COMPARISON OF STANDARD AND CASE-BASED USER PROFILES IN BUILDING'S ENERGY PERFORMANCE SIMULATION

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ABSTRACT

The user's action is a decisive factor in the energy performance of a building. In this paper is demonstrated the necessity of using more specific user's profiles (UPs) in simulations of building's energy performance (EP).

The Spanish Technical Code for Buildings (CTE) offers a unique generic residential UP for all sites in the country. With the purpose of achieving more realistic UP, energy data, obtained during seven years from more than 700 dwellings, are processed by advanced classification tools (Exclusive SOM). The UPs obtained are used to make new TRNSYS energy simulations in the main Spanish cities and the energy consumption predicted of new UPs is compared to the CTE UP. The sharp differences corroborate the importance of more accurate UPs.

INTRODUCTION

Energy profiling, in the building environment, is an analysis of the actual or predicted energy performance of buildings. Recent energy profiling has often involved calculations of both energy consumption and related carbon dioxide (CO2) emissions (Jaccard et al., 1997; Myer and Chaffee, 1997). This move is related to increasing environmental concerns which have brought about new government regulations associated with the energy performance of buildings in many countries (Levine et al., 2007). This new regulatory environment combined with rising energy prices is stimulating a new interest in the role of energy profiling in optimising energy performance during the whole life cycle of both domestic and commercial buildings (O'Donnell et al., 2004).

Nowadays, architects and buildings designers value the importance of energy profiling, but they are forced to take decisions according their experienced knowledge or trusting in generic constants, tables or values that do not represent the real scenario in which they work. Obviously, the result is not as accurate as it should be and, specifically, in user's energy behaviour issues (Mills, 2004).

Oftentimes in building simulation, a superposition principle is being applied, meaning that the resulting effect in energy demand is a linear superposition of the effects of each input. This is an oversimplification as, when different improvements are added, the resulting efficiency gain is not the sum of the efficiency gain of each of the separate improvements. With regards to the influence of UP and, specifically, to the indoor setpoint temperature, it is clear that if the winter set point temperature is higher, the transmission losses through the skin (connected to the surface of the outer skin) will vary in a different proportion to the ventilation losses (linked to the occupancy). Another example is the effect of using a free-run temperature schedule for a residential building during the daytime, as it is partly used in the Spanish building codes; with this UP, the influence of solar shading will be very low.

This paper is motivated by the results obtained from a simulation of the EP of a social housing building in Tossa, Spain. This EP evaluated the heat, ventilation and air conditioning (HVAC) loads and demands as well as lighting loads and comfort bands. These simulations need some inputs like weather data files, the description of the building's geometry and materials but also the UP (occupancy, setpoint temperatures, etc.). Many times these inputs are not available and must be supposed, most of the times being not accurate (Sabaté et al., 2007).

In order to achieve accurate simulations of building's energy performance, the user's energy behaviour must be detailed and well-defined attending to the place and use predicted. As previously stated, the CTE has publicized a unique generic residential UP for all sites in the country. This profile represents the normal energy behaviour of families in residential buildings in Spain, regardless of the number of people living in the dwelling, their activities, etc. This UP is implemented for the design of new buildings and for making energy evaluations and predictions. Thus, specific and more accurate profiles will obtain better results in both simulations and designs.

In this paper, energy data obtained by Leako® system (from now on it is referred as Database) during seven years from more than 700 dwellings in the Basque Country are processed to obtain new specific UP for indoor temperature (more information at http://www.leako.com). These real-data UP are created using Exclusive Self-Organizing Memory Maps (ESOM). ESOM analyze the data and get hidden relationships between the different users in order to obtain a kind of *model user* that has the main characteristics of the group it represents.

As a case study, TRNSYS simulations of a flat from the Database have been done. The idea was to compare the results from simulations made with CTE UP and real-data UPs with the actual energy loads of the flat.

Results conclude that once a specific UP is assumed the conclusions derived from simulation are bound to that UP. Realistic UP must be used in simulations in order to get realistic results that conclude in a better design.

TEMPERATURE PROFILES

Leako® System Database

To be able to obtain realistic UPs, a great amount of real data is needed, and the Leako® System Database is used to this purpose. Leako® is an enterprise from the Basque Country specialized in central heating, Domestic Hot Water (DHW) and air conditioning installation, distribution, and metering. In order to improve conventional installations and obtain more security, efficiency and energy saving, Leako System has been working since 1995. The system is prepared for sets of apartments and office buildings and it takes advantage of communication technology possibilities. It consists of a central installation which supplies heating, DHW and air conditioning to the whole set of apartments or buildings, and it incorporates subcentrals in every dwelling that provide an individual service for each customer. Information and accessibility are two of the main characteristics of the system because all the sensors and actuators are communicated by a dedicated bus or modems, thus all the information about the system (sensor readings, alarms and behaviours) is available for maintenance and later analysis and investigation.

