Improving the Energy Efficiency of the Building Stock: A Bottom-up Model and its Application in an Online Interactive Portal

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ABSTRACT

There is an urgent need to reduce energy uses in new and retrofitted buildings. In Europe, energy consumption in the building sector still represents more than 40% of the final energy use. Emerging countries are also concerned by such issues at even wider levels because of the huge demographic growth they are witnessing. Numerous research studies have highlighted the need to produce more efficient buildings, but also to retrofit the existing building stock. However, research methods and tools that allow a precise quantification of energy uses in buildings and energy savings related to various actions (insulating the roofs, changing the glazing, behavioral changes, etc.) are mainly dedicated to trained professional users, thus neglecting the huge potential energy savings that is linked to individual actions undertaken by citizens in their dwellings. In this context, the main aim of our research is to raise awareness of energy efficiency in residential buildings and encourage positive changes to the energy efficiency of the building stock, starting at the individual scale. This paper first presents the methodology that allows a precise energy assessment (heating, cooling, ventilation, lighting, appliances and cooking) of buildings (at the house, neighborhood, city and region scales) on the basis of a "bottom-up" approach. This methodology uses a typological classification of buildings, thermal simulations and local surveys. In this paper, this methodology is applied to the Walloon (Belgium) building stock. Many parameters are defined and taken into account to capture the specificities of numerous types of buildings (e.g., the number of floors, common ownership, orientation, thermal performances, ventilation, etc.). Several occupation modes are modelled to capture the impact of occupants' behavior on energy consumption. To take into account the impact of urban form, correction factors are defined and applied according to the type of neighborhoods in which the buildings are located. All things considered, 250,000 individual results are obtained and stored in a huge database. Linear extrapolations and correction factors are used to extrapolate and apply these results to any type of residential building in Wallonia. This methodology is then used to develop an online portal that aims to strengthen citizens' awareness of the necessity for ecological changes in the building sector and encourage individual actions to improve the energy efficiency of buildings. This tool allows for a transfer of the main results of a two-year scientific research effort to citizens in a very simple and intuitive way. Although the results presented in this paper are focused on Wallonia (Belgium), the research is easily reproducible to other territories by adapting local parameters.

INTRODUCTION

There is an urgent need to reduce energy uses in new and retrofitted buildings. In Europe, energy consumption in the building sector still represents more than 40% of the final energy use. Emerging countries are also concerned by such an issue at even wider levels because of the huge demographic growth that they are witnessing. Numerous research efforts have highlighted the need to produce more efficient buildings, but also to retrofit the existing building stock, especially in Europe where the renewal rate of buildings is quite low. Moreover, several research and empirical results have demonstrated the significant impact of the behavior of housing occupants on energy consumption (e.g., de Meester et al., 2012; Santin et al., 2009). However, research methods and tools that allow a precise quantification of energy uses in buildings and energy savings related to various actions (insulating the roof, changing the glazing, behavioral changes, etc.) are mainly dedicated to trained professional users, thus neglecting the huge potential energy savings linked to individual actions undertaken by citizens in their dwellings. Citizens are, in fact, the first actors who can concretely act to alter the energy consumption in residential buildings. However, although an increasing number of households are paying attention to their energy consumption and are motivated to undertake light or heavy renovation work, they do not know what action to choose and are unaware of the impacts of renovation in terms of comfort, energy savings, etc. In fact, efforts to promote energy efficiency remain concentrated on the general guidelines; in particular, user-friendly assessment tools dedicated to a non-specialized audience (local authorities, developers, citizens) are lacking (Tweed and Jones, 2000). Most existing BPS (Building Performance Simulation) tools (e.g., TRNSYS, Comfie+Pleiades, Energyplus, phpp) are designed by engineers for use by other trained engineers, which make them too complicated to quickly evaluate the performance of different design concepts or strategies (Attia et al., 2012). Amongst the existing simplified evaluation tools, Gratia and De Herde (2002a and 2002b) developed a simple design tool for the thermal study of dwellings and office buildings. The calculation of the energy consumption is mainly dedicated to architects and based on the results of dynamic thermal software. Performing an assessment by using a simple design tool is much easier than performing an assessment while using this thermal simulation software, but the values of many parameters that are not often known by households and local authorities are still required.

