Sustainable Cities and Society 60 (2020) 102156

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

A methodology to improve energy efficiency and comfort conditions with low-cost ICTs in rural public buildings

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ARTICLE INFO

Keywords:
Methodology
Energy efficiency
Hygrothermal comfort
Public building
Low-cost ICTs
Habit users' suggestion

ABSTRACT

This paper presents a methodology to improve energy efficiency and hygrothermal comfort conditions in public buildings using low-cost ICTs. A change in the daily users` habits is further on suggested. The process develops circularly in four steps: building definition model, monitoring, analysis, and users' participation. The method has been tested in four similar public buildings of traditional construction. Firstly, a building model has been defined (climatology, thermal envelope and maintenance, interior design, systems, and occupancy). Secondly, a low-cost, scalable, and open-source information system has been installed to collect data of energy consumption, temperature, humidity and CO_2 values. The resulting time series were analysed and compared to the energy consumption bills of the previous three years to obtain the real building behaviour. Data gathered by the sensors and suggestions have been made available to users for real-time monitoring. Furthermore, reliable energy indicators to characterize this building typology in services sector have been obtained. Other sub goals include raising awareness among users about the use of public resources, and the initiation of a smart-village strategy using low-cost technologies. The results highlight inefficient consumption patterns and discomfort situation that should encourage users to take action and reorient municipal policies.

1. Introduction

According to the latest annual report of the European Union towards the national energy efficiency targets (European Commission, 2019), energy consumption increased between 2014 and 2017, following a gradual decrease between 2007 and 2014. The fact is that these values take into account industrial, residential, transport, and services sectors, but there are quality differences between them. In the first two, energy consumption has declined considerably, in the transport sector it has remained almost unchanged, but the services sector recorded the highest increase in energy consumption from 2005 to 2017.

There are some incentive projects as the GreenBuilding Programme promoted by the European Commission (D'Agostino, Cuniberti, & Bertoldi, 2017) in a thousand non-residential buildings in 25 partner countries, whose results estimate savings around 985 GW h/year thanks to envelope, appliances systems, and the introduction of a wide range of technological devices. There are initial approximations based on the collection of limited and easily accessible data such as regression works with energy bills and climate data (Geng, Ji, Lin, Hong, & Zhu, 2018), or analysis of massive building automation data (Fan, Xiao, & Yan, 2015). Further, the services sector is not characterized well enough and lacks many detailed energy information due to its heterogeneity in uses, surfaces and systems.

On the other hand, three crucial aspects have to be taken into consideration on this matter. Firstly, numerous studies conducted in recent years have shown that one of the most influential factors affecting energy consumption in buildings is the behaviour of the users living (Stazi, Naspi, & D'Orazio, 2017; Delzendeh, Wu, Lee, & Zhou, 2017). These studies highlight the difference between the predicted final energy consumption according to the building design and the real final energy consumption. This difference can sometimes be up to 200 % (Tam, Almeida, & Khoa, 2018) or 300 % (Delzendeh et al., 2017). In fact, a few research projects and studies have already been initiated either about the existence of a correlation between occupant and energy consumption (Ahn & Park, 2016), the understanding of occupant behaviour (Zhang, Bai, Mills, & Pezzey, 2018), or the tracking of the human-building interaction (Langevin, Gurian, & Wen, 2015). The OrbEET project, applied in Asparrena Town Hall (Basque Country,

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https://doi.org/10.1016/j.scs.2020.102156
Received 30 September 2019; Received in revised form 24 March 2020; Accepted 24 March 2020
Available online 18 May 2020
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Spain) (OrbEEt, 2017), exploited novel and extended approaches with behavioural changes. And some studies analysed how users' direct, personalized, and comparative knowledge of energy consumption data favours a change in habits that affects significantly the reduction of final energy consumption (Vine & Laurie Buys, 2013). Furthermore, the commitment to carry out these projects in public buildings would also allow users to value energy savings as a common good and then to translate it into their private homes (Chen, Liu, & Shi, 2018). To this end, changes in use, in work methods and in the interior hygrothermal operating conditions have to be be implemented (Ahn & Park, 2016). Additionally, connection between density of occupation and total final energy consumption in public buildings has to be studied (Kang, Lee, Hong, & Choi, 2018).

Secondly, ICTs must be incorporated in the energy-saving process (Aste, Buzzetti, Caputo, & Del Pero, 2018). They are key to accessing quantitative information through accurate, real-time readings. Thanks to these readings, environmental and consumption variables can be perfectly measured in time and space, (Sharmin et al., 2014; Vellei, Natarajan, Biri, Padget, & Walker, 2016), either by implementing with auto-regressive models (Batista, Freitas, & Jota, 2014), or by applying smart technologies (Nižetić, Djilali, Papadopoulos, & Rodrigues, 2019; Jia, Komeily, Wang, & Srinivasan, 2019; Alavi, Jiao, Buttlar, & Lajnef, 2018). Another experience related to the matter was implemented in Monterroso (Spain) in the context of the ENERInTOWN project (European Commission, 2008). In this case, the project and pilots aimed at monitoring and controlling energy consumption in 100 municipal public buildings in 8 partner countries. In addition, the ability to make a rapid diagnosis and follow-up rules is also required. Low-cost (Ciuffoletti, 2018; Bamodu, Xia, & Tang, 2017), scalable, and open-source technology (Priyanka Jain, 2018), with the necessary quality standards has been probed to reach more fields of action, territory, and people (Ahmad, Mourshed, Mundow, Sisinni, & Rezgui, 2016; Allab, Pellegrino, Guo, Nefzaoui, & Kindinis, 2017).

