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Efficient Heat Demand and Solar Air Collector Heat Supply Estimation Using 3D Geospatial Information

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***Abstract*:** *Modelling of buildings' heat demand provides decision makers information on the required energy on a house level. This is important, among other, to orient supply and subsidy policies. In residential buildings of the Netherlands around 70% of the gas is consumed on space heating, which is therefore the dominant share of the total heat demand. Different parameters have influence on space heat demand of a residential building: such as building architecture, material, age and inhabitants behavior. Collecting such information manually on a building level is a laborious process which can in many cases be substituted by automated extraction from geospatial information. This study proposes an automated workflow to extract the key parameters on heat demand of residential buildings. We have implemented the workflow in Amsterdam using geospatial technology and geospatial data. The case study revealed that the automatic extraction of data increased the efficiency of the whole process and the scalability of the analysis. Subsequently, we focused on renewable energy as heat supply source. We model the heat energy gain of a solar air collector, as a renewable energy source, using geospatial information for each building. Heat demand and solar air collector heat supply results for each building are crucial elements for decision making, both at policy level and at individual citizens to decide on investing in renewable energy. In order to make such information available to the largest possible audience, we implemented this information flow in an interactive web application.*

Keywords: *heat demand modelling, heat supply, solar air collector, renewable energy, geospatial, GIS*

1. Introduction

In the Netherlands 35% of the total energy is consumed in the built area. This amount equals to 30% of the total CO2 emissions in this country. Energy consumption ratio between residential and utility buildings is almost 50/50. Considering the total amount, we come to the conclusion that reducing energy consumption in residential sector will lead to considerable reduction in total consumed energy of the Netherlands. Currently there are policies on European and Netherlands level for the energy reduction in built areas. Based on EPBD directives, from 2020 new buildings should be energy neutral. Reducing energy consumption in buildings and using renewable energy sources are the important goals in EPBD directives for European Union.

In the Netherlands more than 55% of the total energy is being consumed for space heating which is large share of the total used energy. Decreasing this energy amount and using renewable energy sources for space heating will lead to considerable energy savings in building areas. To move towards this goal, the first step will be having an overview on the current status of space heating demand in building and neighbourhood level. This will help decision makers and energy sector by proving them the heat demand information. However, estimating the heat demand for each building manually is an expensive and time consuming task, especially when performed for the whole country or even a whole city. Therefore automated procedures for estimating the heat demand is greatly appreciated.

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GIS databases contain geospatial data which can be used in automating various environmental analysis. There have been several studies which have focused on the energy consumption estimations using GIS data on different levels [1, 2, 3, 4]. GIS- based bottom-up approach to estimate the heating demand of domestic stocks has been performed for London [5]. However, the output of that approach is limited to around 3000 households rather than individual buildings. At building scale, 3D city models have been used to predict urban scale heating energy demand [6], where the rooftop shapes were approximated as flat rooftops which can lead to underestimation of building heating volume.

The objective of this study is to estimate the space heating demand and supply of individual buildings based on detailed 3D geospatial information. Energy yield of solar air collector, as a renewable energy source, has been modelled for each building using geospatial information. The heat demand and solar air collector energy yield was calculated for each month of the year. To present the outcomes of the modelling framework, we developed a web-tool that depicts the temporal variation (throughout the year) of the information as graphs making it easy for everyone to access and understand the information.

2. Method

2.1. Heat Demand

The heat consumption of a building block is commonly defined as a function:

$$TCH = TTHLB + VHLB + IHLB \quad \text{[gj]} \tag{1}$$

This model relies mainly on physical properties of the building, where *TCH* is the total heating consumption of the building block, *TTHLB* is the total block transmission heat loss, *VHLB* the ventilation heat loss and *IHLB* is the infiltration heat loss. These parameters are functions of building geometry and material. Table 1 presents the input parameters of the model. The second column of the table defines whether the parameter is extracted through geospatial information.

TABLEI: Input parameters of the heat consumption model. The second columns define whether the parameter is extracted through geospatial data.

Parameter	**Geospatial Information**	**Parameter**	**Geospatial Information**
Solar Heat Gain Coefficient	-	Brick RC value	Yes
Window-Wall ratio	Yes	Heating hours per month	-
Exposed Perimeter	Yes	Ventilation hours per month	-
Building type (attached, detached, terraced, etc)	Yes	Infiltration hours per month	-
Rooftop(s) vertical angle and horizontal orientation	Yes	Block Area	Yes
Ceiling height	Yes	Density Air	-
Number of floors	Yes	Solar altitude (average per month)	Yes
Temperature difference (outside-inside)	Yes	Solar azimuth (average per month)	Yes
Glass RC value	Yes	Specific Heat Capacity Air	-
Roof RC value	Yes		

Geospatial parameters have been extracted using GIS databases and functionalities. Section 3 presents these results.