In this paper, we argue that the implementation of energy efficiency measures into concrete policies and the popularization of academic research to the general public (citizens, local authorities, policy makers, etc.) are crucial to ensure a more sustainable development of our territories and to reduce energy consumption in buildings. The main aim of our research is, thus, to encourage positive changes to the energy efficiency of the building stock, starting at the individual scale, by transferring the main results of a two-year research to a non-specialized audience. The need for this type of research lies in the fact that its dissemination is for “normal people,” for them to have the necessary information to conduct themselves and their homes more energy efficiently.

To this end, this paper first presents the methodology that enables a precise assessment of energy uses in buildings. This methodology is applied to the Walloon building stock and a huge database comprised of more than 250,000 individual results is produced. Then, the methodology and the database are used to develop an online portal that aims to raise public awareness on energy efficiency in buildings.

METHODOLOGY: A BOTTOM-UP MODEL

A methodology was developed to assess energy uses (energy requirements for space heating, cooling, ventilation, electrical appliances, cooking and domestic hot water) in residential buildings at an individual scale. This methodology must allow researchers to precisely assess energy uses at the individual building scale, but also to draw trends, at the neighborhood, city and regional scales. This methodology combines several research methods and tools, including a typological classification of buildings, dynamic thermal simulations, surveys, etc. The energy consumption levels related to heating, cooling and ventilation are derived from dynamic thermal simulations. The energy consumption levels related to domestic hot water, electrical appliances and cooking are based on regional empirical surveys and are linked to the number of inhabitants in each dwelling. In this paper, this methodology is applied to the Walloon (Belgium) building stock. However, this work is also reproducible to any other territory by adapting local parameters.

Parameters taken into account to develop the bottom-up model

The parameters that were taken into account to build the bottom-up model are related to (A) the environment in which the building is located, (B) the characteristics of the building, (C) the thermal performances of the envelope and the systems. They are explained below and summarized **in Figure 1**.

As far as the environment in which the building is located is concerned, 1,347 possibilities were defined to cover the variation of the climate (see column A.1 **in Figure 1**) (in comparison with Brussels, a temperate climate in the northern part of Europe) in Wallonia. A coefficient based on degree-day was attributed to each location and then applied to thermal simulation results (performed with Brussels' climate). Eight main types of residential neighborhoods (A.2) were defined (dense urban core, continuous urban, semi-continuous urban, homogeneous semi-continuous and social housing, villages and rural cores, suburban neighborhoods, isolated rural, great sets) on the basis of a typological classification of the whole Walloon building stock (Marique and Reiter, 2013). Simulations were performed on 24 selected representative neighborhoods with Townscope software (Teller and Azar, 2001): 500 points were randomly defined on the facades and roofs of each neighborhood and an assessment of solar gains was performed in order to define corrections factors according to the density of the neighborhood. These correction factors were stored in the database and then applied to the results of thermal simulations of buildings, in order to take into account the diminution of solar gains on facades and roofs, according to the built density of the neighborhood in which the considered building is located.

A. ENVIRONMENT		B. TYPOLOGY				C. THERMAL PERFORMANCES AND SYSTEMS								
1. Climate	2. Neighborhood	1. Housing type	2. Number of floors	3. Common ownership	4. Orientation	1. Wall type	2. Slab insulation [cm]	3. Wall insulation [cm]	4. Roof insulation [cm]	5. Glazing	6. Ventilation	7. Thermostat	8. Heating system	9. Fuel type
Choice amongst 1347 locations and their related degree days	Dense downtown	Wide house	1,5	Detached or semi-detached	North	Solid	0	0	0	Simple, double-old or double-new	A	18°C	Hot water boiler condensing	Natural gas
				Terraced	North or East				16					
	Continuous urban		2	Detached or semi-detached	North		3	3	3				Hot water boiler non condensing	Gazole
				Terraced	North or East				16					
	Semi-continuous urban	Narrow house	1,5	Detached or semi-detached	North		6	6	6				Electric resistance heating	Propane
				Terraced	North or East				16			20°C		
	Homogeneous semi-continuous or social city		2	Detached or semi-detached	North		10	10	10	Double-old, double-new or triple	C or D		Heat pump	Butane
				Terraced	North or East				20	Double-new or triple				
	Village or rural nucleus		3	Semi-detached	North	Cavity	15	15	15	Double-old, double-new or triple			Micro-CHP	LPG
				Terraced	North or East				30	Double-new or triple				
	Suburban subdivision		4	Terraced	North or East		20	20	20	Double-old, double-new or triple			stove	Coal
		Wide crossing apartment	1	Top, intermediate or ground	North or East				30	Double-new or triple		20-16°C		
	Isolated rural	Narrow crossing apartment	1	Top, intermediate or ground	North or East		25	25	25	Double-old, double-new or triple			Radiator or electric heater	Wood (4 forms)
		Three fronts apartment	1	Top, intermediate or ground	North				35	Double-new or triple				
	"Great Sets"	One front apartment	1	Top, intermediate or ground	North, East, South or West		30	30	30	Double-old, double-new or triple			Electric storage heater	Electricity
		Corner apartment	1	Top, intermediate or ground	North, East, South or West				35	Double-new or triple				