And thirdly, the impact of indoor environmental quality on occupant well-being and comfort (Al horr et al., 2016), and its implications on energy efficiency (Zomorodian, Tahsildoost, & Hafezi, 2016; Yang, Yan, & Lam, 2014) has to be taken into account. Technical solutions quite often neglect occupants' comfort (Allab et al., 2017), thereby pre and post-occupancy comfort of the built environment have to be evaluated (Deme Belafi, Hong, & Reith, 2018).

It is therefore mandatory to establish a methodology that gathers all the mentioned factors to diagnose the different building typologies that populate the services sector, and to change user's habits regarding energy efficiency and hygrothermal comfort conditions through ICTs and social participation. The methodology proposed in this paper has been validated in four public buildings used as town halls with an administrative function, and located in small municipalities (bellow 6000 inhabitants). Low cost ICTs have to be used in these cases to make it accessible. These urban nucleus host 50.9 % of the population in Extremadura region, spread over 375 scattered municipalities, many of them are being in process of depopulation (National Statistics Institute, 2019). Besides, many of the public administrative buildings existing in this area are old constructions in historical centres related to the traditional architecture. In this regard, this initiative will make rural municipalities more competitive and sustainable (Aste et al., 2018), on the way to smart villages (European Network for Rural Development (ENRD) (2020); Nižetić et al., 2019; Zygiaris, 2013).

2. Materials and methods

The methodology proposed is presented schematically in Fig. 1 as a sequence of four steps. The process starts with the building model definition in order to identify the parameters that affect energy consumption and comfort. There are several classifications proposed in the literature that stand out some influential factors, discerning between external and internal influences (Ma et al., 2017). The classification used in this project is more detailed and distinguishes among six factors: climatology (including situation and orientation), thermal envelope, maintenance, interior design, systems (including consumption), and occupancy (including user profile, Sun & Hong, 2017).

The second step involves the installation of a low-cost, scalable, and open-source information system (IS) to collect and store measurements of the relevant parameters selected beforehand. This system has been previously implemented with satisfactory results in SmartPolitech project developed at School of Technology (EPCC, Extremadura University, 2016). Sensor devices and networking are key elements, but the most complex part resides in the rest of the IS, the so-called back and front-ends. The methodology proposes a layered organization of the IS that pursues both scalability and maintainability. The back-end is composed of four layers: hardware and virtualization infrastructure, data storage (time series and other static and semi-dynamic information), the model logic (set of existing or customized microservices to receive and validate incoming sensor data, and transform it into more elaborated and informative variables), and a service bus (to manage microservices, access control and external communications from a unique, monitored and scalable process). At the front-end, the minimum requirement is an open-source, web-based data viewing application that can be used either by final users or by researchers. There are some aspects that should be evaluated: location and number of sensors, cost, connectivity and trade-off between introducing new routing elements (as in ZigBee) versus using existing devices (as in commonly found WiFi networks) or ad-hoc protocols over free-band radio frequency bands. The sensors used can be commercial devices or custom-made units, but connectable to any open information system.

The third step is concerned with the collected data's analysis. The goal is to assess the real building behaviour by comparing model data, time-evolution of the measured variables and energy consumption, and to obtain energy efficiency and comfort indicators. Building's weaknesses and strategies should be identified in order to be transferred to the final users.

The last step refers to the users' participation. Firstly, owners and technicians should improve thermal envelope and system. Secondly, final users receive the suggestions about energy consumption, and comfort conditions in order to change their habits. Pre-questionnaires identify user profiles, and following recommendations should be adapted to them. The key to success lies in monitoring the IS available to users, empowering social participation, and being able to change habits. Finally, post-evaluation of users should be carried out to evaluate impact.

The process is continuously retro feeding: the designed IS improves the definition of the model, indicators upgrade the IS configuration, and users' participation develops better strategies. The IS develops communication strategies as well. This effect provides feedback to the previous ones closing an error-correcting loop whose goal is to achieve a final state of lower energy consumption and better comfort conditions. This loop should be iterated as many times as needed to obtain the predefined objectives and stopped when an acceptable score has been achieved. In every iteration, new information is obtained by the researchers and technicians as a deviation from what was predicted and what finally happened. Due to the project deadline, this retro feeding was not implemented in the case study.

3. Results

Following the results of each of the steps of the methodology applied in the four case studies are exposed:

3.1. Building model definition

The four buildings were selected by the Provincial Council of Cáceres and EPCC according to several factors. They include public managers' interest and awareness regarding enhancement of cultural

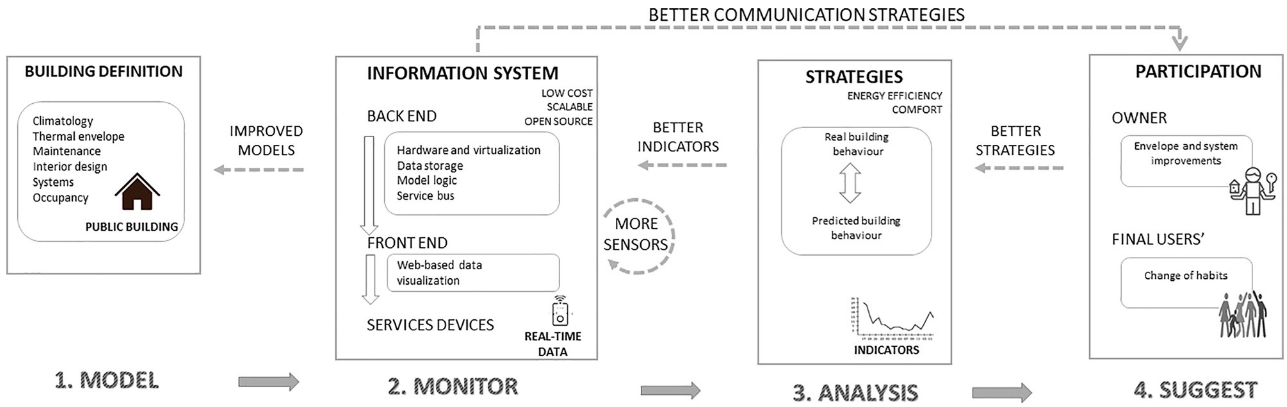

Fig. 1. Methodology to improve energy efficiency and comfort conditions with low-cost ICTs in rural public buildings.

