGains	Given as W/m^2 residential space. This is a simplification that is deemed reasonable. If more detailed information is available it can be transformed into W/m^2 and thus accounted for. // In the case study 3 W/m^2 was taken in accordance with the TABULA project defaults. (Episcope, n.d.)
SolarGainsFactor	SolarGRec	This reduction factor accounts for shading, percent transparent surface on windows (substracting frame area, glazing effects and others) // 0.3024, (Episcope, n.d.)
TotalAnnualHeatDe mand	KwhAnnum	Output variable – heat demand (KWh) per annum
TotalAnnualHeatDe mandperSqMeter	KwhMetAnnu	Output variable – heat demand per annum per square meter gross floor area (KWh/m2*a)

Table 1: Input and Output variables for heat demand estimation tool.

The example shapefile schema provided can be altered in the beginning of the script.

5.3 Algorithm

The computation starts with a classification of the buildings into two categories – "attached" and "detached". This is done in order to account for party walls, which are assumed not to have heat losses in the beta version of the script.[1] Then, if a building is classified as "having party walls", a spatial check is made to find which segments of the outer walls border other buildings. For these segments no thermal loss is computed. If, however, the height of the current building is larger than the neighbouring, the area of the party wall which is above the neighbouring building is considered for thermal losses.

In the next step each segment of the footprint of each building is multiplied with the height of the building and a percentage of windows is applied. In addition, a percentage of renovated insulation and windows is also applied, so that each segment wall (each segment of the footprint multiplied by the height) is divided into four parts – window area, wall area, renovated window area and renovated wall area. This is a simplification of reality which is considered plausible. The geometry of the building shell of the building is also simplified in this way, but remains as complex as the building footprint. For each wall, heat losses are considered and then ventilation losses for the buildings are added. In the next step, solar gains and internal gains are computed and added to the equation. Finally, a utilization factor for the gains is calculated and applied. The script does not take into account cooling demand. For a step-by-step explanation of all computation steps also in "pseudo code" see README file at: https://github.com/ivandochev/QGIS-Heat-Demand.git

6 APPLICATION TO CASE STUDY: THE CITY OF SHUMEN, BULGARIA

In order to test the algorithm a case study city was chosen – the city of Shumen, Bulgaria. The choice was based, on the one hand, on the relatively rich building data that was available – a digital cadastre and census data and, on the other, on the scale of the city - with 5500 residential buildings (circa 70 000 inhabitants) the performance of the algorithm for larger datasets could be tested.

[1] The assumption in the beta version is that the temperature difference between two buildings will not be great enough for meaningful losses to occur through party walls. This issue will be further developed.

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6.1 Data available

The data was gathered from three sources – cadastral data from the municipal administration of the city, census data (2011) from the National Statistics Institute of Bulgaria and finally, in order to map the roof types of the buildings, satellite imagery from Google Earth (2014). An overview of the variables thus made available is given in Table 2.

OVERVIEW OF DATA AT THE BUILDING LEVEL	
Variable	**Possible values**
Cadastral Data	
Building Geometry	Coordinates (Float)
Building Type	Single-family, Multifamily
Number of Floors	Integer
Building Height	Approximated = Floors * 3
Statistical Data from Census 2011, provided by the National Statistical Institute of Bulgaria	
Building Material	Brick, Adobe brick, Steel-Concrete, Prefabricated Panels, Stone, Wood, Other
Construction Year	Integer
Number of dwelling units in the building	Integer
Energy Efficient Insulation	Number of dwelling units with EE Insulation (Integer)
Energy Efficient Windows	Number of dwelling units with EE Windows (Integer)
Dwelling units heated on Wood or Coal	Number of dwelling units (Integer)
Inhabitants	Integer
Data gathered by visual analysis of Satellite Imagery	
Roof Type	Flat Roof/Other Roof type – Google Satellite Imagery from 2014 used.

Table 2: Data available at the building level.

6.2 Modifying the Existing Building Typology for Bulgaria

Although the data available from the digital cadastre and the census was relatively rich, key variables needed for the heat demand calculation algorithm were missing. In order to estimate these, a typology had to be used. Such a typology actually exists – designed by the consulting company SOFENA as part of the TABULA project (SOFENA, 2012), however, some discrepancies[2] within the data available from the TABULA website (Episcope, n.d.) and in the documentation provided by SOFENA were found and therefore only three building types were taken from this typology. In order to estimate the thermal properties of the building envelope for other types of buildings the Bulgarian Ordinance 16 (Bulgarian Ministry of Economics, Energy and Tourism, 2009) was used. This is a legislative document that determines the lawfully binding minimal U value (thermal transmission coefficient) for parts of the outer shell of buildings for different construction epochs. Based on these two sources a new typology was constructed (referred to as the "mixed typology" - Table. 3). It has to be noted, that the construction of a typology based on legislative norms, despite its logicalness, has to be viewed with caution – the level of quality of construction could result in deviations from these norms and furthermore – deteriorations due to aging also have a strong effect on transmission coefficients. For the purpose of testing the algorithm, however, these effects were neglected.