Figure 1 Summary of the parameters related to (1) the environment in which the building is located, (2) the characteristics of the building, (3) the thermal performances of the envelope and the systems.

As far as the characteristics of the buildings are concerned, 60 main types of dwellings were defined to cover the whole Walloon residential building stock on the basis of the main characteristics of Walloon dwellings, as identified in previous research (Evrard et al., 2012; Kints, 2008). The typology is comprised of houses and apartments. For houses, the characteristics that were taken into account to build the typology are the plan orientation (B.1) (perpendicular or parallel to the street), the number of floors (B.2) (one and half, two, three or four), the common ownership (B.3) (detached, semi-detached or terraced house) and the orientation (B.4) of the building (north, east, south, west). For apartments, the characteristics were the plan configuration (B.1) (wide crossing, narrow crossing, three fronts, one front or corner apartment), the position (B.3) of the apartment in the building (ground floor, intermediate floor or top floor apartment) and the orientation (B.4) of the building (north, east, south, west). Each of the 60 types has a fixed heated surface area. Extrapolations are then performed to extend the results obtained in the thermal simulations to similar types of buildings presenting different heated surface areas (see below).

As far as the thermal performances of the housing are concerned, two types of wall (C.1) are defined (solid or cavity). The insulation in the slabs and the walls (C.2 and C.3) vary from 0 to 30 centimeters. The insulation in the roofs (C.4) varies from 0 to 35 centimeters. The glazing type (C.5) may be simple, double-old, double-new or triple. The glazing surface area on each façade is defined according to the housing type. For all types of dwellings, the ceiling height is worth 2.4m; no attachments are modeled as such, but they can be taken into account by including them in the total area of the dwelling; the basement floor is not taken into account.

Three ventilation modes (C.6) are defined: natural ventilation (type A), ventilation with mechanical extraction (type C) and double flow ventilation with heat recovery (type D). For the ventilation of type A, the windows are opened for an internal temperature higher than 25°C and are closed when this temperature drops down to 23°C. In the case of ventilation of types C and D, air flows are defined according to the Belgian requirements (NBN, 2008). The heat recovery system efficiency is set at 85%.

Three types of thermostat (C.7) are defined (18°C constant during day and night, 20°C constant during day and night and 20°C with a reduction to 16°C in a daily work-pattern and during night. No weekly or annual profile has been defined.). Eight types of heating systems (C.8) and 11 types of fuel (C.9) were taken into account. For each type, a correction coefficient was used to integrate the efficiency of the heating system (production, distribution and emission). These coefficients come from the Belgian regulation (PEB, 2008 and 2012).

A couple of rules of combinations were finally defined to eliminate nonrealistic cases (for example, a building with 20 cm of insulation and simple glazing). In all, 250,000 types of buildings were defined.