2.2. Heat Supply

Solar air collector is a renewable energy source which collects solar energy and converts it into heat. Energy balance of a solar air collector is calculated as follows:

$$Q_U = A_C * F_R * (S - U_L(T_{fm} - T_a)) \quad [\text{w}] \tag{2}$$

Where A_C is the collector area (m^2), F_R is heat removal factor, S is the absorbed solar radiation per unit area (W/m^2), U_L is the collector overall heat loss coefficient (W/(m^2.K)), T_{fm} is the mean fluid temperature (K) and T_a is the ambient temperature (K).

Absorbed solar radiation depends on the solar angle and rooftop angle which are extracted from geospatial information. The results are presented in section 3.

3. Results

3.1. Building Height, Number of Floors and Volume

We have used accurate Airborne LIDAR point cloud data of the Netherlands to calculate the height of buildings in the study area. This dataset has the density of 8-20 points per square meter and 5 centimeter planar and vertical accuracy. Figure 1 presents a sample of this dataset

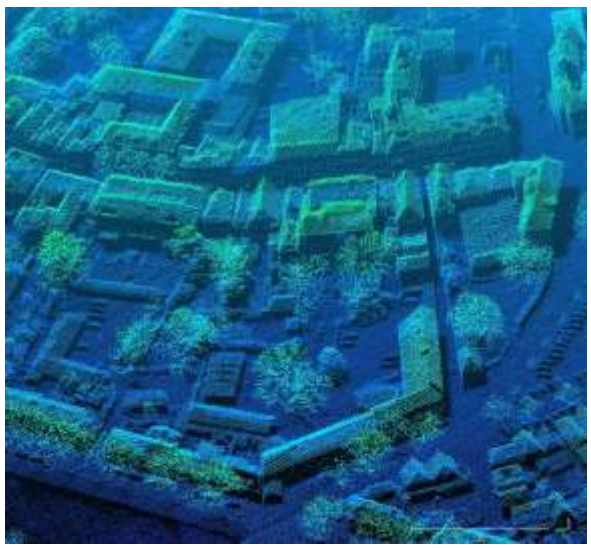

Fig. 1: Airborne LIDAR point cloud data pf the Netherlands. The point density of the dataset is 8-20 points per square meter and the planar and vertical accuracy is 5 centimeter.

Number of floors and building volume for each building is calculated using the same dataset.

3.2. Building Type

This parameter defines the connection status of a building to the neighbouring buildings. Five types of buildings are defined here, namely, terraced house, detached house, corner house, semi-detached house and apartment. This is an important factor on the heat demand of a building since it expresses the number of shared walls with the neighbouring buildings.

We have extracted the type of each building using existing building footprints and GIS intersection functionality. For each building, the number of shared edges defines it type. Figure 2 presents the results of the GIS intersection function on building footprints to define building types.

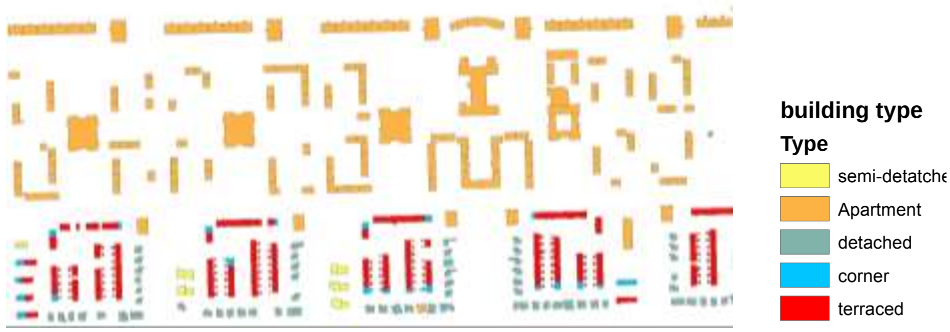

Fig. 2: Five classes of building types have been defined using GIS intersection function on the existing 2D building footprints.

3.3. Exposed Perimeter

Exposed perimeter of a building is the perimeter of its wall exposed to air, that is, the detached walls. We have used the same function, as for the building type definition, to define the exposed perimeter of each building. Total exposed perimeter of a building is the multiplication of the building footprint exposed perimeter with the number of floors.