It becomes clear from the typology construction that even with the two sources mentioned above, many values still had to be assumed - for buildings built before 1969 the values were taken from the available data from the SOFENA typology, similarly, U values for windows of buildings between 1969 and 1999 were also assumed to be equal to the ones of single-family houses in this period from the SOFENA typology. Apart

[2] In the data provided online (Episcope, n.d.), some example buildings were found to have implausible window areas and U values for external walls (a maximum of 0.93 for all buildings built after 1960). These however, varied in the documentation provided by SOFENA (SOFENA, 2012, p.12-14), where much more plausible values were presented. Due to this, the U values and estimations for only the types in the documentation were taken and considered as plausible - single-family house (1960-1998), multifamily building (1918–1939) and a prefabricated block of flats (1960-1968).

from U values, the algorithm has a number of additional values that need to be specified (e.g. air change rate, internal temperature etc), the values used in the case study and their sources were mentioned in Table. 2.

"MIXED TYPOLOGY" OVERVIEW						
SOFENA Typology – types considered plausible						
Epoch	**Building Type**	**U Values**				**Assigning principle**
		Walls/Windows/Roof/Base				
1918-1939	Multifamily	1.39	2.32	2.10	2.10	BuildingType: *Multifamily*; Construction Year: *1918-1939*; Material: Not *Prefabricated Panels;* Roof Type: *Flat*
1960-1968	Single-family	1.39	2.63	0.59	2.10	BuildingType: *Single-family*; Construction Year: *1960-1998*; Roof Type: *Hip*
1960-1968	Multifamily, prefabricated block of flats	2.12	2.63	1.98	2.10	BuildingType: *Multifamily*; Construction Year: *1960-1968*; Material: *Prefabricated Panels;* Roof Type: *Flat*

ORDINANCE 16 – Assignment of all buildings, not covered by the above types							
Epoch	**Building Type**	**Walls Massive/ Panels**		**Win/Roof/Base**			**Assigning principle**
1969-1980	All	1.61	***1.61***	***2.63***	1.25	1.04	BuildingType: *any*; Construction Year: *according to epoch*; Material: Not *Prefabricated Panels/Prefabricated panels* – were applicable Roof Type: *any*
1980-1999	All	1.25	0.9	***2.63***	1	0.66	
1999-2004	All	0.5	-*	2.65	***0.3***	0.5	
2004-2009	All	0.45	-*	2	0.3	0.5	
2009-	All	0.35	-*	1.7	0.3	0.5	

OTHER TYPES – buildings not covered above,						
Epoch	**Building Type**	**Walls**	**Win/Roof/Base**			**Assigning principle**
Before 1969	Multifamily	***1.39***	***2.32***	***2.10***	***2.10***	BuildingType: *Multifamily*; Construction Year: *before 1969*; Material: Not *Prefabricated Panels;* Roof Type: *any*
Before 1969	Single-family	***1.39***	***2.63***	***0.59***	***2.10***	BuildingType: *Single-family*; Construction Year: *before 1969*; Roof Type: *any*

Table 3: Typology Construction. *Not applicable. "1.61"-value not given and assumed according to other values.

A tendency that energy-efficiency gradually increased with time is observable. Exceptions are present however – for example, according to the SOFENA typology, multifamily buildings, built between 1939 and 1950, have lower U values (1.39) than residential buildings in the period 1969-1980 (1.61). On the other hand, a 0.9 U value for walls of prefabricated blocks of flats (Material: Prefabricated Panels) built after 1980 is surprisingly low and such high energy-efficiency of these buildings can be questioned.[3]

The data on renovation levels was in the form of: "number of dwelling units per building with energy-efficiency insulation" and "number of dwelling units per building with energy-efficiency windows" and in order to translate these into U values some assumptions again had to be made. According to the SOFENA (SOFENA, 2012, p.8), most refurbishments in the period 1999-2009 involved the decrease of the U values of insulated walls and energy-efficient windows down to 0.5 W/m2.K, and 1.8 W/m2.K respectively. On the other hand, U values of renovations decreased to 0.35 W/m2.K for walls and 1.1 – 2.0 W/m2.K for windows in the period after 2009. However, the census data acquired dated from 2011 and since no indication of the date of renovation was given, it was assumed that most renovations took place in the longer period – 1999-2009 rather than the shorter - 2009-2011. An argument in favour of taking the higher values is also the questionable quality of the renovations undertaken.

