Global Sensitivity Analysis applied to Total Energy Use in Buildings

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ABSTRACT

The work presented in this paper has been carried out in the frame of the IEA-ECBCS Annex 53 project: “Total Energy Use in Buildings: Analysis and evaluation methods”. The aim of this work is to present a methodology to identify the most influential parameters affecting the final energy consumption in office buildings.

In order to represent buildings and HVAC systems, a representative typology was defined, modeled and simulated and subsequently a global sensitivity analysis (variance-based method) was performed.

This paper provides useful information to future works related to design building decisions, building calibration, energy management strategy, etc. helping to detect and rank those factors which need to be better measured and/or estimated, in order to improve building energy efficiency.

1. INTRODUCTION

One of the most significant barriers for achieving the goal of substantially improving energy efficiency of buildings is the lack of knowledge about the factors determining the energy use (Annex 53). This is often reflected by the significant discrepancy that can be found between the designed and the real total energy use in buildings.

The reasons for this discrepancy are generally poorly understood, and often have more to do with the role of human behavior than the building design.

Building energy consumption is mainly influenced by six factors: (1) climate, (2) building envelope, (3) building services and energy systems, (4) building operation and maintenance, (5) occupants’ activities and behavior and (6) indoor environmental quality provided. These factors cannot be isolated and must be investigated together.

When investigating their influence by means of building simulations, global sensitivity analysis (GSA) plays a key role; because, it allows evaluating the relative importance of each input when they are varied simultaneously and generously. Depending on the method “relative importance” is measured by means of different indices calculated from different statistics. In this work, a method based on the disaggregation of the total variance is applied.

Once, the amount of variance induced by each factor is known, it is possible to rank them and then focusing on those parameters which are responsible of the biggest part of the uncertainties, prioritizing their estimation.

For carrying out this analysis, a thermal model was built to simulate building and HVAC behavior. The model is based on typology collected in the frame of Annex 53 and the assigned ranges of selected parameters is carefully collected from surveys, standards and national regulations taking care of making them as realistic as possible.

Next chapters present in detail the methodology used and a description of the model built.

2. VARIANCE-BASED SENSITIVITY ANALYSIS

Saltelli et al. (2004) defines sensitivity analysis (SA) as “The study of how uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input”.

Variance-based sensitivity analysis focuses on the questions “which of the input variables influences the model output variance at most?” and “which of the input variables has to be known more accurate to reduce the output variance?” (Schwieger, 2004).

Let be the model function: $Y = f(\boldsymbol{X})$, where Y is the output and $\boldsymbol{X} = (X_1, X_2, \dots, X_k)$ are k independent input factors, each one varying over its own probability density function.
Sobol proved that any square integrable mathematical function can be decomposed by a unique high dimensional model representation (HDMR) if and only if inputs factors are independents among them[1]. This fact leads to the variance of a model output can be divided according to equation (1).

$$V_y = \sum_{i=1}^{k} V_i + \sum_{i>j}^{k} V_{ij} + \dots + V_{12\dots k} \tag{1}$$

Where:
V_y is the total variance of the output model (output function), V_i is the marginal variance induced by X_i and $V_{i_1 \dots i_s}$ is to define the cooperative fractional variance generated by $\{X_{i_1}, \dots, X_{i_s}\}$.

Equation (1) leads to the definition of variance-based sensitivity indices. For convenience, it is rewritten as follows.

$$\sum_{i=1}^{k} S_i + \sum_{i>j}^{k} S_{ij} + \dots + S_{12\dots k} = 1 \tag{2}$$

Where:
$S_i = V_i / V_y$ is the first order sensitivity index, which measures the amount of variance of Y explained by X_i alone.
$S_{ij} = V_{ij} / V_y$ is the second order sensitivity index that measures the amount of response variance explained by the interaction between X_i and X_j and so on.

Due to the computational cost of evaluating all the sensitivity indices is prohibitive (i.e., 2^{k-1}), only two indices are investigated in practice: the first-order sensitivity index defined earlier and the total sensitivity index (Equation (3)) because they summarize the essential information.

$$S_{T_i} = S_i + \sum_{i \neq j}^{k} S_{ij} + \cdots + S_{12\dots k} \tag{3}$$

The total sensitivity index includes all the contributions of X_i (marginal and cooperative) to the variance of Y so that if its value is close to zero, X_i can be deemed as non-significant (factor fixing).

Several methods are currently available to get sensitivity indices: Sobol, Jensen, FAST (only first sensitivity indices), EFAST (extension of FAST for total sensitivity indices), among others[2]. From them, FAST is known for being a very robust method with a low computational cost. However, it still remains prohibitive for complex and large dimensional models (its cost dramatically increases with k). This is the main reason for seeking a simplified method that allows performing sensitivity analysis without an excessive computational cost.

Methodology applied in this work only comprises the calculation of first sensitivity indices. This decision has been taken under the hypothesis of high linearity and additivity of the models.