Assessment of energy uses in buildings

The TRNSys thermal simulation software was then used to perform an energy consumption analysis of space heating needs and electricity needs for ventilation systems and solar gains for each of the 250,000 cases in the Belgian context (the climate of Brussels without any surroundings buildings). Cooling was not considered in the analysis because cooling needs are minimal in Belgium. In these simulations, internal gains were defined according to Massart and De Herde (2010), such as 70W/person for occupation and 6W/m² and 4W/m² for nominal power lighting and appliances, respectively. They are functions of the dwelling's surface and of the number of occupants which are set in function of the type of housing. Internal gains are also set according to a daily and weekly schedule. In addition, three standards defined by the European Energy Performance of Buildings Directive (EPBD) were added: the low-energy standard, the very low-energy standard and the passive standard, which correspond to annual heating requirements lower than 60 kWh/m².year, 30 kWh/m².year and 15 kWh/m².year, respectively.

The energy consumption related to appliances and cooking are respectively evaluated at 1,000 kWh per person and per year and 165 kWh per person and per year in Belgium on the basis of a local survey of energy uses by households (ICEDD, 2008). The energy consumption related to domestic hot water is assumed to be dependent on the number of inhabitants. We consider that each inhabitant needs 100 liters of cold water (10°C) and 40 liters of hot water (60°C) per day in accordance with the regional trends (ICEDD, 2008). The number of inhabitants is dependent on the surface area of the dwelling.

Storage of the results

The results of the energy assessments (space heating, cooling, ventilation, appliances, cooking and hot water) were stored in a huge database comprised of seven parts: Part 1 is dedicated to the based degree-days coefficient, Part 2 stores the solar factors depending on the built density of the neighborhood in which the building is located, Part 3 is dedicated to space heating requirements and electricity needs for the ventilation system, Part 4 relates to the characteristics of the heating systems, Part 5 addresses domestic hot water requirements, Part 6 relates to cooking requirements and Part 7 is dedicated to electrical appliances requirements.

Part 3 (space heating energy needs and electricity needs for the ventilation system) is comprised of seven columns, **as illustrated in Table 1**. The first column includes a unique numeric code that allows one to directly and easily identify the corresponding building and its characteristics: each item of the code corresponds to a specific variation of a parameter and provides the identity card of the tested case.

Table 1. Example of the database for the space heating and ventilation needs

Code	m_q	p_q	m_s	p_s	m_v	p_v
1_3_2_1_c_l_g_3_2_1	41.9	38.6	8.1	486	2.2	-23.1
1_3_2_1_c_l_g_3_2_2	54.1	142.3	13.9	768.9	2.2	-23.1
1_3_2_1_c_l_g_3_2_3	49.1	105.5	8.1	486	2.2	-23.1
1_3_2_1_c_l_g_3_3_1	24.7	558.9	8.1	486	6.9	-73
1_3_2_1_c_l_g_3_3_2	32.4	792.5	11.3	646.2	6.9	-73
1_3_2_1_c_l_g_3_3_3	30.2	681.6	8.1	486	6.9	-73

Columns 2 and 3 are used to store the slope (m_q) and the intercept (p_q) of the linear extrapolation used to generalize space heating energy needs obtained through thermal simulations to any similar building that presents a different heated surface area. Columns 4 and 5 (m_s and p_s) store parameters related to solar gains. The two last columns (m_v and p_v) are used to calculate the electrical needs of the ventilation's fans. The coefficients that are used to transform energy needs into fuel consumptions, primary energy consumptions, CO_2 emissions and into an estimation of the annual cost are also stored in the database. These coefficients are used with an identification number that depends on the systems used in the simulations.

Extrapolation and final results

Energy needs for space heating, cooling and ventilation are obtained by using the surface area of the dwelling (S) and the data from the linear extrapolation (m_q and p_q) stored in the database. Afterward, a first correction is applied to energy need for space heating, cooling and ventilation to take into account the neighborhood in which the dwelling is located and the loss of solar gains related to the density of the neighborhood (F_s, m_s and p_s). A second correction factor (C) is applied to take into account the location of the dwelling on the territory and the corresponding degree-days in comparison with Brussels' climate. Finally, the annual space heating consumption (Q_{SH}) – expressed in kWh/year – is obtained by multiplying the space heating need by the efficiency of the whole heating installation (SH_n), **as shown in equation 1**.

$$Q_{SH} = [(m_q * S + p_q) + (m_s * S + p_s) \text{ x } (1-F_s)] * C * SH_n \quad (1)$$