Fig. 2. Images of the study buildings used as Town Halls in Arroyo de la Luz, Casar de Cáceres, Malpartida de Cáceres and Sierra de Fuentes.

heritage and energy saving, similarities between buildings, geographic and climate zone, and viability of devices location. Based on these criteria, buildings from the following locations were chosen: Arroyo de la Luz (from here on, Arroyo), Casar de Cáceres (from here on, Casar), Malpartida de Cáceres (from here on, Malpartida), and Sierra de Fuentes (from here on, Sierra, Fig. 2). Building model definition according to parameters presented in the previous section was then accomplished. (Table 1).

3.1.1. *Climatology*

It is categorised as “Csa” by Köppen-Geiger classification: temperate, dry and hot summer; and in “zone C4″ by the Spanish Technical Code: very high summer severity and a high winter severity (Ministry of Housing, 2019). Buildings land at an altitude between 350 and 425 m above sea level and within a 30 km radius from the capital of the province (location of the outdoor hygrothermal sensor). They present different orientations: Sierra is an isolated construction, Arroyo and Malpartida have two façades and Casar has one façade and an inner courtyard (Fig. 3).

3.1.2. *Thermal envelope*

Buildings were constructed before 1900 with traditional architecture techniques such as load-bearing granite masonry walls (about 1 m thickness on the ground floor, U = 1,90 W/m^{2}K; and a little thinner on the upper one), Extremadura's vault on the ground floor (U = 0,85 W/m^{2}K), an inclined and ventilated ceramic tile roof with plaster suspended ceilings on the upper one (U = 1,76 W/m^{2}K), and carpentry works made of wood with simple glazing (Fig. 3, theoretical characteristics of the thermal envelope obtained in (Extremadura Regional Government, 2014)).

3.1.3. *Maintenance*

The four buildings were refurbished in the 1980s. Wooden roofs were replaced by brick openwork roof supported with concrete floor, creating covered and ventilated spaces. Some parts of the internal walls were also refurbished by adding some lightweight partitions of brick. An air chamber, a hollow brick wall (U = 1,38 W/m^{2}K, Extremadura Regional Government, 2014), and a lift were added in Casar and Malpartida. A concrete deck was built in contact with the ground. Additionally, some of the windows were restored in the past few years.

Table 1
Building model definition (climatology, thermal envelope, systems, interior design criteria, maintenance and occupancy of the town halls).

	ARROYO	CASAR	MALPARTIDA	SIERRA
CLIMATOLOGY				
Classification	“Csa” by Köppen-Geiger, “C4” by Spanish Technical Code			
Facades orientation	North and West	West	East and West	SE, NE, NW, SW
THERMAL ENVELOPE AND MAINTENANCE				
Exterior walls	Load-bearing granite masonry walls (on ground floor thickness 1 m. approx. U = 1.90 W/m^{2}K)			
	Air chamber and hollow brick wall U = 1.38 W/m^{2}K	–	Air chamber and hollow brick wall U = 1.38 W/m^{2}K	–
Vertical internal separations	Granite masonry walls and lightweight brick partitions			
Horizontal internal separations	Extremadura vault and concrete floor on the ground floor U = 0.85 W/m^{2}K, concrete slab upstairs			
Roof	Inclined cover of ceramic tile and ventilated, U = 1.76 W/m^{2}K			
Carpentry	Wood, double glazing	Wood and aluminium without thermal break, simple or double glazing	Wood double glazing	Wood and aluminium with thermal break, simple or double glazing
INTERIOR DESIGN				
Rooms	Hall, administration and public attention area, offices, toilets, stairs, archives, and plenary room			
Plot area	398 m^2	250 m^2	425 m^2	306 m^2
Gross/usable floor area	688 m^2/532 m^2	467 m^2/291 m^2	1096 m^2/636 m^2	606 m^2/441 m^2
Number of floors/floor height	2 / 3.90 & 3.20 m	2 / 3.90 & 3.30 m	2 − 3 /main facade 3, 4 & 2.9, back´s 3.8 & 2.9 m	2 / 3.85 & 3.45 m
SYSTEMS				
Heating system	15 individual electric heaters, total heating power 30 kW	Central heating, gasoil C boiler, nominal power 108 kW, 17 steel radiators	Central heating, gasoil C boiler, nominal power 116,3 kW, 31 radiators	10 individual electric heaters, total heating power 20 kW
Cooling system	2 cool and heat pump with 2 cassettes indoor units. Cold power 13.6 kW Heating power 15 kW	8 cool and heat pump with 8 wall indoor units. Cold power 31.36 kW Heating power 34.74 kW	2 VRV heat pump. Cold power 56 kW Heating power 63 kW	4 cool and heat pumps (ea 3 kW) with 7 floor indoor units
Lighting	LED and compact fluorescent lamps Power = 1,170W-4.56 W/m^2	Fluorescent, LED and incandescent lamps Power = 1,139 W-3.06 W/m^2	Fluorescent and compact fluorescent lamps Power = 2,360W-3.71 W/m^2	Fluorescent and LED lamps Power = 2,408W-5.54 W/m^2
Workstations and other equipment	15 workstations	10 workstations and elevator	18 workstations and elevator	13 workstations
Elec. contracted power	15.1/15.1/17.3 kW	9.9 kW	15.1,15.1,20 kW	24.25/24.25/24.25 kW
Average annual electricity consumption	19131 kWh/y	11319 kWh/y	22573 kWh/y	9780 kWh/y
	35.75 kWh/m^2*year	38.91 kWh/m^2*year	35.46 kWh/m^2*year	22.20 kWh/m^2*year
Average annual gasoil C consumption	–	18590 kWh*year	41405 kWh*year	–
		-(2015 - 2017)(2014 - (2015–2017)	(2014–2016)	
OCCUPANCY				
Number of workers	15	9.25	18	12.75
Density of occup. (m^2/p)	35.49	32.31	35.37	36.71

Fig. 3. Town Halls interior design and location of the sensors.