Mechri et al. (2010) carried out a variance based sensitivity analysis for energy design purposes in several Italian cities. They showed that for heating and cooling needs, interaction effects (the sum of higher order indices of all parameters) never reached more than 3% of total variance. This fact supports the hypothesis mentioned in the paragraph above.

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[1] For a detailed description see (Mara and Tarantola, 2008)

[2] For detailed information see (Ekström, 2005)

Taking into account this background, first sensitivity indices are obtained following the next methodology:

From equation (2), it can be deduced that always: $\sum_i S_i \leq 1$.
Then, the closer this value to 1, the lower the effect of interactions among input parameters. Therefore, an indicator of interaction's presence can be defined as: $1 - \sum_i S_i$.

A model without interactions is said to be additive (i.e., linear one). Its first order indices sums up to one if the inputs are orthogonal. For additive models, the first order indices coincide with what can be obtained with regression methods (squared standardized regression coefficients). Therefore, in this work, sensitivity indices are computed from linear regression models of selected outputs to be studied. This method coincides with Monte Carlo regression analysis when inputs are independent.

First sensitivity index for variable X_i is obtained by means of equation (4)

$$S_i = \frac{V[E[Y|X_i]]}{V[Y]} = \frac{{b_i}^2 V[X_i]}{V[Y]} = {\rho_{Y,X_i}}^2 \tag{4}$$

Where b_i is the linear regression coefficient of the variable X_i with respect to Y, and ρ_{Y,X_i} is the Pearson coefficient between X_i and Y.

The main advantage of this method is its cheap computational cost (number of runs does not depends on the number of inputs) and the possibility of using the same sample to perform both uncertainty and sensitivity analysis.

On the other hand, the main drawback of this assumption is the accuracy of the sensitivity indices will depend on the nearness of the model coefficient of determination (R^2) to 1, but if that were not so, does not imply that the analysis is useless but only that its results cannot be taken as quantitative (Saltelli et al., 1999).

3. METHODOLOGY

GSA treats the model under consideration as a black-box. The investigation is performed by the following steps (Mara and Tarantola, 2008):

1. Select the model and the output of interest,
2. Select the uncertain model inputs (k) and set their probability density functions,
3. Generate a sample of the model input space size (N)
4. Run the model for each sample point and save the responses
5. Perform uncertainty and sensitivity analysis on the response of interest and interpret the results

In step one, the selection of the output of interest should allow the analyst to answer the problem at hand properly.

In step two, model inputs were selected according to 6 family factors listed above and translated as input parameters to TRNSYS environment. A total of 68 parameters were chosen which are mainly related to building geometry and envelope, internal heat gains (occupancy, lighting, and appliances), set points, equipment efficiencies, etc.
Ranges and probability distributions of input parameters should be defined from real data (surveys or statistical data available for different countries). This is the most difficult task due to the lack of data sources available. Generally, when no a priori information is available, the uncertainty range is selected large enough so as to be plausible and a uniform distribution is assumed (Mara and Tarantola, 2008). Range values were taken from few real data available and mainly from standards and national regulations.

In step three, a Latin hypercube sampling (LHS) is performed to generate a sample matrix of inputs. The advantage of this method is to ensure a full coverage of the range of inputs variables. Generated sample can be thought as a matrix which contains, for N model runs, the sampled values of each one of the k input factors under examination. During the course of this work, the author became aware about the correlation's degree provided by LHS in the generated sample. As it has been explained before, most of the methods are based on the assumption of

orthogonality among the inputs, so for solving this problem, a technique propose by Iman and Conover (1982) was implemented defining a correlation matrix equal to identity. For details see (Ekström, 2005).
Related to the sample's size, Lomas (1992) precises after 60-80 simulations only marginal improvements in accuracy are obtained. Taking into account decorrelation step, a new constraint must be considered. In this case sample's size must be greater or equal to the number of inputs.
Despite this and to ensure accurate results, the number of samples was set as 250 (for each climate).

In step four, thermal model is run N times changing all the inputs according to sample matrix. This step requires large computational time (in this case 3-5 minutes per run).

Finally, in step five, an uncertainty and sensitivity analysis is carried out according to methodology described above.

To perform all this steps, several models in different environments were created.
The main code is written in Matlab (2009) and handles: reading data, performing LHS, carrying out a sizing procedure (to calculate nominal capacities of equipment), editing input files and collecting the desired outputs from thermal building model.

Building model was developed TRNSYS (Klein, 2010) and comprises all the components needed for performing thermal simulation.

4. MODEL DESCRIPTION

4.1 Description of a reference building

Proposed building is considered as a generic example in Europe of large buildings with huge glazed surface. The floor plan (Figure 1) is based on statistical research on Flemish-Belgian office buildings (BBRI, 2001).
The building has a rectangular base (67m and 15m) and its internal layout corresponds to an open plan (landscape). It is a 15 storey high building. The total height of the building is 45 m. The floor area of the building is 1005 m^2. The room height is 3 m. The two long facades are identical as are the two short ones (see Figure 1).