Electricity consumption of the ventilation system (Q_{VT}) – in kWh/year – is calculated on the basis of the surface area (S) and the data of a linear extrapolation (m_v and p_v) from the heating database, **as shown in equation 2**.

$$Q_{VT} = (m_v * S + p_v) \quad (2)$$

Energy needs for domestic hot water, electric appliances and cooking depend on the number of inhabitants in the dwelling (N). Such statistics also incorporate data from regional surveys, **as shown in**

equations 3, 4 and 5. The energy need for hot water (Q_{HW}) takes into account the quantity (liter) of hot water consumed annually ($L_{liter/year}$), the difference between the hot and cold water temperatures (ΔT) and the water heat capacity (C_v), **as shown in equation 3**. As for space heating consumption, energy consumptions for domestic hot water, appliances and cooking – expressed in kWh/year – are obtained by multiplying the respective energy need by the corresponding yield coefficient (HW_n, EA_n and CK_n respectively).

$$Q_{HW} = (L_{liter/year} * N * \Delta T * C_v) * HW_n \quad (3)$$

$$Q_{EA} = (-40 * N^2 + 550 * N + 1765) * EA_n \quad (4)$$

$$Q_{CK} = (200 * N) * CK_n \quad (5)$$

Finally, the household annual consumptions can also be converted into primary energy consumptions, CO_2 emissions and euros by applying the conversion coefficients stored in the database.

Validation and relevance of the results

The methods and data used to build the database were presented extensively in previous papers (Marique and Reiter, 2012; Marique et al., 2014). The software used in the analysis has namely been validated by the International Energy Agency Bestest. We used the database to calculate the energy consumption of the whole building stock of Wallonia and compared this result with an in-situ survey ("annual thermal survey") carried out by ICEDD (2008) on the basis of the real consumption of Walloon households. Differences between our simulations and figures from ICEDD are worth a maximum of 8.2%, which was considered to be acceptable.

AN ONLINE INTERACTIVE PORTAL DEDICATED TO CITIZENS

The model developed to assess energy uses in Walloon buildings and the numerous results stored in the database were then used to develop several types of applications that benefit different types of users (citizens, architects and urban planners, local or regional authorities, etc.). Due to the restricted length of this paper, in this section we will only present the online interactive portal that we developed for citizens.

The main aim of this portal is to raise awareness of current energy issues and offer concrete solutions to reduce energy uses in buildings by arguing that citizens are the first actors who can concretely act to improve energy efficiency in residential buildings (the building stock is mostly private in Belgium). However, citizens often face huge difficulties in highlighting key parameters and strategies in the energy efficiency of their dwellings and in identifying the most efficient retrofitting work to perform in each particular case. To this end, the online portal that we developed makes available, in a very simple and intuitive way, more than 250,000 results of dynamic thermal simulations to a non-specialized audience. This knowledge aims to help them to assess energy uses in their dwellings and to make the best choices to improve its energy efficiency. Thus, it addresses one major shortcoming of existing simulation tools (BPS tools): the accessibility to citizens and local stakeholders.

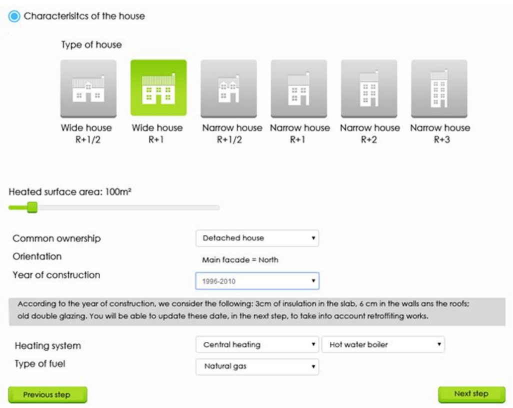
The online portal comprises three different evaluation tools, two of which are specifically dedicated to citizens. The simplified evaluation allows an individual user or household to assess building energy consumption on the basis of limited information. Completion of the questionnaires is very simple to allow the user to complete them quickly and without specific data and technical knowledge. The detailed evaluation allows an individual user or household to assess building energy consumption more precisely than the simplified evaluation. The questionnaires are more complex, but the results are closer to the real situation of the user and can be strongly personalized.