Malpartida was later connected to a second building, and a polycarbonate skylight was installed (Fig. 3).

3.1.4. Interior design

All the buildings have similar zoning due to their common use (i.e. entrance hall, administration area, public attention area, offices, bathrooms, stairs, archives and a plenary hall). Plots are rectangular, have between 250 and 425 m^2 of usable floor area, and between 500 and 1100 m^2 of gross floor area. Buildings usually have two floors, which are around $10 - 12$ m high, while inner height can be up to more than 3 m. (Fig. 3).

3.1.5. Systems

Mechanical systems are divided in heating, cooling, lighting, and other high energy consumption equipment, as well as workstations. Air-conditioning systems consist of heating and cooling pumps with indoor units installed on ceilings, walls and floors. Arroyo and Fuente are also provided with electric heaters. Casar and Malpartida have central heating by oil boilers and steel radiators as terminal units. Total heat installed power is between 15.0 kW (without boilers) and 116.3 kW (with oil boilers), whereas total cold installed power is between 13.6 kW and 56.0 kW. Lighting systems are formed by LED, fluorescent and incandescent lamps disposed on suspended, recessed, and wall luminaires with a total installed power between 3.06 and 5.54 kW/m^2 per building.

3.1.6. Occupancy

Working hours are usually from 8 a.m. to 3 p.m. There are between 10 and 20 permanent workers in each building and some ones with reduced schedule, plus the government team and the non-permanent users of the municipal services. The population in these municipalities, who are the potential users of the buildings, ranges from 2000 to 6000 inhabitants. Population density goes from 32.31 m^2/p (usable area per person) in Casar to 36.71 m^2 /p in Sierra. Collected pre-questionnaires indicate that most of the users feel comfortable (according to thermal conditions) in spring and summer, not in winter. Although, users know some measures of energy efficiency, they do not apply them.

3.2. Information system

An internal WiFi network was deployed to the sensor system due to the wide existing deployment of these ones in these and many others public buildings. To that end, TP-LINK TL-WR841ND routers were connected to the wired network. The following variables have been monitored: electricity consumption (to define the energy efficiency in devices and lightning and, additionally, in users' behavioural pattern), CO_2 concentration (to determine the air quality and, indirectly, the presence of people and infiltrations), and temperature and humidity (to assess indoor comfort).

In this way, Wibeee analysers (Circutor, 2019) were installed to measure electricity consumption and were configured to send measurement data to a specific IP address. Analysers were located according to the existing electrical panels' settings. In Arroyo, an analyser was installed on each floor; in Malpartida, one was located in the conditioning circuit and another in the rest of circuits; and in Sierra, a general single analyser was installed. Due to issues on the internal network, analysers were not set in Casar. Additionally, Wireless sensors (Ray Ingenieria Electronica, 2015) were installed to measure temperature, relative humidity, and air quality. These sensors had access to internal programming. Temperature and humidity were monitored in four representative rooms of each building, which were distributed by floors and orientations in order to assess air stratification and sun radiation influence (Fig. 3).

A single sensor was placed in the most occupied room (public attention room) to determine air quality. These commercial devices use their own formats, so a basic middleware was designed to accept, validate and homogenise data. The middleware is composed of several scripts (Python Software Foundation, 2020) that guarantee a baseline

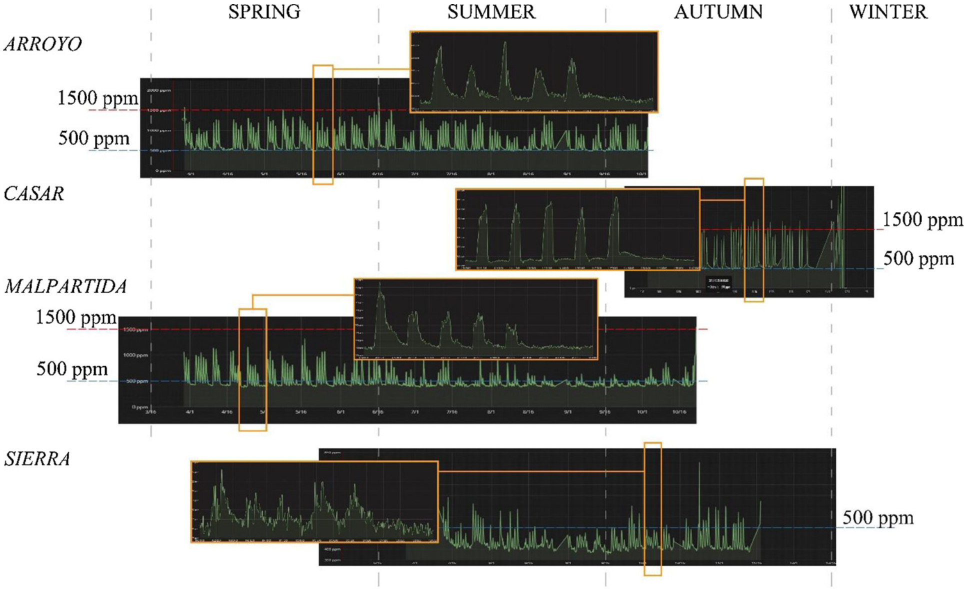

Fig. 4. Evolution of the concentration of internal CO_2 in the public attention rooms and its relationship with the welfare limits according to (Ministry of Industry Energy & Tourism, 2007).

security by checking the validity of packages via an API access key. This also enabled the IS division into two virtual machines: one open to the Internet receiving the data and the second one located in a private segment hosting the database and other internal processes. Servers were hosted in EPCC and the data was available through an open visualization software (Grafana Labs, 2020) that created attractive dashboards, alerts and educational messages with real-time graphics (Figs. 4 and 5, Table 2).