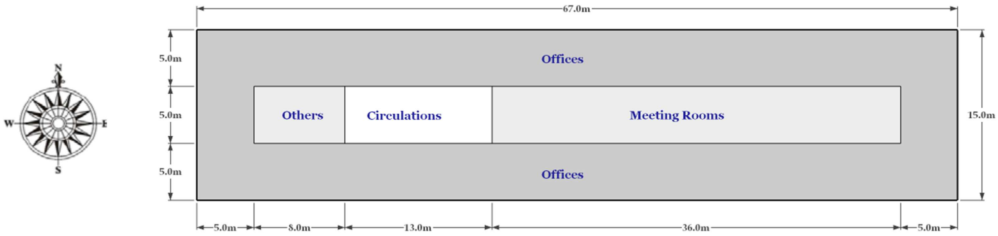

Figure 1: Plan Scheme

Building has been divided in five zones (listed on previous figure) defined according to usage and orientation.
For modeling purposes was only considered an intermediate floor[3]. In order to calculate the total building performance, each zone type was multiplied by the number of floors. Since no shading for neighboring buildings was considered, the multiplication is fairly reasonable.

4.2 Occupants' Behavior

Occupants' behavior was implemented by means of a simplified model based on diversity factor approach. This model generates daily profiles (hourly base) for occupant presence, lighting and appliances usage.
Profiles are created in function of operation building hours and assigning a specified diversity factor value for each period. It must be remarked that profiles only depend on time and periods and not on any physical variable.
No operation of terminal unit, blinds or windows opening has been implemented.
Figure 2 shows a generic daily profiles that applies to occupancy, lighting and appliances usage.

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[3] In modeling terms, it means that floor and ceiling were considered as adiabatic surfaces.

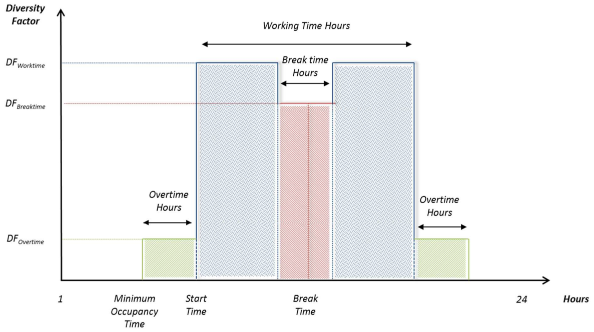


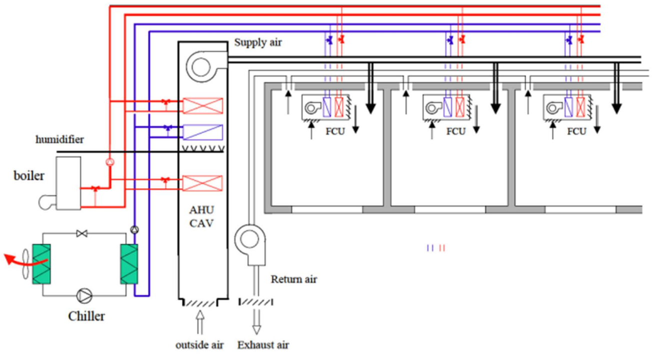
Figure 2: Diversity factor-based daily profile for occupancy at offices (scheme).

Each profile comprises 4 different periods: Working time (including an intermediate pause), break time, overtime and a base time which corresponds to a non-occupancy period when building is closed and at some zones lighting and appliances still work at stand by, security or "base" level consumption.

The addition of every period of time constitutes a daily operation profile. Each portion weights differently when occupant's behavior into different zones of the building (offices, meeting rooms, etc.) and different days of the week (working days, holydays, week end days and vacations), has to be represented.

4.3 HVAC System and Building Operation

Proposed system corresponds to an "air to water system". It is composed by a constant air volume AHU which handles latent internal loads and several FCUs which take in charge sensible internal loads. Hot water is supplied by a gas fired boiler and cold water by an air cooled chiller. Next figure provides a scheme of HVAC system layout.