The Leako® Database consists of energy data obtained each hour during seven years from more than 700 dwellings; specifically, the collected data are: heating KWh, DHW KWh, consumed water liters, and average indoor temperature.

This paper is focused on temperature UPs and only the average indoor temperature is used in this first stage.

CTE profiles

The Spanish Technical Code for Buildings offers a set of profiles for energy simulation. Table 1 shows the summarized temperature CTE UP (CTE specifies temperatures for each hour of a day and each month of a year, but the repetition of the values allows to condense the 24x12 table in a 3x3 table without information loss); where “J-M” means January to May, “Jn-S” means June to September and “O-D” means October to December; “0-7”, “8-15”, “16-23” refer to periods of daily time, in other words: “early morning”, “morning/afternoon” and “evening/night”.

Table 1

Summarized Temperature CTE UP

Months/Hours	0-7h	8-15h	16-23h
January-may	17ºC	20ºC	20ºC
June-september	27ºC	25ºC*	25ºC
October-december	17ºC	20ºC	20ºC

Temperature CTE UP tries to define comfort temperature for human users in each season or period of a year in a dwelling. The asterisk (*) marks that comfort temperature in this period is not defined in the CTE UP; the pointed value is determined establishing analogies with the others temperatures, and it will be useful and necessary to make comparisons, simulations and later analysis.

It is important to remark that UP showed in Table 1 is the only temperature UP defined by CTE for all the Spanish country and it is used by default in all the simulations of building’s EP or energy study regardless of the place and use of the building.

Exclusive SOM classification

In the data classification and new UPs generation, the pile of information about every Database sample has been condensed using the main value to fill the representative 3x3 table as CTE UP table showed in Table 1. Beyond the CTE case, this data condensation implies a considerable information loss, but it is assumed because, in a first approximation, the objective is to obtain better and realistic UPs without increasing the CTE UP effective resolution.

Thus, the actual Database is converted into a new database with samples or members made up of matrices of 3x3 temperature values (from now on it is referred as temperature database). All these samples are filtered in case of monitoring errors and later classified by ESOM. New UPs are obtained.

A Self-Organizing Map (SOM) is a type of Artificial Neural Network (ANN) that produces a low-dimensional discretized representation of the input space of the samples (Rojas, 1996). Paying attention to the inherent characteristics of the information, the SOM divides the space of the samples and creates differentiated groups. Every group gets a model or super-patron that is the best approach to the group essence and using these models all the samples are classified by SOM. The Exclusive SOM is able to rule out chaotic or lonely samples (i. e. people whose behaviour do not represent the common trends) and, thus, the super-patrons are not contaminated with the effect of non-representative samples (equivalent to noise filtering). Figure 1 shows the difference between SOM and ESOM classification in a hypothetical example. The super-patron of each group (coloured area) is shown with a coloured dot of the same colour of the area it represents. Notice that super-patrons move in the absence of ruled out samples.

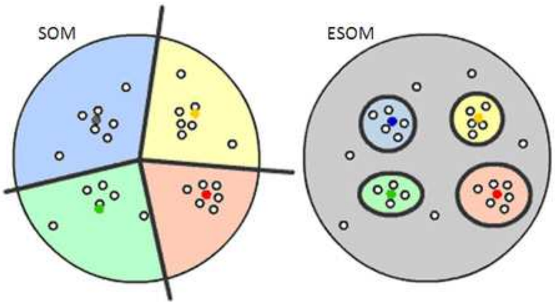

Figure 1 SOM versus ESOM

ESOM involves an additional parameter called tolerance (or distance) which determines the special features from which the sample is out of any group; in other words, this tolerance fixes the bearing radius used by every group to establish the affinity of the samples. It is based on the euclidean distance of the nine characteristics (temperatures) between an individual sample and the current super-patron.

ESOM Result analysis

In this paper, temperature database is classified with different ESOM performances (different distances). Therefore, a set of tests have been executed making a sweep of ESOM tolerances. All the performances agreed to create two separated groups of samples. The most significant feature rejects the 6.8% of samples and generates the super-patrons showed in Table 2 (42.3% of the samples) and Table 3 (50.9% of the samples).