3.3. *Analysis of energy efficiency and comfort conditions*

Energy bills from 2014 to 2017 were analysed and then compared with data obtained through sensors in the following periods: April 10th to December 8th, 2017 (Arroyo); October 2nd 2017 to January 26th, 2018 (Casar); March 27th to December 1st, 2017 (Malpartida); June 27th to December 25th 2017 (Sierra). Periods depended directly on the ease to install the devices. Moreover, due to the short duration of the project, batteries were not replaced and sensors stopped transmitting when batteries drained. The statistical metrics of the data, and the number of sensorized days and of valid records are shown in Table 3. Analysis of three parameters (air quality, hygrothermal comfort and energy consumption) follows.

3.3.1. *Analysis of air quality*

Air quality in the buildings is associated with occupancy during morning working hours from Monday to Friday. Air quality is considered acceptable with 800 ppm CO_2, being 1500 ppm CO_2 the maximum level of comfort conditions (Ministry of Industry Energy & Tourism, 2007); or 1200 ppm (800 ppm above outdoor conditions (Technical committee AEN/CTN 100, 2007)). In this case, a concentration of approximately 430 ppm is measured at 8 a.m. (opening time) and it increases to a maximum of 1500 ppm at 2 pm (closing time). This behaviour is repeated in three of the four rooms. However, in Sierra, which is an isolated construction, levels were observed between 380 ppm and 820 ppm. Concentration levels plunge immediately from 2 pm without intentional openings for air renewal, and continue decreasing slightly from 6 p.m. to 7 a.m. This latter drop implies that air infiltrates easily through the envelope in all buildings due to the fact that it is not associated with the occupation. (Fig. 4).

3.3.2. *Analysis of hygrothermal comfort*

Hygrothermal data was registered and analysed in all the seasonal periods except in February and March. The following general questions were observed once all data was analysed. Firstly, there is a deviation in temperature ($2 - 5$ °C) and humidity (up to 20 %) between the ground and the upper floor (the communication nucleus is not split in any case). Secondly, behaviour does not depend on the orientations of the buildings. And thirdly, results regarding hygrothermal comfort among four buildings are quite similar in the monitored seasonal periods (Fig. 5).

The hygrothermal comfort range, for which the PPD (predicted percentage of dissatisfied) is below 10 %, considers the optimal temperature between 20 °C and 24 °C in winter, and between 23 °C and 26 °C in summer (Technical committee AEN/CTN 100, 2007; Ministry of Industry Energy & Tourism, 2007). Regarding optimal relative humidity, values range between 25 % and 60 % (Technical committee AEN/CTN 100, 2007); or between 30 % and 70 % (Ministry of Industry Energy & Tourism, 2007), in both seasons. Moreover, comfort values for the intermediate autumn and spring periods have been established on this paper between 20 °C and 26 °C, a range that include the extreme winter and summer periods.

Generalised comfort or discomfort situations have been observed according to the following periods:

a Spring: the upper floor temperature was 2 °C higher and humidity was 10 % lower than on the ground one. Indoor temperature was constant in the central period and, in general, within comfort levels (22 °C and 25 °C), and humidity levels range from 40 % to 60 % (outdoor temperatures are lower and humidity higher than indoor ones). Indoor temperatures reached 16 °C and 31 °C with similar humidity values without conditioning systems at the end of the periods. Indoor values, in exchange, differed greatly from outdoor ones (temperature between 5 °C and 30 °C, and humidity between 40 % and 100 %).

b Autumn: indoor temperatures remained within comfort values (between 20 °C and 26 °C) until half of the period, with humidity levels ranging from 40 % to 60 %. From this point, the temperature dropped to 15 °C and humidity climbed above 65 % without activating conditioning systems. Indoor values were also far from the outdoor ones (temperature between 26 °C and 0 °C, and humidity between 40 % and 100 %).