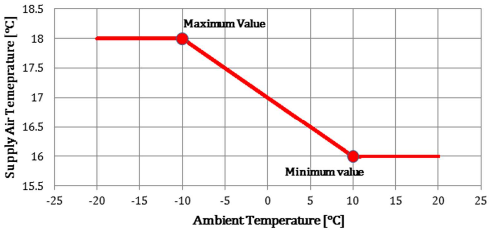


Figure 3a: Multi zone Constant Airflow Volume system and water distribution (FCU 4 pipes) - scheme according to (Stabat, 2010).
Figure 3b: AHU supply air temperature control

Ventilation is provided by an AHU. Ventilation flow rate correspond to minimal hygienic one needed per occupant and zone usage according standards and national regulations.
Air flow rate enters by offices and meeting rooms and then it is recirculated to circulations, others. Ventilation profiles takes into account only week days during working time (not overtime).
Air supply temperature is function of outside temperature. Control is implemented defining a minimum and a maximum value according to Figure 3b.
Infiltration rates are calculated by means of K1-K2-K3 method (ASHRAE, 1989) and are supposed to be enabled when ventilation is turned off.
Air handling unit is modeled by TRNSYS types for each component present in it. AHU comprises: preheating coil, adiabatic humidifier, cooling coil (and dehumidifier), post heating coil and supply and return single speed fans.
Fan coil units are implemented from a calibrated model obtained from manufacturer data. It corresponds to Carrier 42N16 unit. This model was implemented by multidimensional interpolation type available in TRNSYS (type 581).
Heating plant has a gas fired boiler with a fixed efficiency. No consideration about part load has been done on this issue.

Cooling plant comprises an air cooled chiller. Model has been implemented in TRSNSYS and based on manufacturer data.

Hot and cold water temperatures are controlled in way AHU supply air i.e. in function of outside temperature.

Water distribution system which provides hot and cold water to secondary system are supposed to have constant flow. For allowing different water flows during operation, it has been implemented a layout based on bypass valves.

No thermal losses through pipes have been taken into account.

For auxiliary devices such as fans and pumps, consumptions are defined by means Specific Fan Power (SFP) in W/m^3/s and Specific Pump Power (SPP) in W/kg/s, respectively. Values for SFP and SPP have been taken from European regulation and ASHRAE standards. This method avoids making unnecessary and detailed calculation of pressure drop in ducts and pipes.

Indoor set points control comprises 2 aspects: temperature and humidity. Temperature is controlled in every occupied zone. Set point and setback temperatures have been defined for occupancy and non-occupancy hours respectively.

For humidity control have been defined a minimum and maximum humidity level defined by relative humidity and measured at return flow rate that re-enters to AHU. If relative humidity goes out of this range, humidifier or dehumidifier starts to operate depending on the case.

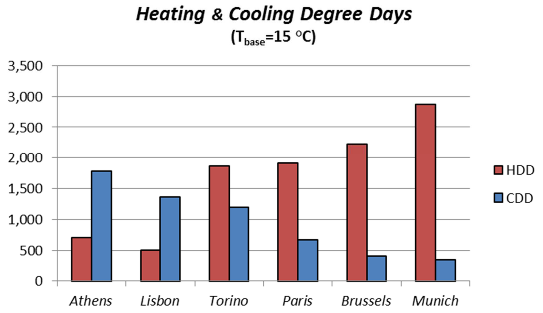
5. FAMILY FACTORS DEFINED IN ANNEX 53

68 input parameters were considered for carrying out sensitivity analysis. All of them were translated in TRNSYS input/parameter variables and grouped according to six family factor listed above. The same variables, ranges and probability distribution were used for each simulated climate.

To take into account first family factor, six climates are chosen in order to have an overview of the different European climates. They are defined based on heating and cooling degree days (15 °C base temperature).

The meteorological data from Athens, Lisbon, Torino, Brussels, Paris and Munich were taken from tmy2 files available in TRNS YS library.

Degree days shown in Figure 4 were also calculated from tmy2 files.



Zone	Representative City	HDD	CDD
Zone 1	Athens	703	1777
Zone 2	Lisbon	499	1358
Zone 3	Torino	1862	1201
Zone 4	Paris	1911	669
Zone 5	Brussels	2227	405
Zone 6	Munich	2876	346

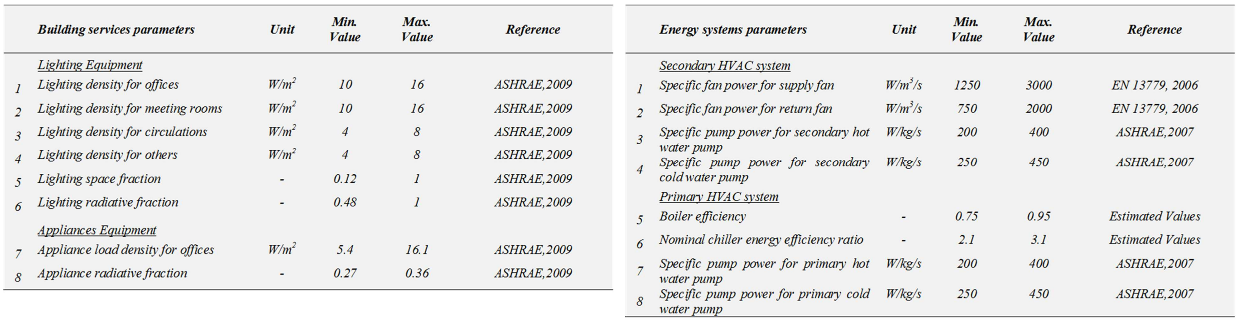
Figure 4: Heating (sensible) and cooling (sensible and latent) degree days for selected cities