3.4. Window-Wall Ratio and Heat Transfer Coefficient

Window-wall ratio is required for the calculation of transmission heat loss in building façade. Heat transfer coefficient of wall, roof, glass and floor are used in the calculation of transmission heat loss of these elements. Window-wall ratio and heat transfer coefficients of a building can be estimated based on the building type and year. We have used *Sample Buildings Brochure*[1] for this estimation. Building year data is an existing attribute in the building footprint dataset[2] and building type has been estimated in 3.2. Table 2 presents the estimated area of the closed part of the wall as well as the glass part, divided into single glass, double glass and HR++ glass. This table also presents the Heat transfer coefficient (R_C) of wall, roof, glass and floor based on building type and year.

Table2. Building window-wall ratio and R_C values of its elements estimated based on the building year and type derived from *Sample Buildings Brochure*.

Building Type	Building Year	Closed (m^2)	Single glass	Double glass(m^2)	HR^{++} glass	R_C Wall (W/m^2K)	R_C Roof (W/m^2K)	R_C Glass (W/m^2K)	R_C Floor (W/m^2K)
Detached	<=1964	136.7	8.0	20.3	-	1.61	1.54	2.90	1.72
	1965-1974	164.7	5.8	29.5	-	1.45	0.89	2.90	2.33
	1975-1991	144.0	2.9	31.8	-	0.64	0.64	2.90	1.28
	1992-2005	150.9	-	18.1	21.5	0.36	0.36	1.80	0.36
Semi-Detached	<=1964	97.8	6.5	19.5	-	1.61	1.54	2.90	1.72
	1965-1974	104.7	6.7	24.6	-	1.45	0.89	2.90	2.33
	1975-1991	96.6	3.4	23.0	-	0.64	0.64	2.90	0.64
	1992-2005	108.5	-	25.9	3.1	0.36	0.36	2.90	0.36
	<=1945	49.0	6.9	14.2	-	2.22	2.08	2.90	2.44
	1946-1964	42.3	6.5	14.9	-	1.61	1.54	2.90	1.72
	1965-1974	40.5	4.3	21.3	-	1.45	0.89	2.90	2.33

[1] *Voorbeeldwoningen Brochure* is published by AgentschapNL which contains thirty residential buildings samples based on which the policy advices about energy savings are underpinned (http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/gebouwen/woningbouw/particuliere-woningen/voorbeeldwoningen)
[2] This dataset is called BAG and is provided by Dutch cadastre (http://www.kadaster.nl/bag)

Terraced	1975-1991	40.6	3.1	16.2	-	0.64	0.64	2.90	1.28
	1992-2005	49.9	-	7.0	14.8	0.36	0.36	1.80	0.36
Corner	<=1945	49.0	6.9	14.2	-	2.22	2.08	2.90	2.44
	1946-1964	42.3	6.5	14.9	-	1.61	1.54	2.90	1.72
	1965-1974	40.5	4.3	21.3	-	1.45	0.89	2.90	2.33
	1975-1991	40.6	3.1	16.2	-	0.64	0.64	2.90	1.28
	1992-2005	49.9	-	7.0	14.8	0.36	0.36	1.80	0.36
Apartment	<=1964	20.8	4.5	14.8	-	1.61	1.54	2.90	1.72
	1965-1974	21.2	6.9	14.4	-	1.45	0.89	2.90	2.33
	1975-1991	23.7	1.2	12.4	-	0.64	0.64	2.90	0.64
	1992-2005	24.7	-	4.7	11.1	0.36	0.36	1.80	0.36

3.5. Rooftop Vertical Angle and Horizontal Orientation

We have used LIDAR point cloud dataset to detect rooftops and their characteristics automatically. Figure 3 presents the LIDAR points on buildings colorized based on their height value.

After interpolating the point clouds to make a regular grid, we have calculated the slope and aspect of the grid using the height information of each LIDAR point and its neighbouring points. Figure 4 presents the aspect of buildings' rooftops.