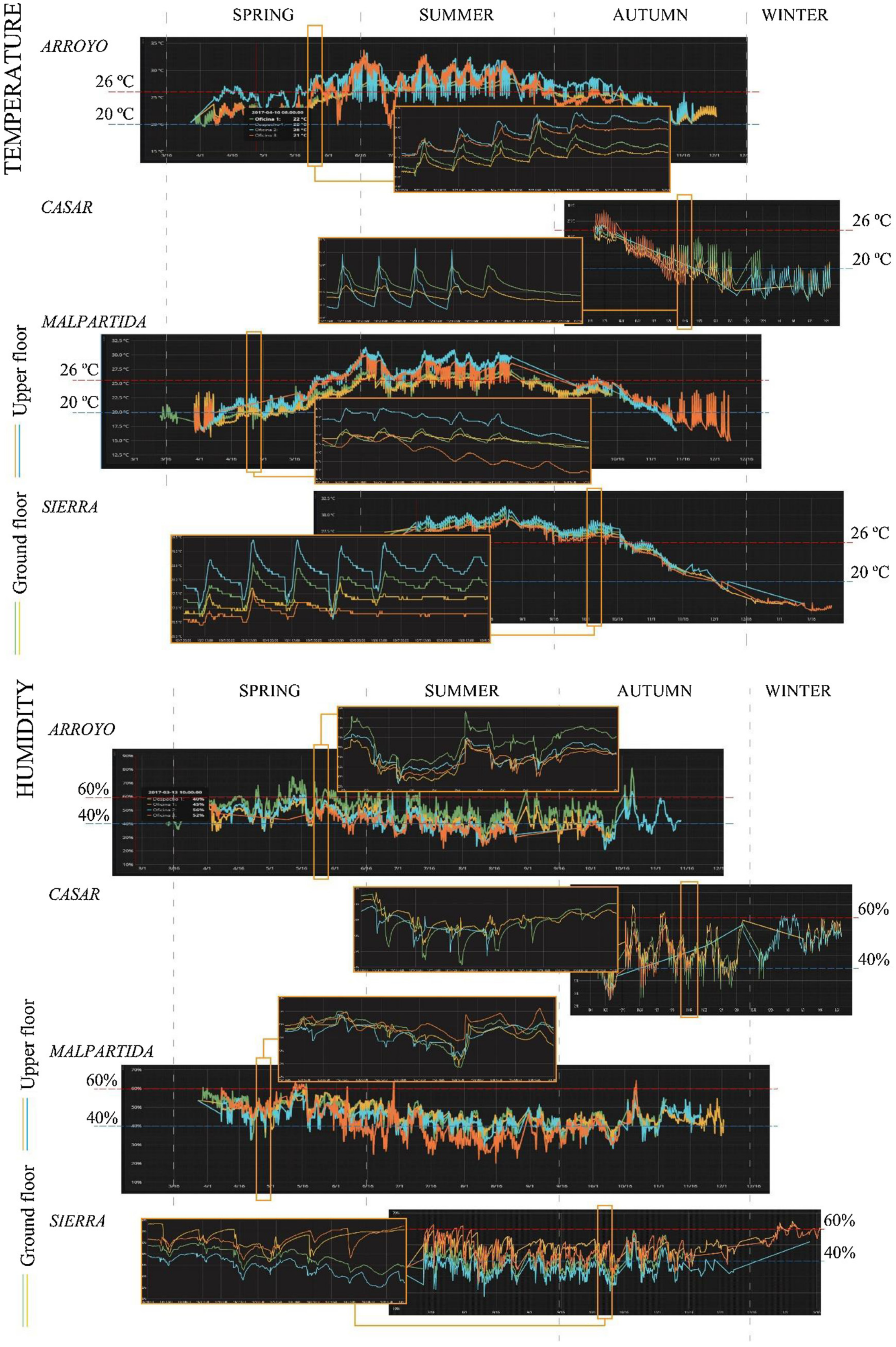

Fig. 5. Temporary data obtained from the hygrothermal monitoring long term and week of sample, with admissible limits according to (Ministry of Industry Energy & Tourism, 2007).

Table 2
Description of the used devices.

Device	Parameters	Range	Accuracy	Power	Communication
Circutor Wibeee	Voltage	$0-440\ V_{AC}$	± 2 %	94 - $440\ V_{AC}$	WiFi
	Current	0 – 63 A	± 2 %		
	Power	0 – 48000 W	± 4 %		
RAY STC/STH	CO_2	400 - 10000 ppm	± 3 %	2 batteries LR14	WiFi
	Temperature	−40 – 80 °C	± 0.5 °C		
	Relative humidity	0 – 100 %	± 3 %		

c Summer: values were, in general, within the comfort range on the ground floor and outside on the upper floor. Temperature was up to 5 °C higher and humidity was up to 20 % lower in the upper floor than on the ground one. Indoor temperatures varied from 28 °C at the beginning and at the end of the period to 33 °C at the middle of it. Outdoor temperatures ranged from 15 °C to 38 °C. Conditioning systems, which lower temperatures temporarily, were only available in some rooms of the upper floor.

d Winter: data showed uncomfortable maximum records of 19 °C from periods closer to late autumn and early spring with the conditioning systems disconnected.

3.3.3. Analysis of energy consumption

Energy consumption is divided into electricity for conditioning, lighting, equipment, and diesel for the central heating system in Casar and Malpartida.

a According to monitoring

The annual baseline energy demand was 0.02 kW in Arroyo, and 0.4 kW in Malpartida and Sierra. The annual peak energy demand ranged from 1.98 kW in Sierra (both in winter and summer), 4.6 kW in Malpartida (in winter), to 9.7 kW in Arroyo (in winter). The occupancy and the suitability of conditioning systems may be assessed by analysing the seasonal behaviour of the buildings according to their energy demand.

Taking these points into consideration, on November 10th, 2017 in Arroyo, the energy demand observed during working hours ranged from 4.5 to 5 kW. Workstations and individual electric heaters were responsible of this consumption. The automatic start of a conditioning system led to a constant and heavy consumption of 3.5 kW in the early hours of the morning. On the same day, the baseline energy demand was 1 kW in Malpartida. The energy demand varied from 7 and 10 kW during working hours until 1 pm. This consumption was basically due to conditioning systems. Moreover, the energy demand was lower in Sierra the same day. In fact, the baseline energy demand was 1 kW and the peak energy demand 3 kW, following the use of heat pumps with constant start-up power peaks.

The results obtained on a summer day July 11th, 2017 are as follows: the baseline energy demand during working hours is very low: 0,2 kW; according to the observed temperatures. It was not necessary to use conditioning systems to achieve comfort conditions. In Malpartida, the energy demand fluctuated between 4 and 9 kW in working hours due to conditioning systems installed on the upper floor (Fig. 6).

b According to bills

The first matter was to compare the contracted electrical power and the required electrical power. The electrical power is adjusted in Arroyo and Casar. However, the required electrical power in Malpartida is much lower than the contracted, so it was advised to lower it. Afterwards, a seasonal behaviour pattern related to the use of conditioning systems is observed over the four years analysed. Buildings without diesel central heating systems faced an increase of energy consumption during the cold months because of the activation of individual electric heaters. This happened in Sierra and especially in Arroyo, where consumption was quadrupled. Energy consumption did not show significant changes during the summer period.