Parameters related to remaining family factors are presented in the following tables:

Table 1: Selected inputs parameters for “building envelope” family group

	Geometry and envelope parameters	*Unit*	*Min. Value*	*Max. Value*	*Reference*
1	*Ground albedo*	-	*0.07*	*0.70*	*Thevenard and Haddad, 2006*
2	*Surface azimuth angle for south facade*	*Degrees*	*0*	*90*	*Estimated Values*
3	*Surface percentage of offices*	-	*0.65*	*0.75*	*BBRI, 2001*
4	*Surface percentage of meeting rooms*	-	*0.1*	*0.15*	*BBRI, 2001*
5	*Surface percentage of circulations*	-	*0.03*	*0.08*	*BBRI, 2001*
6	*Window to wall ratio*	-	*0.35*	*0.65*	*Estimated Values*
7	*U value for external walls*	*W/m^2-K*	*0.40*	*2.90*	*BBRI, 2001 - Stabat,2010*
8	*U value for windows*	*W/m^2-K*	*1.20*	*5.10*	*BBRI, 2001 - Stabat,2010*
9	*Internal heat capacity per building’s area*	*J/m^2-K*	*120,000*	*260,000*	*ISO13790*
10	*Normal solar heat gain coefficient (SHGC)*	-	*0.20*	*0.80*	*ASHRAE,2009*

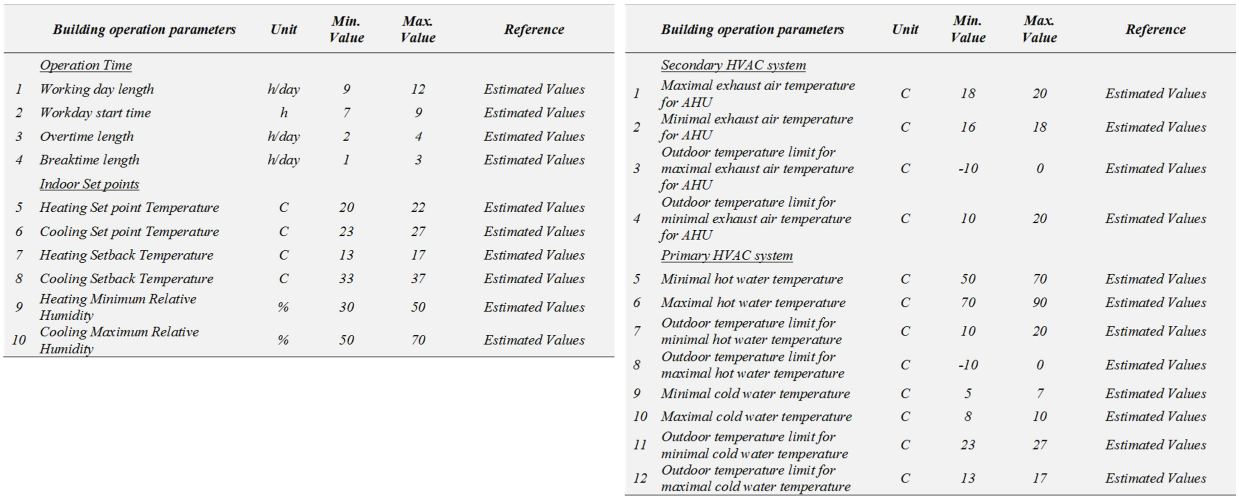
Table 2: Selected inputs parameters for “building services and energy systems” family group



	Building services parameters	Unit	Min. Value	Max. Value	Reference
	Lighting Equipment				
1	Lighting density for offices	W/m²	10	16	ASHRAE,2009
2	Lighting density for meeting rooms	W/m²	10	16	ASHRAE,2009
3	Lighting density for circulations	W/m²	4	8	ASHRAE,2009
4	Lighting density for others	W/m²	4	8	ASHRAE,2009
5	Lighting space fraction	-	0.12	1	ASHRAE,2009
6	Lighting radiative fraction	-	0.48	1	ASHRAE,2009
	Appliances Equipment				
7	Appliance load density for offices	W/m²	5.4	16.1	ASHRAE,2009
8	Appliance radiative fraction	-	0.27	0.36	ASHRAE,2009

	Energy systems parameters	Unit	Min. Value	Max. Value	Reference
	Secondary HVAC system				
1	Specific fan power for supply fan	W/m³/s	1250	3000	EN 13779, 2006
2	Specific fan power for return fan	W/m³/s	750	2000	EN 13779, 2006
3	Specific pump power for secondary hot water pump	W/kg/s	200	400	ASHRAE,2007
4	Specific pump power for secondary cold water pump	W/kg/s	250	450	ASHRAE,2007
	Primary HVAC system				
5	Boiler efficiency	-	0.75	0.95	Estimated Values
6	Nominal chiller energy efficiency ratio	-	2.1	3.1	Estimated Values
7	Specific pump power for primary hot water pump	W/kg/s	200	400	ASHRAE,2007
8	Specific pump power for primary cold water pump	W/kg/s	250	450	ASHRAE,2007