[3] Not low enough, however, to be considered implausible, since energy-efficiency was indeed increasing through the 1970s.

7 RESULTS OF CASE STUDY

The python script was ran on a 6 GB RAM and Intel Core i5 1.8 Ghz Processor computer and it took it approx. 1 hour to compute heat demand values for 5500 buildings. Steps are foreseen to increase efficiency and speed of the script.

7.1 Plausibility Check

Before the results of the python script can be discussed, a plausiblity check is required to ensure that observed patterns are not caused by computational mistakes. In order to do that, a comparison was made between values, computed with the python script and values taken from the TABULA project for the same building type (Table 4). The building type in question is a prefabricated block of flats from the 1960s (Source).

Prefabricated block of flats, built between 1960-1969 (Variables according to the TABULA web tool (Source))		
U value Walls / U value Windows / U value Roof / U value Base	0.93 / 2.60 / 1.98 / 1.29 W/m^2.K	
Air Change rate	0.6 h^{-1}	
Internal Gains / Internal Temperature	3 W/m^2 / 20^{o}C	
	Python Script	TABULA calculator
Estimated Heat Demand kWh/m^2*a	114.3	108.9

Table 4: Comparison between computed values with script and TABULA calculator

Although a small difference is observable, this could be contributed to the nature of the computation. The TABULA project uses an yearly computation, while the DIN-4108-6, on the basis of which the python script operates, is a monthly calculation, which leads to some discrepancies – the yearly demand is based on a 192 days of heating season, while the monthly computation is based on a six month heating season – 182 days. Furthermore, the TABULA computation assumes a ground floor bordering earth, while the python script assumes that the ground floor borders unheated basements with a temperature of 10oC. These differences lead to discrepancies, however the results of the python script are definitely plausible and quite close to the calculation of the TABULA project.

7.2 Spatial pattern of heat demand

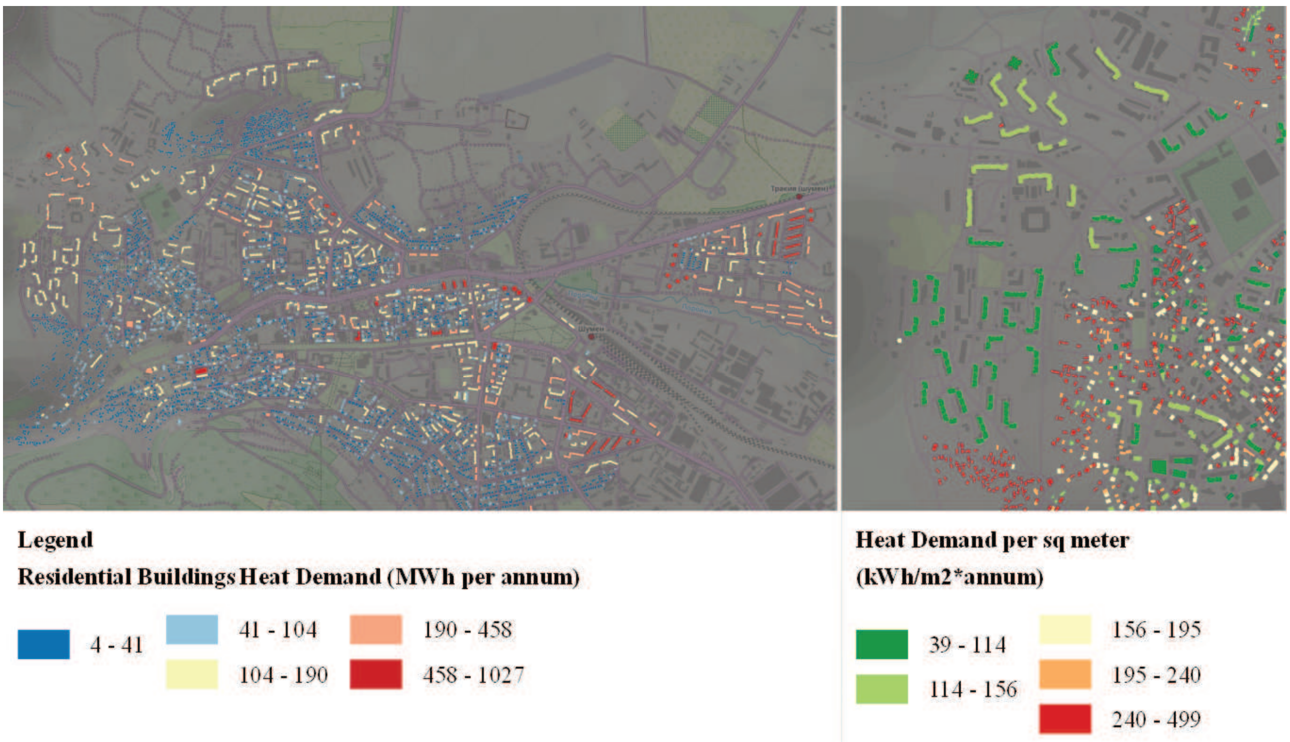

Fig. 1: (A) Residential buildings heat demand meter per annum in MWh; (B) Heat demand per square meter per annum of residential buildings. City of Shumen, Bulgaria. Own calculation, Basemap source: OpenStreetMap Landscape