Furthermore, energy consumption remained stable throughout the year in Casar and Malpartida. It did however increase during summertime, as hot and cold systems were completely electric. They all had cooling systems on the upper floor, but their occupancy was generally occasional (Fig. 7).

Average annual consumption ranged from 600 kWh (Arroyo and

Table 3
. Information about the statistical metrics of the data and the number of sensorized days and valid records.

		ARROYO	CASAR	MALPARTIDA	SIERRA
ELECTRICITY DEMAND (W)	Nº of sensorized days	384	0	303	55
	Nº of valid records	3497	0	2088	3420
	Minimum value per day	24	–	512	837
	Maximum value per day	4789	–	2430	1298
	Mean value per day	1184	–	424	1045
	Standard Deviation	1218	–	522	118
CO_2 (ppm)	Nº of sensorized days	189	78	207	128
	Nº of valid registers	1451	1446	1551	1378
	Minimum value	475	445	373	377
	Maximum value	1686	1852	1384	820
Nº of sensorized days[a]		92/93/75/0	0/0/80/89	87/93/89/0	34/0/87/89
Nº of valid records[a]		2406/2440/1282/0	0/0/547/1450	2391/2726/1567/0	282/0/2126/1707
RELATIVE HUMIDITY (%)[a]	Minimum value	34/26/24/-	-/-/38/28	25/20/28/-	-/18/20/49
	Maximum value	64/59/69/-	-/-/67/64	64/68/64/-	-/63/59/65
	Mean value	50/41/41/-	-/-/54/45	50/41/43/-	-/43/42/58
	Standard Deviation	5/6/7/-	-/-/5/7	5/6/5/-	-/8/7/3
TEMPERATURE (ºC)[a]	Minimum value	15,6/21,6/14,9/-	-/-/15,8/15,0	17,5/18,2/15,9/-	-/25,6/16,7/15,6
	Maximum value	31,3/30,9/26,4/-	-/-/29,1/20,9	33,7/32,9/28,7/-	-/31,3/29,2/17,5
	Mean value	22,0/26,5/22,1/-	-/-/22,0/17,6	24,3/27,3/23,6/-	-/28,3/25,0/16,6
	Standard Deviation	3,2/1,7/2,5/-	-/-/2,8/1,3	2,8/1,9/2,3/-	-/0,9/2,4/0,5

[a] Spring / Summer / Autumn / Winter.

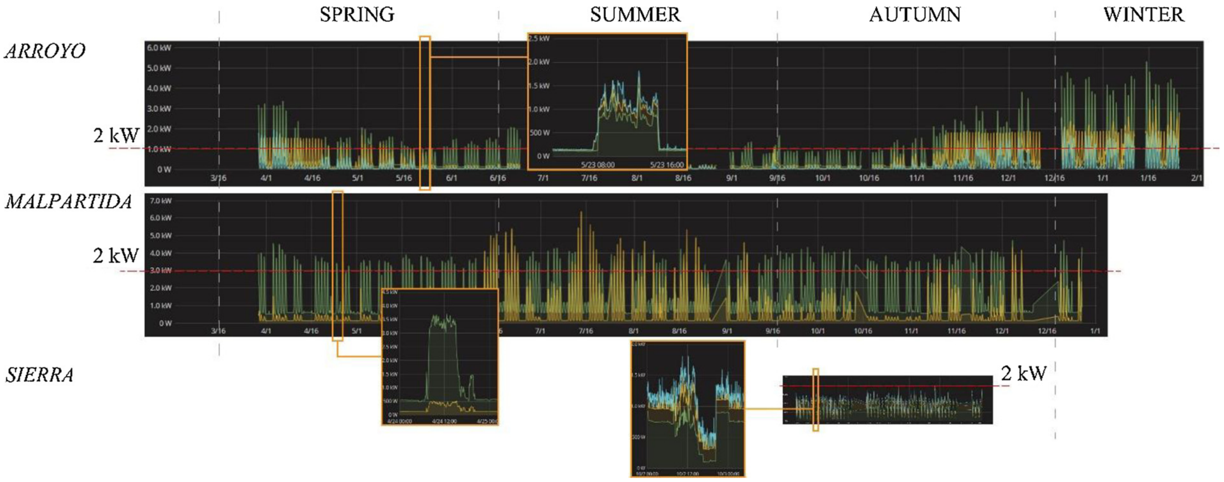

Fig. 6. Electric power demanded in three of the buildings analysed, long term and day of sample.

Sierra in summer) to 3000 kWh (Arroyo in winter), whilst Casar kept constant at 2000 kWh. Annual values remained between 10000 and 22500 kWh. These consumptions were directly dependent on the density of occupation. As this value was quite similar in the four buildings studied, the comparative analysis led to the same aforementioned numerical differences (Fig. 8). Thus, average annual electricity consumption ranged from 22.2. kWh/m^2 in Sierra to 38.9 kWh/m^2 in Casar, and from 15.65 kWh/(m^2/p) to 86.36 kWh/(m^2/p).

Differences in magnitude were due directly to conditioning systems. There was only a 10 kWh/(m^2/p) increase in Sierra during cold months. During the same period, individual heating equipment caused a 50 kWh/(m^2/p) increase in Arroyo, indicating an inefficient system which must be replaced. Moreover, in these cases there was no connection between density of occupation and total final energy consumption.

Additionally, there was no difference in energy consumption throughout the year between Casar and Malpartida, the two buildings using diesel central heating systems. Moreover, there was a small increase during summertime (in August or September) because of the cooling systems (Figs. 7 and 8). An analysis on the consumption of fossil fuels for the central heating systems revealed differences between the winter and summer consumption increase, which is evidence of the impact of the boundary conditions of buildings. Heating demand was much higher than cooling demand in Casar. Both heating and cooling demands were quite consistent in Malpartida, which was an extreme case (Figs. 7 and 8).