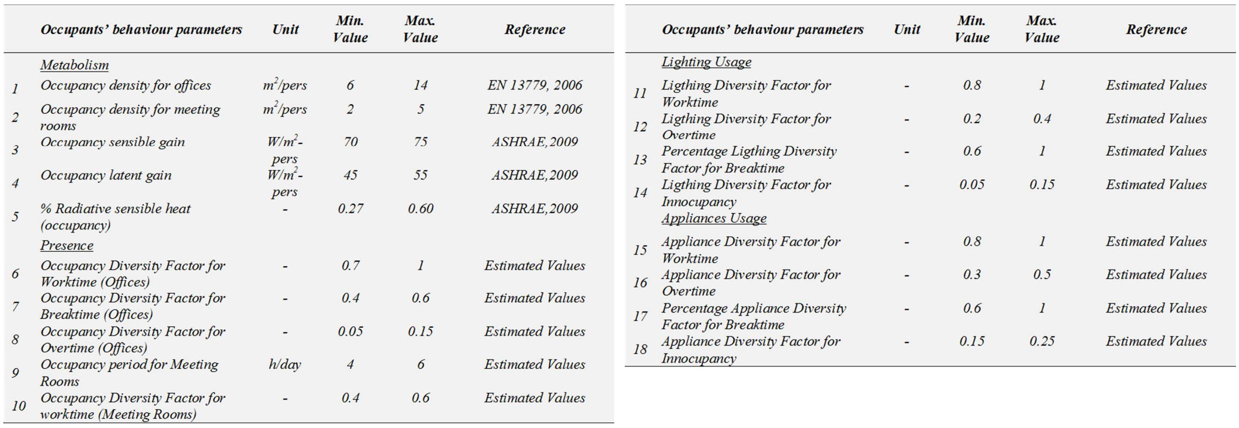
Table 3: Selected inputs parameters for “building operation” family group



	Building operation parameters	Unit	Min. Value	Max. Value	Reference
	Operation Time				
1	Working day length	h/day	9	12	Estimated Values
2	Workday start time	h	7	9	Estimated Values
3	Overtime length	h/day	2	4	Estimated Values
4	Breaktime length	h/day	1	3	Estimated Values
	Indoor Set points				
5	Heating Set point Temperature	C	20	22	Estimated Values
6	Cooling Set point Temperature	C	23	27	Estimated Values
7	Heating Setback Temperature	C	13	17	Estimated Values
8	Cooling Setback Temperature	C	33	37	Estimated Values
9	Heating Minimum Relative Humidity	%	30	50	Estimated Values
10	Cooling Maximum Relative Humidity	%	50	70	Estimated Values

	Building operation parameters	Unit	Min. Value	Max. Value	Reference
	Secondary HVAC system				
1	Maximal exhaust air temperature for AHU	C	18	20	Estimated Values
2	Minimal exhaust air temperature for AHU	C	16	18	Estimated Values
3	Outdoor temperature limit for maximal exhaust air temperature for AHU	C	-10	0	Estimated Values
4	Outdoor temperature limit for minimal exhaust air temperature for AHU	C	10	20	Estimated Values
	Primary HVAC system				
5	Minimal hot water temperature	C	50	70	Estimated Values
6	Maximal hot water temperature	C	70	90	Estimated Values
7	Outdoor temperature limit for minimal hot water temperature	C	10	20	Estimated Values
8	Outdoor temperature limit for maximal hot water temperature	C	-10	0	Estimated Values
9	Minimal cold water temperature	C	5	7	Estimated Values
10	Maximal cold water temperature	C	8	10	Estimated Values
11	Outdoor temperature limit for minimal cold water temperature	C	23	27	Estimated Values
12	Outdoor temperature limit for maximal cold water temperature	C	13	17	Estimated Values

Table 4: Selected inputs parameters for “occupant activities and human behaviour” family group



	Occupants’ behaviour parameters	Unit	Min. Value	Max. Value	Reference
	Metabolism				
1	Occupancy density for offices	m²/pers	6	14	EN 13779, 2006
2	Occupancy density for meeting rooms	m²/pers	2	5	EN 13779, 2006
3	Occupancy sensible gain	W/m²-pers	70	75	ASHRAE, 2009
4	Occupancy latent gain	W/m²-pers	45	55	ASHRAE, 2009
5	% Radiative sensible heat (occupancy)	-	0.27	0.60	ASHRAE, 2009
	Presence				
6	Occupancy Diversity Factor for Worktime (Offices)	-	0.7	1	Estimated Values
7	Occupancy Diversity Factor for Breaktime (Offices)	-	0.4	0.6	Estimated Values
8	Occupancy Diversity Factor for Overtime (Offices)	-	0.05	0.15	Estimated Values
9	Occupancy period for Meeting Rooms	h/day	4	6	Estimated Values
10	Occupancy Diversity Factor for worktime (Meeting Rooms)	-	0.4	0.6	Estimated Values