Table 2

SOM UP 1

Months/Hours	0-7h	8-15h	16-23h
January-may	19.7ºC	19.4ºC	19.7ºC
June-september	24.0ºC	23.8ºC	24.1ºC
October-december	20.5ºC	20.2ºC	20.5ºC

Table 3

SOM UP 2

Months/Hours	0-7h	8-15h	16-23h
January-may	21.6ºC	21.3ºC	21.6ºC
June-september	25.3ºC	25.0ºC	25.4ºC
Ocober-december	22.3ºC	22.0ºC	22.3ºC

Figure 2 (CTE UP in green, ESOM UP 1 in red and ESOM UP in blue) shows the absolute temperature values in degrees of three UPs arranged as follows: 1:(J-M, 0-7), 2:(J-M, 8-15), 3:(J-M, 16-23), 4:(Jn-S, 0-7), 5:(Jn-S, 8-15), 6:(Jn-S, 16-23), 7:(O-D, 0-7), 8:(O-D, 8-15), 9:(O-D, 16-23).

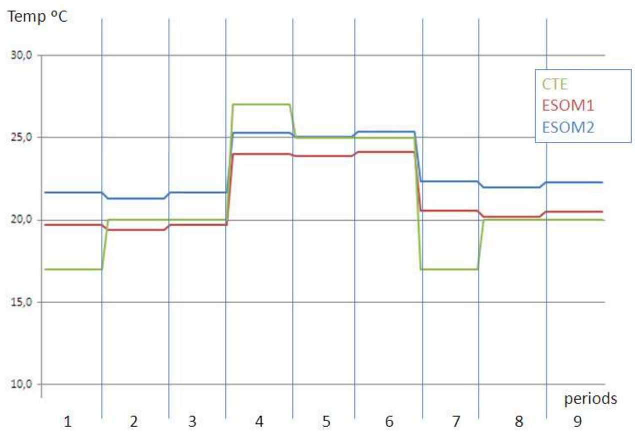

Figure 2 UPs

UPs Discussion

The classification tool ESOM, analysing the temperature database, resolves that there are two significant UP; in other words, there are mainly two kinds of dwelling users attending to the temperature. It is important to compare the three available UPs.

ESOM UP 1 and ESOM UP 2 show very similar curves, mainly an offset difference (between one or two degrees, depending on the case) separates them. On the other hand, CTE UP behaviour shows another nature, and it is sometimes above both ESOM UPs, sometimes below both ESOM UPs; in cold and temperate seasons is more similar to ESOM UP 1 and in warm season as ESOM UP 2.

Attending the purpose of this paper, the differences between CTE UP and ESOM UPs are easily perceptible and considerable. At the present, asking about the meaning of the two UPs generated is not as important as the fact that there are two UPs (obtained from real data) that notably differs from the CTE UP.

The meaning of ESOM UPs is object of future investigations and maybe it is due to building orientation, behaviour trends, family size, etc.

Figure 3 shows temperature difference in degrees between CTE UP and ESOM UP 1, and between CTE UP and ESOM UP 2 (ESOM UP 1 in red and ESOM UP 2 in blue). It is arranged as in Figure 2. The difference, in one case, exceeds beyond five degrees. It is important to remember that one-degree temperature difference can suppose about 7% of energy consumption difference in the season where the bigger difference is noticed (IDEA, 2007).

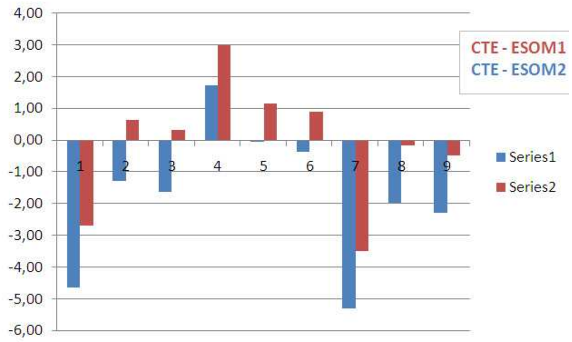

Figure 3 Temperature difference

EVALUATION OF THE UPS EFFECTS ON BUILDING PERFORMANCE

Energy Demand Simulation

In order to determine which the differences of using CTE UP and ESOM UPs are, dynamic energy simulations have been undertaken using TRNSYS software [3].

These simulations result in the energy demand needed to achieve the UP ambient temperatures [1] assuming that there is a HVAC system that allows any load to be supplied.

To calculate these demands a 3-store flat dwelling has been simulated in TRNSYS. This building is CTE compliant [2] so it can be supposed that using CTE UP would result in a realistic energy demand. Anyway, as the aim of this paper is to compare CTE UP with other UPs, it will be good enough to simulate what is the energy needed to fulfil the comfort requirements of every UP and to compare every demand with each other.