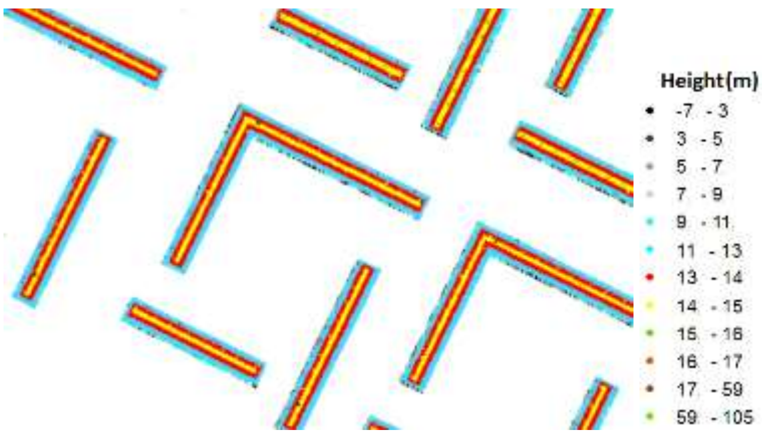

Fig. 3: 2D projected LIDAR points overlaid on building footprints

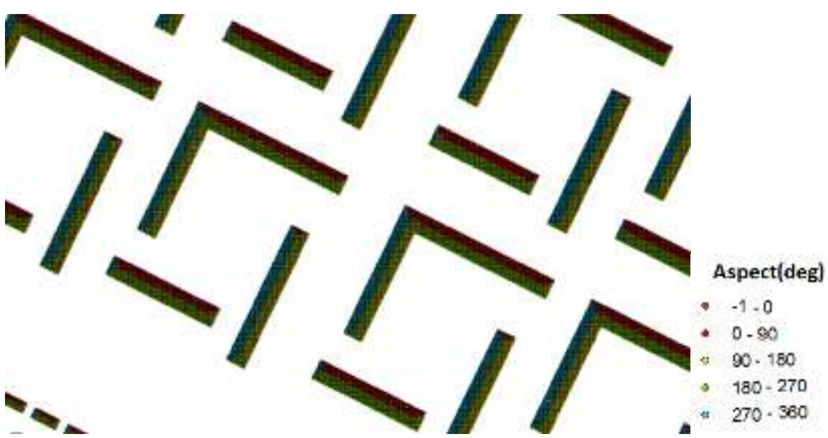

Fig. 4: Calculated grid-based aspect. Of building rooftops

We have used the aspect values to cluster the points of each building to detect its rooftops characteristics. Neighbouring points with close aspect values are segmented as a separate cluster. Each cluster presents the points of a separate rooftop segment. Aspect and slope of each rooftop segment is calculated based on the average aspect and slope of each point cluster. Area of each rooftop segment is calculated based on the area of the convex hull that surrounds the point cluster of that segment. Rooftop aspect and slope, together with solar azimuth and altitude, are used to calculate the solar irradiance on rooftops which is used in the calculation of solar transmission heat for heat demand as well as the absorbed solar radiation in solar air collector for heat supply.

3.6. Heat Supply

We have calculated the yielding heat energy of solar air collector, as a renewable energy supplier, for all of the residential buildings in Amsterdam using equation 2. Buildings type and age are used to estimate the overall heat loss using *Sample Building Brochure*, as explained in 3.4. The absorbed solar radiation is calculated based on rooftops slope and aspect as well as solar azimuth and altitude. A constant amount of 0.3 is used for heat removal, as suggested in [7], for simplification. We have used the equation suggested by [7] to estimate the temperature difference between mean air temperature and ambient temperature (ΔT), where S is the absorbed solar radiation:

$$\Delta T = 0.015S + 0.673 \tag{3}$$

3.7. Heat Demand Versus Heat Supply

We have developed a web application which presents the space heating demand and the yielding heat from solar air collector for each building in each month of the year. The user needs to type the postal address of the building and the application will demonstrate the building information as well as the heat demand and supply graph for the 12 months of the year. Figure 5 presents an example of this.