To ensure a wide diffusion of the portal, the questionnaires used in the evaluation tools are simple, intuitive and easy to complete, **as illustrated in Figure 2.** The results are also expressed in a very simple form, **as seen in Figure 3,** for energy uses in the considered dwellings. Several strategies to improve the energy efficiency of the tested building are then provided (such as the insulation of the roof, the change of the glazing, the insulation of the whole building's envelope, behavioral changes) to the user. They are personalized according to the characteristics of its dwelling. The quantification (in kWh/year and in %) of the potential energy savings linked to each strategy is also provided on the basis of the results stored in the database and the unique code used to store the results (**Table 1**). In addition to the results presented in this paper that are focused on energy uses in buildings, additional indicators are also provided in the online portal. In particular, it is possible to take into account the impact of the location of the dwelling on the daily mobility of inhabitants by assessing the energy consumption for daily mobility. The use of renewable energy is also included in the portal on the basis of the methodology developed by Marique et al. (2013) and Marique and Reiter (2014). The final version of this portal is online as of the end of August 2014 at www.solen-energie.be (only in French for the moment).

In addition to the development of this online portal, numerous actions have been – and will be-undertaken by the research teams to promote this initiative and to extensively raise awareness of the importance of improving energy efficiency in buildings, starting from the individual scale. These actions are dedicated to a wide range of actors: students in architecture and urban planning, researchers, local and regional stakeholders, private developers, architects, and, of course, citizens.

It is too early to provide the results of usability testing since the final version of the tool has only been online for a few weeks, but the first simplified version of the portal that is solely comprised of suburban types of dwellings (Marique et al., 2012 and 2014) was launched between 2012 and August 2014. We have registered approximately 400 visits per month on the website. Direct interviews and workshops have shown positive feedback from users of the online interactive portal.

Last, but not least, in May 2014 the online portal and the research project that allowed its development were awarded the “Energy Globe Award” for Belgium, one of the world's most prestigious environmental awards (see also http://www.energyglobe.info/belgium2014?cl=english).



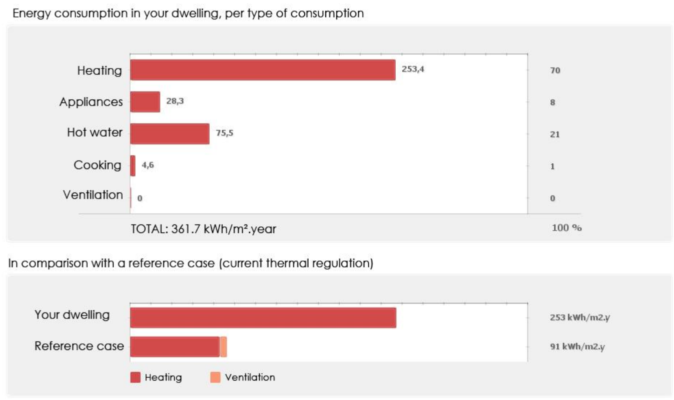


Figure 2 Example of the questionnaires provided in the online portal (left)

Figure 3 Example of results provided in the online portal (right)

CONCLUSIONS

This paper presented a methodology that enables one to precisely assess energy needs and energy consumption for space heating, cooling, ventilation, lighting, appliances and cooking within individual dwellings on the basis of a “bottom-up” approach. This methodology was based on a typological classification of buildings, thermal simulations, local surveys and linear extrapolations to cover a wide range of buildings and parameters. Among others, the impact of the location in which a dwelling is located is taken into account via the application of correction factors based on the built density of the neighborhood. This methodology was applied to the Walloon (Belgium) residential building stock to build a huge database that included more than 250,000 individual results.

This database was then mobilized to build an online interactive portal that aims to raise public awareness of energy efficiency in buildings. Thus, citizens are able to easily assess the sources of energy consumption for buildings. They may also compare these different energy consumption sources in order to determine relevant and personalized recommendations with which to reduce their energy consumptions. This interactive online portal represents the main results of an important two-year scientific research project dedicated to energy efficiency in Wallonia that is accessible to a large non-specialized audience, which is crucial in the scope of sustainable development.

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