As the Database comes form several buildings in the Basque Country (cold, seaside climate) and this could affect or bias the data that have been simulated, some other climates have been chosen to decouple results from climate.

Thus, several simulations have been done each using a different weather file to see how do weather conditions affect the results. Four sites have been used: Bilbao (colder, seaside), Madrid (continental), Barcelona (Mediterranean) and Seville (warmer, non-seaside).

Table 3

WESOM UP

Months/Hours	0-7h	8-15h	16-23h
January-may	20.6ºC	20.3ºC	20.6ºC
June-september	24.6ºC	24.3ºC	24.7ºC
October-december	21.3ºC	21.0ºC	21.3ºC

For each site, the building has been simulated using four different UP: CTE UP, ESOM UP 1, ESOM UP 2 and the Weighted Mean ESOM UP 1 and ESOM UP 2 (WESOM UP) calculated as shown in equation (1). Weights are calculated using results from ESOM (ESOM UP1 has 43.2% of the total population and ESOM UP2 has 50.9%).

$$wesomUP = \frac{0.432 \cdot esomUP1 + 0.509 \cdot esomUP2}{0.432 + 0.509}$$

Equation (1)

WESOM UP is used to compare CTE UP versus a unique UP, it represents a mean inhabitant behaviour in the absence of more information (as CTE UP does). This way, 16 simulation results are obtained.

As a whole building is used, data from every flat has been obtained. From all this data, those from a sample flat have been chosen. This chosen flat lies on the second floor and is in between two other flats (not in a corner of the building).

Seasonal EP simulations have also been done as they could lead into better knowledge of what is actually happening in the flat.

Results of simulation

The results of the energy demands in kWh/year of the simulations of EP on each site can be seen in figures 4, 5, 6 and 7. Seasonal EP are summarized in tables 4, 5, 6 and 7.

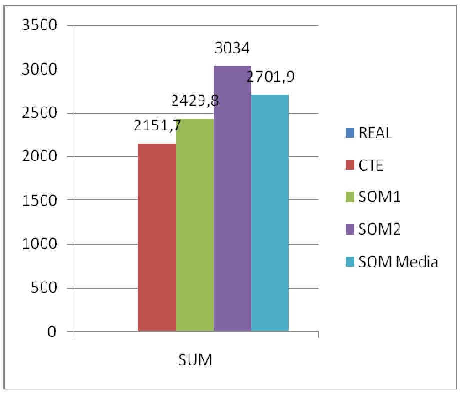

Figure 4 EP in Bilbao

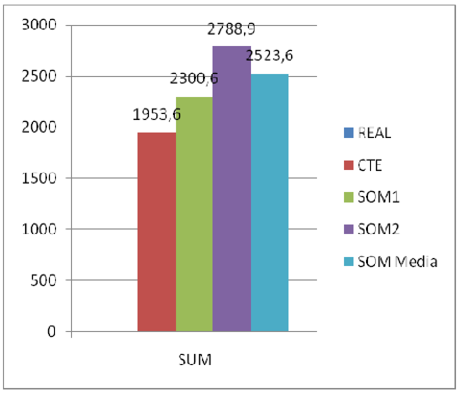

Figure 5 EP in Barcelona

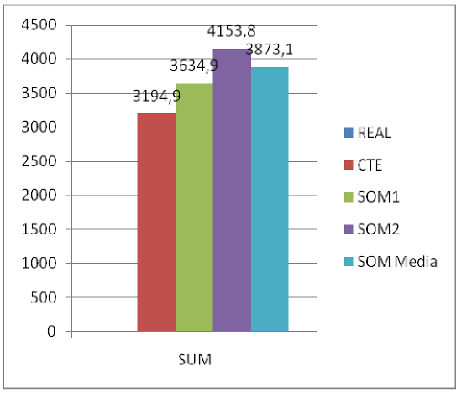

Figure 6 EP in Madrid

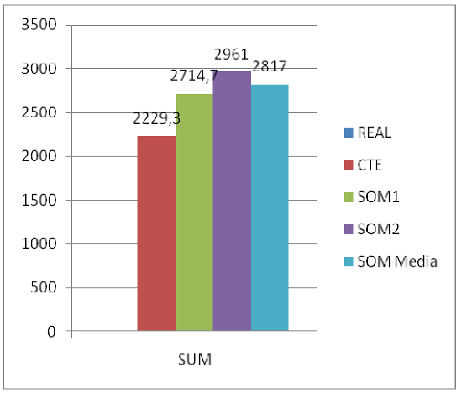

Figure 7 EP in Sevilla

Discussion on EP Simulation's Results

At a first glance, CTE UP EP simulations results are lower than any other UP. All the simulations are summarized in tables 4 and 5.