	Occupants’ behaviour parameters	Unit	Min. Value	Max. Value	Reference
	Lighting Usage				
11	Ligthing Diversity Factor for Worktime	-	0.8	1	Estimated Values
12	Ligthing Diversity Factor for Overtime	-	0.2	0.4	Estimated Values
13	Percentage Ligthing Diversity Factor for Breaktime	-	0.6	1	Estimated Values
14	Ligthing Diversity Factor for Innocupancy	-	0.05	0.15	Estimated Values
	Appliances Usage				
15	Appliance Diversity Factor for Worktime	-	0.8	1	Estimated Values
16	Appliance Diversity Factor for Overtime	-	0.3	0.5	Estimated Values
17	Percentage Appliance Diversity Factor for Breaktime	-	0.6	1	Estimated Values
18	Appliance Diversity Factor for Innocupancy	-	0.15	0.25	Estimated Values

Table 5: Selected inputs parameters for “indoor environmental quality provided” family group

	IAQ parameters	*Unit*	*Min. Value*	*Max. Value*	*Reference*
1	*Minimum Ventilation Rate for Offices*	*m3/h-pers*	*20*	*40*	*Stabat, 2010*
2	*Minimum Ventilation Rate for Meeting Rooms*	*m3/h-pers*	*20*	*40*	*Stabat, 2010*

6. RESULTS

6.1 Annual fuel and electrical consumption - uncertainty assessment

Mean value, standard deviation and the coefficient of variation of fuel and electrical consumptions per unit of floor are shown in Figure 5.

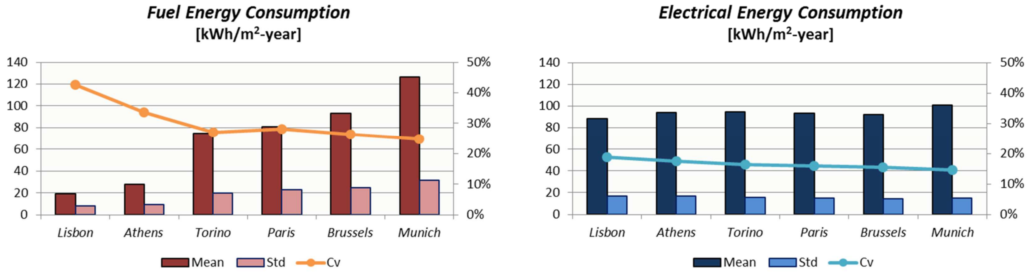


Figure 5 : Mean, standard deviation and coefficient of variation of fuel and electricity consumption

Note: Cities are ranked in ascending order according to number of heating degree days (HDD).

Fuel consumption shows a very clear relationship with weather conditions. This is because; it covers hot water demands which are climate dependent.

Mean value increases highly from a hot to a cold climate (from 20 to 130 kWh/m^2-year). Standard deviation also increases; however, coefficient of variation presents an inverse relationship with respect to heating degree days. This means that despite being quantitative less important, values are more dispersed around the mean value in hot weathers than cold ones.

On the other hand, electrical consumptions present a slightly variation on all its statistics over all the cities. A mean value around 95 kWh/m^2-year can be seen and a coefficient of variation around 15%. This causes that total variance of electrical consumption does not vary significantly (compared to fuel consumption) and allows to infer a weak influence of single consumptions related to climate conditions (such as chiller or auxiliaries) in the total electrical consumption.

6.2 Annual fuel and electrical consumption – sensitivity analysis

6.2.1 Fuel consumption

Figure 6 shows the first sensitivity indices and variance decomposition for annual fuel consumption corresponding to a hot and a cold weather, Lisbon and Brussels respectively.

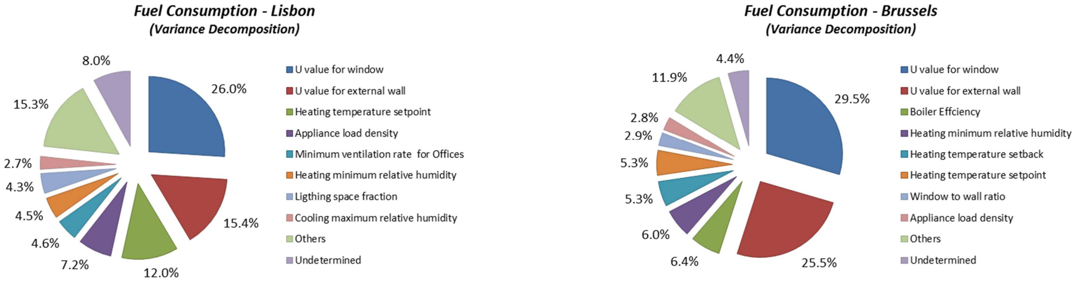


Figure 6 : Variance decomposition for annual fuel consumption – Lisbon and Brussels

Fuel consumption shows a high linear behavior evidenced by a low percentage of undetermined variance (8 and 4.4% respectively); this means a high value of the coefficient of determination (R^2) and therefore, the error on determining first sensitivity indices can be neglected. This fact supports the hypothesis made in Chapter 2 about high linearity in additivity of the model.