Computing heat demand for the building stock of the city of Shumen with the procedure presented above produces the following pattern (Fig.1(A)): The largest demand (in absolute terms) comes, not surprisingly, from the prefabricated blocks to the north, northwest and east of the city. However, there is some heterogeneity in building heat demand, even in relatively homogeneous-looking neighbourhoods (neighbourhoods having relatively uniform urban fabric – only prefabricated blocks, or only single-family houses etc).

Normalizing absolute heat demand by buildings with building gross floor area reveals an additional pattern (Fig.1(B)). Heat demand per square meter gross floor area is lower for larger buildings. This could be traced back to the construction epochs. More than 70% of the single-family houses of Shumen (that is: small buildings) were built before 1969, while only 16% of multifamily buildings (prefabricated blocks of flats included) were built before 1969. However, this reasoning, presupposes that energy-efficiency increased with time, which could have exceptions that were not acounted for in the process of the typology construction. Additionally, any of the assumptions made with regard to air-change-rate or internal temperature could also distort results.

One other parameter that influences specific (i.e. per square meter) heat demand is the surface-to-volume ratio (S/V), the ratio between the surface area of a building and its volume. The lower this ratio, the more compact a building, the lower the heat transmission losses throught the shell. Multifamily buildings have a smaller S/V ratio than single-family buildings which decreases their specific (i.e. per m2) heat demand, all else equal. – Inspecting specific heat demand of single-vs multifamily buildings separately shows that spatial heterogeneity is present within both groups.

7.3 Effects of large-scale computation of heat demand for individual buildings

As argued above, the benefit of computing heat demand for every single building, is the flexibility thus attained. This section presents an example of this flexibility with respect to “patchwork renovation” mentioned earlier – a phenomenon typical for former Eastern block countries that is not captured by building typologies for these countries (see section 4). A metric for the influence of this phenomenon on the spread of heat demand could be estimated by taking the average and standard deviation of the heat demand per square meter for different types of buildings with patchwork renovations (Table 5.). By controlling for materials (via construction epoch) and the S/V ratio (via construction type) one can estimate the effect of patchwork renovation on heat demand (complete renovations are excluded, all else equal). It becomes clear that a substantial standard deviation due to renovations exists with all construction types, apart from the prefabricated blocks of flats. This, however, could be due to the relatively high energy efficiency of newer generations of prefabricated blocks of flats according to the typology (U values of Walls equalling as low as 0.9), which is a questionable assumption (as mentioned earlier). The effects of any renovation would be much higher if these buildings are less energy-efficient in reality and that would make accounting for patchwork renovations all the more important.

Furthermore, as presented in chapter 5.2, many assumptions about buildings have to be taken into account in order to compute heat demand (e.g. air change rate, internal gains, etc), which means that variance would be even greater if these are not assumed to be uniform for all buildings (as in this case study).

Type	Number of buildings	Average kWh/m^2*a	Standard Deviation
SFH-before 1959	1485	271	57
SFH-1960-1969	1313	251	65
SFH-1970-1980	545	249	67
MFH-1970-1980	270	144	20
PFB-1970-1980	241	131	13
PFB-1981-1987	232	96	7

Table 5: Overview of average and standard deviation of kWh/m2*a per building type in the city of Shumen. SFH – single family house, MFH – multifamily house, PFB – prefabricated block of flats. Only the six most frequent types are included – sum of buildings adhering to these types amounts to 80% of the building stock. Buildings with complete renovation (whole building) are excluded.

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8 CONCLUSIONS

Computing heat demand for entire building stocks is a chalenging task. As presented in this paper, an assigning of heat demand types with kWh/m2*a values is based upon typologies that make use of numerous averaged values mirroring building characteristics and user behaviour. Although extensive data on all of the important variables that influence heat demand will very rarely be available and the typology approach is the usual basis for estimations, sample, empiric or census data could reveal spatial patterns, that averaged values obscure. Tools are therefore needed, that are flexible enough to allow one to account for a large number of variables. The python script presented in this paper is a step in this direction. Although it is still in a beta version and relatively time-consuming, it shows potential to be a flexible tool in the hands of analysts and planers. Being executed directly within a GIS is also beneficial, since this is the software environment in which spatial analysis is taking place and which provides decision support for spatial planning.

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