Table 4

EP Simulation Results in kWh (absolute values)

Site\UP	CTE	ESOM1	ESOM2	WESOM
Bilbao	2152	2430	3034	2702
Barcelona	1954	2301	2789	2524
Madrid	3195	3635	4154	3873
Seville	2229	2715	2961	2817

Table 5

EP Simulation Results (relative values)

Site\UP	CTE	ESOM1	ESOM2	WESOM
Bilbao	100%	113%	141%	126%
Barcelona	100%	118%	143%	129%
Madrid	100%	114%	130%	121%
Seville	100%	122%	133%	126%

These tables show that in every simulation, CTE UPs gets lower energy demands than any other UP, being ESOM UP 1 the closest one to CTE UP. The biggest difference comes to 43% extra demand in Barcelona with ESOM UP 2.

CTE UP should be compared to WESOM UP as both try get a profile that better represents the whole population. This comparison shows that CTE underestimates energy demand between 21% to 29%.

This underestimation is valid not only from the whole year but also for seasonal EP simulations. As it is shown in tables 6 and 7. Heating EP varies from 120% to 139% of the EP according to CTE UP. Cooling EP varies from 119% to 162% of the CTE UP EP.

When looking into detail, ESOM UP 1 better fits CTE UP in winter and the beginning of the spring and ESOM UP 2 does in summer and early autumn.

Table 6

Heating EP Simulation Results in kWh (absolute values)

Site\UP	CTE	ESOM1	ESOM2	WESOM
Bilbao	2024	2146	2906	2495
Barcelona	1475	1549	2294	1890
Madrid	2568	2737	3497	3087
Seville	872	938	1540	1200

Table 7

Cooling EP Simulation Results in kWh (absolute values)

Site\UP	CTE	ESOM1	ESOM2	WESOM
Bilbao	128	284	128	207
Barcelona	479	752	495	634
Madrid	627	898	657	786
Seville	1357	1777	1421	1617

According to non-linearity of simulations, it is suitable to compare the results of WESOM UP and ESOM UP 1 and ESOM UP 2. WESOM UP has been calculated assuming that if 50,9% of the people acts like ESOM UP 2 and 43,2% acts like ESOM UP 1, the mean UP should be calculated as equation (1), that is absolutely linear.

If the EP of this WESOM is compared to the weighted mean of ESOM EP, the error is lower than 0,35%.

Conclusions

CTE UP from Alternative Proceedings is currently used as an input for the energy simulation sotfware in order to better design new buildings. These buildings are designed following wrong user profiles that lead into wrong results and conclusions. Thus, a bad energy performance of the building is obtained.

Actual data monitored from more than 700 dwellings is processed by ESOM tools and two realistic UP are obtained (there are a few samples ruled out because they are a bit away from UPs; nevertheless, they can be assimilated in the nearest group and the effect in UPs will be negligible, about 1% difference). WESOM UP is presented as CTE UP replacement; in this early stage, ESOM UP 1 and ESOM UP 2 can not be used until the nature of their difference can be identified; in other words, it is necessary to know when either ESOM UP 1 or ESOM UP 2 must be used. Obviuosly, the use of ESOM UP 1 and ESOM UP 2 leads to better and more realistic results. Anyway, as it has been shown in tables, WESOM UP is a much better aproximation to real behaviour than CTE UP.

The existence of two models could be explained from architectural features, orientation, users behaviour, family size, use of dwelling, etc., and to elucidate this is a future work of investigation. Conversations with Leako® technitians corroborate that there are two main user behaviours in other Databases. More Leako® Databases will be studied in the future.

These UP surely will be closer to the real UP in the Basque Country, but they will be also quite close to UP in Spain (CTE UP does the same) because habits in the whole country (mainly due to working timetables) are very similar despite weather differences.

In future investigations, it is interesting to compare real data of energy consumption versus simulation results.

Nowadays, other kinds of UP (not only temperature) are being obtained from the Database (electricity consumption, occupation, etc.).

In a parallel way, real data will be collected from a social housing building in Spain. TRNSYS simulations with CTE UP, ESOM UP 1, ESOM UP 2 and WESOM UP will be made, with the purpose to compare the real energy consumption from Tossa's building versus his simulations (with the different UPs).

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