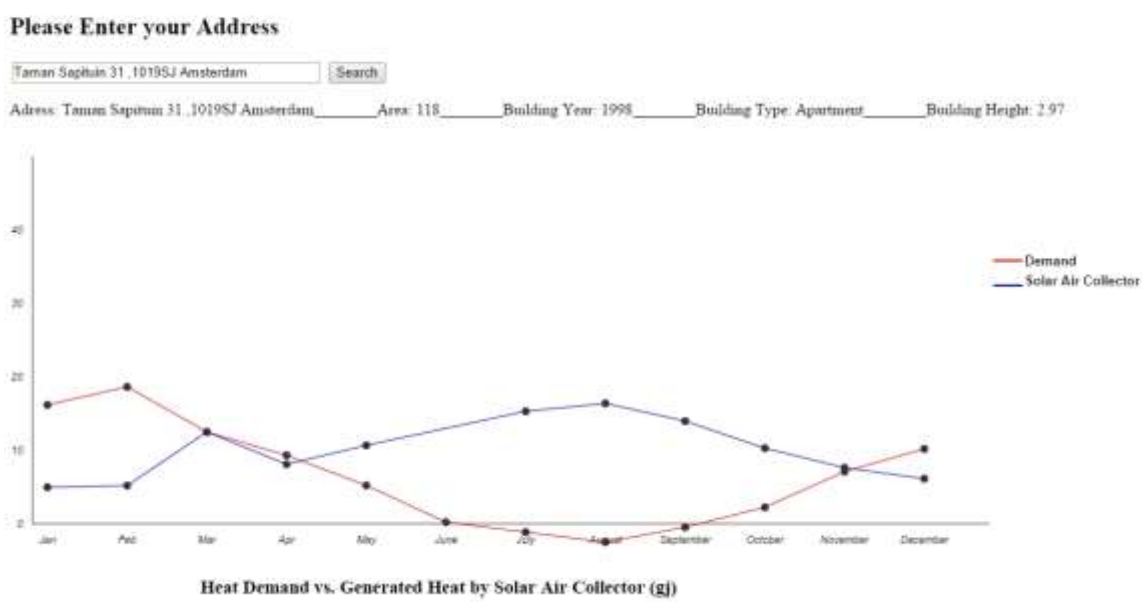

Fig. 5: Heat demand and yielding heat energy from air solar collector are calculated for each building in each month and presented by graphs through a self-developed web application

Since in the Netherlands around 70% of the heat is used for space heating, we have multiplied this fraction with the total yielding heat from the solar air collector to present the space heating supply versus space heating demand. The server calculates the heat demand and supply using geospatial information which was discussed in this chapter. The variant parameters in each month are temperature, solar azimuth and altitude and heating hours.

4. Conclusion

This study focused on the role of geospatial information on automating the process of estimating heat demand of buildings as well as heat supply. For each building, its geometry, location, material, age and connection to neighbouring buildings are important factors on calculating its heat demand. These parameters are estimated efficiently and automatically in this research using geospatial data and GIS functions through self-developed scripts. For heat supply we have investigated solar air collector as a renewable energy source and tried to estimate its heat production for each building. The above mentioned building-related parameters also influence the yielding energy from a solar air collector. Therefore the resulting energy of solar air collector for each building can also be estimated using geospatial information.

A web application was developed in this study to present the demand and supply results to users. By entering an address of a residential building, the user can visualize the heat demand and supply from solar air collector for the building in each month of the year. This provides an overview on the closeness of demand and supply to householders towards their investment for solar air collector as a renewable energy source.

This research demonstrates the feasibility of using geospatial information and techniques for the automated estimation of heat demand and supply of buildings in a large scale. This helps, among others, urban planners, decision makers, energy sector and citizens on performing different demand/supply analysis on different scales. The developed web application helps distributing the results easily around the world without requiring a special software package.

Further studies can focus on cost estimation and comparison between the costs of the current energy source and the solar air collector for each building. Furthermore, the same research settings can be applied to investigate other renewable energy sources rather than solar air collector.

5. References

[1] J. P. J. Patterson and S. Lannon. (2007). Modelling the built environment at an urban scale—Energy and health impacts in relation to housing. *Landscape and Urban Planning*. 83 (1). pp. 39-49.
http://dx.doi.org/10.1016/j.landurbplan.2007.05.015

[2] J. Tornberg, "A GIS energy model for the building stock of Goteborg," in *ESRI International User Conference Proceedings*, 2005.

[3] R. M. Rylatt, S. J. Gadsden and K. J. Lomas. (2003). Methods of predicting urban domestic energy demand with reduced datasets: a review and a new GIS-based approach. *Building Services Engineering Research and Technology*. 24 (2). pp. 93-102.
http://dx.doi.org/10.1191/0143624403bt061oa

[4] S. Heiple and D. J. Sailor. (2008), Using building energy simulation and geospatial modeling techniques to determine high resolution building sector energy consumption profiles. *Energy and Buildings.* 40(8). Pp. 1426-1436.
http://dx.doi.org/10.1016/j.enbuild.2008.01.005

[5] A. Mavrogianni, M. Davies, M. Kolokotroni and I. Hamilton, "A GIS-based bottom-up space heating demand model of the London domestic stock," in *Proceedings 11th International IBPSA Conference, Building Simulation*, 2009.

[6] A. Strzalka, J. Bogdahn, V. Coors and U. Eicker. (2011). 3D City modeling for urban scale heating energy demand forecasting. *HVAC&R Research.* 17 (4). pp. 526-539.

[7] P. Matuszewski and M. Sawicka, "Optimization of solar air collector," M.A. thesis, Indoor Environmental Engineering School of Energy and Science, Aalborg Univ., Aalborg, Denmark, 2010.