No matter the weather, it is possible to see some marked similarities:

- Envelope properties (U value of walls and windows) account for the biggest part of the variance (41.4 and 55%). This fact is totally related to the wide ranges defined for both parameters (see Table 1).
- There is no significant impact of the human behavior on fuel consumption. Special case would be if we consider the management of indoor set points directly on the terminal units by occupants (this is not the case). In that case, managing of indoor set point temperature would be more sensitive on warmer than colder climates. However, if we analyze total building energy consumption, fuel consumption weights much more in colder climates than hotter climates.

From figure above can be recognized that results show more sensitivity on parameters related to demands instead of boiler efficiency. Despite this effect decrease in cold weathers (see the position of boiler efficiency in the ranking), space heating demand impacts more than air conditioning demand on fuel consumption.

6.2.2 Electrical consumption

Electrical consumption comprises: lighting, appliances, auxiliaries and chiller consumption.

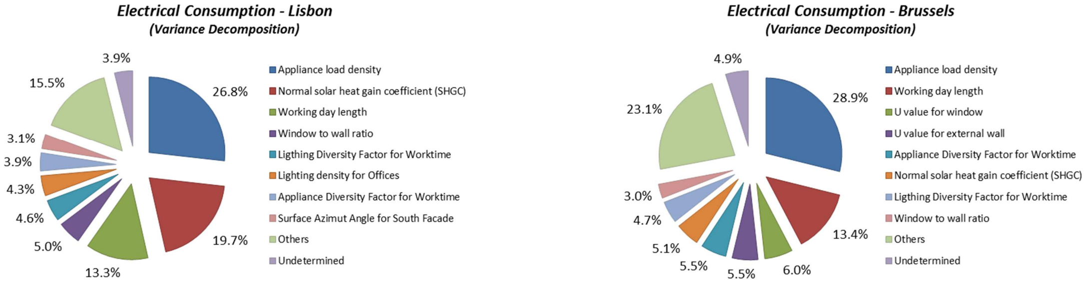


Figure 7 : Variance decomposition for annual electrical consumption – Lisbon and Brussels

Electrical consumption is influenced by envelope (related to cooling loads) and building services family factors (mainly installed capacities for appliances and lighting).

Because this consumption depends on four single ones, it is difficult apportioned the variance of the inputs to each consumption. Their action can contribute to the variance of several single consumptions and its real weight on each one cannot be determined.

Regarding to human behavior, lighting and appliances diversity factors are present not being in both cases a big source of variance.

7. CONCLUSIONS

First of all, proposed methodology proved to be adequate being able to predict more than 90% of the variance and allowing a significant reduction sample's size and computational time.

From all the family factors studied, climate is the most influential. It presents a big influence on fuel consumption increasing the variance as we move to colder climates. On electrical consumption its influence lies on the order of the ranking of most influential parameters.

Envelope properties (U value of walls and windows) present the biggest effects on fuel consumption. If we knew the true value of thermal transmittance of walls and windows, we would be able to take apart the 41.4% of the variance for hot climates and 55% for cold ones.

On electrical consumption, appliances load density is responsible for the first big part of the variance. It could be due to the big assumed range. Although, these values were taken from known standards (ASRAE, 2009) its real impact must be checked. For the rest of parameters affecting electrical consumption, it is difficult to recognize where their influence is bigger. Sometimes, one variable can impact to more than one single consumption; such is the case of variables related to lighting and appliances consumption where its specific weight in each one cannot be clarified. A more detailed analysis desegregating the variance must be done.

Although 68 parameters were defined, only a small group is responsible of the biggest part of the variance. It can allow simplifying the models and therefore decreasing the simulation time.

Parameters related to human behavior only show a small effect on electrical consumption variance. On fuel consumption, if it were assumed that occupant operates indoor temperature set point, its impact is only appreciable in hot climates, where fuel consumption is very small compared to the electrical one.

It must be remarked that results obtained in this work, total variance of fuel and electrical consumptions and ranking of most influential parameters, are totally linked to the definition of the ranges for the selected inputs. If they were shortened, it would be possible to see a reduction on the variance as well as a different (maybe not so much) order in the ranking of most influential parameters.

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