3.4. Suggestions

Users received recommendations obtained from the previous analysis. First, managers and technicians should improve and maintain the envelope, and adjust systems. This building typology contributes to comfort values, as previously seen on the analysis results, due to the construction typology and, specifically, to the walls and the ground thermal inertia. Therefore, only minor refurbishments on the envelope are required, primarily on the upper floor. These should include the placement of insulation inside the suspended ceiling or the roof, the installation of evacuation systems for the hot air, the sealing of air infiltration, and the upgrade of windows. Furthermore, individual electrical heaters should be replaced with more efficient systems, and fans should be used in order to improve the thermal sensation in summer. The second line of action involves informing the users about the equipment and their programming. On our use-cases, they were given access to the visualization front-end and basic instructions regarding the maintenance of IS. The system requires very little maintenance, and thus public buildings in rural areas with little technical staff can support it.

Additionally, town hall buildings could be improved by real-time data monitoring and a change in final users' habits. In this way daily ventilation habits should follow indoor air quality data, Moreover, the use of conditioning and ventilation systems should be adjusted according to temperature and humidity data and comfort conditions. This data should enable to optimise the occupancy of each floor taking into account each season. Saving would be addressed by avoiding the use of individual electrical heating systems, as this equipment is frequently switched on (even if they are not being used), and by disconnecting the stand-by systems. Users would be also more likely to save after observing updated consumption values in real-time. For the continuity of the project, the public managers should monitor the information for its visualization in the existing personal computers, and facilitate the subsequent decision-making.

4. Conclusions

This project provides low-cost solutions, on a sustainable and real

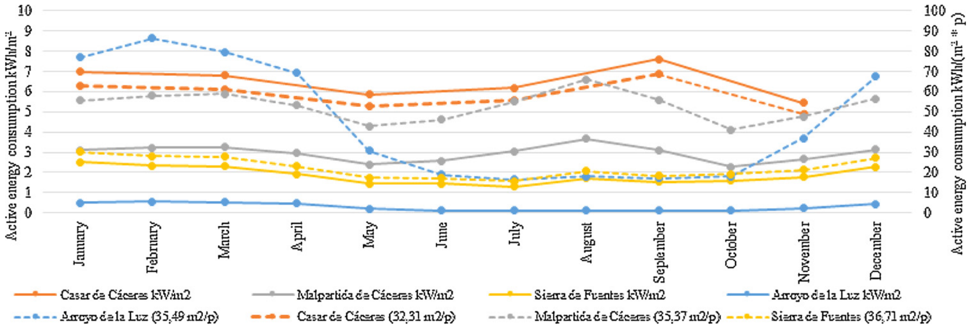

Fig. 7. Average consumption of electric energy according to invoices years 2014 to 2017.

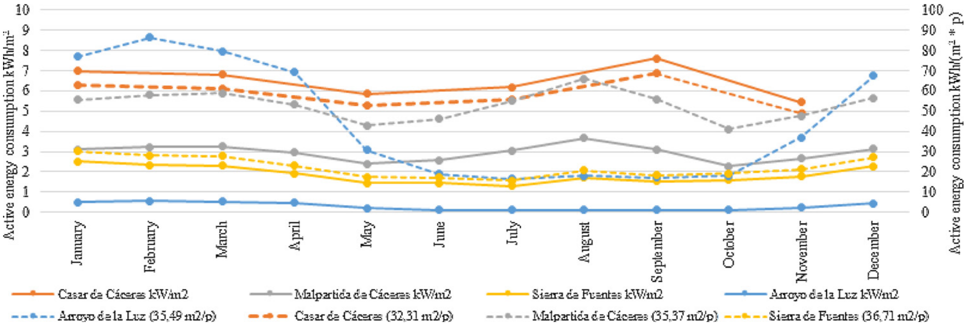

Fig. 8. Average consumption of thermal energy according to invoices, 2014 – 2017.

basis, which can be integrated in the daily building maintenance through environmental, social, and policy actions. Moreover, both, the proposed methodology and the actions, contribute to increase impact and involve other agents. It is also observed that the comparison of real-time data with energy consumption makes it possible to propose of savings decisions that do not harm comfort. In this way, a methodology that resolve the tracking to improve energy patterns and hygrothermal comfort conditions in rural public buildings has been presented. Furthermore, the following proposed objectives have been attained in this case:

- To monitor energy consumption and comfort conditions in real-time, and transmit data to an open source, scalable information systems with low cost ICTs.
- To characterize buildings typology in services sector towards the reduction of the energy consumption and the improvement of comfort conditions.
- To make available a smart tool that manage resources and sensitize users in public resources.

The consumption values given on this article are specific to small historical public buildings and the use of administrative services. However, this methodology would allow to characterize other typologies that would help to identify consumption in this sector.

In conclusion, innovative procedures in technologies and application methodologies provides the appropriate opportunities to retrofit existing buildings and communities towards smart development.

Acknowledgements

This paper is part of the research project (Research groups: Comphas & Robolab, 2017) belonging to the Plan for Initiation to Research, Technological Development and Innovation of the UEx (University of Extremadura) of 2016. This project is included in a topic focused on local development, TICs in rural areas, and smart villages. This work was supported by the European Regional Development Fund (ERDF) and the regional government of Extremadura (Junta de Extremadura) and was carried out thanks to the grant GR15107. Authors wish to acknowledge Cáceres Provincial Council and the assistance of the town halls for transferring the data. They would also like to thank L. M. ª Colchón Méndez, A. Arévalo Paredes, and A. Núñez Izquierdo, Building Engineering students at the EPCC who were carrying out their bachelor thesis and created the graphics in Fig. 3.

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