Simulation-assisted evaluation of potential energy savings: Application to an administrative building in France

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Abstract:
The case study presented here falls within a project of feasibility studies to improve the energy efficiency, the carbon footprint and the environmental impacts of several administrative buildings in France.

The first part of the paper briefly presents the data obtained during a classical audit and inspection procedure: the description of the building in term of design, the HVAC system characteristics, the occupancy and operating profiles and the control strategy applied. The second part of the paper gives the first results obtained using an evidence-based calibrated building energy simulation model to analyze the actual building global consumption but also analyze the local consumptions (heat pumps, air handling units, terminal units, lightings, pumps,...).

The last part of the paper then demonstrates the possibilities given by the building energy simulation model to evaluate potential energy saving scenarios through different examples. The advantages and drawbacks of the applied methods and tools are also discussed.

Keywords:
Building energy simulation, potential savings, ECO, audit

1. Introduction

While our economy is heavily dependent on energy resources, the building sector is directly involved. European Union’s countries regulate more and more strictly the construction, renovation and management of their buildings. The building sector represents by itself 40% of the European energy consumption. Non-residential buildings are an important part of the energy consumer and are part of a great challenge for the next decades. As national and local regulators are showing more and more their desire to push in the future years and decades for more energy efficient building through directives like the Energy Performance of Buildings Directive (EPBD, 2002), they are also starting to directly integrate their directive into action in their own administrative building.

Building energy simulation (BES) models are of a great help when analyzing energy use and assessing energy conservation opportunities in the frame of the energy audit of an existing office building (HARMONAC, 2010). Using BES models to help in understanding the thermal behavior of an existing installation requires the BES model to be able to closely represent the actual behavior of the building under study. The calibration of a BES model to an existing situation involves using as-built information, survey observations and short and/or long term monitoring data to iteratively adjust the parameters of the BES model. Obviously, after the calibration process, the tool can be used to identify at first the main energy consumers and then to evaluate some energy consumption opportunities (ECOs). The present paper can be divided in three parts.

In the present work, a simplified BES model and an associated audit methodology have been developed in the frame of several successive research projects (AUDITAC, 2007) (HARMONAC, 2010) and thesis (Bertagnolio, 2012). The Building-HVAC System global model presented here includes simplified models of building zone and of HVAC equipment. The development and the implementation of this BES model are briefly discussed in the first part of the paper along with the audit methodology (including data collection issues) and the calibration process of the BES model.

The second part of the paper presents the main findings of the application of the developed model and methodology. The case study presented here falls within a contract of feasibility studies to improve the energy efficiency, the carbon footprint and the environmental impacts of several administrative buildings in France. Each building study is subdivided into 3 phases which two of them involve the use of a building energy simulation model.

The phase 1 consists in obtaining a calibrated building energy simulation model using data collected by a consulting firm from as-built files, utility bills and on-site tests and measurements. The phase 2 then uses the calibrated building model to simulate various individual technical solutions or ECOs at first, and then some overall concepts scenarios. Finally, the phase 3, the preliminary design, aims to clarify and bring the overall concepts held after phase 2 in terms of accuracy on the technical feasibility and execution planning. This third phase is completely realized by the consulting firm and does not involve anymore the BES model. Through this paper, accent will be mainly put on the findings of the second phase even though part of the first calibration phase will be presented.

2. Building description

2.1. Building design

The building has a floor area of 19,000 m², was built in the 80s and is composed of 11 levels. The building is composed of multiform facades oriented:

- South (flat facades, salient angle and convex)
- North and West in several arcs

The facades are of curtain walls type made of aluminum and glass.

The main building houses offices, a few conference rooms that can accommodate around hundred people, bathrooms and a nursery.

2.2. HVAC system

2.2.1. General principle

The main HVAC production system in the building is composed of reversible geothermal heat pumps, producing hot and chilled water simultaneously, when needed, to satisfy the cooling needs of IT rooms all year and heating and / or cooling of all other spaces throughout the seasons.

The meeting rooms and the other large volumes are only served by CAV air handling units while the office spaces are served by CAV air handling units and 2-pipes fan coil terminal units.

2.2.2. Production

The production of heat and cold necessary to cover the needs of the building is thus fully provided by three similar geothermal heat pumps. In detail, these machine are each composed of 2 screw compressors operating with refrigerant R134-a. The nominal performances of the heat pumps in winter mode and in summer mode are summarized in Table 1 and Table 2.

Table 1: General characteristics and performances of the heat pumps in winter mode

Condenser		
Heating capacity	*Water in-out temperature*	*EER "hot"*
758 kW	*50/40°C*	***4.10***
Evaporator		
Cooling capacity	*Water in-out temperature*	*EER "cold"*
582 kW	*6/11°C*	*3.15*

Table 2: General characteristics and performances of the heat pumps in summer mode

Condenser		
Heating capacity	*Water in-out temperature*	*EER "hot"*
772 kW	*20/30°C*	*5.68*
Evaporator		
Cooling capacity	*Water in-out temperature*	*EER "cold"*
643 kW	*6/11°C*	***4.73***

2.2.3. Air Handling Unit

The building has 17 air handling units for a total of approximately 200 000 m^3/h of supply air according to as-built files. 16 of the 17 air handling units are running since the first commissioning of the building in the late eighties. Some of them allow partial recirculation while some other are equipped with heat pipe energy recovery systems even though some of those systems are in poor condition or even have been removed from the air handling units.

2.3. Occupancy and operating profiles

The building studied here is an administrative building that has atypical occupancy and operating profiles. The number of occupant can vary from 135 to more than 600 depending on the period. These different types of periods will be referred in the rest of the paper in term of week as work period (WP), pre-work period (PrP) and post-work period (PoP).

This unusual use of a building is a major issue in term of building operation but also a major challenge in term of potential savings especially during the PrP and PoP where the number of occupants falls down to nearly 20% of the normal WP occupancy.

In term of schedules, 5 air handling units and the fan coils are working from 6am to 11pm only during WP, are shut off during PoP and restarted during the week of PrP.

The 12 others (about 75% of the total supply air) are working round the clock during the WP. 7 of those 12 even run round the clock during PrP and PoP, the 5 other being started during the PrP week and stop at the end of the WP.

2.4. Control strategy

From the inspection procedure a first observation can be made regarding the control strategy implemented by the building managers. The building management systems BMS is poorly utilize. The system operator rather prefer the principle of the daily round and of starting and stopping of an important part of the installation then the implementation of schedule in the BMS, leaving these system working round clock sometime a whole week before the WP.

In term of indoor setpoint, the setpoint is fixed at 21°C in winter and 22°C in summer in theory during occupation hours but each office is equipped with potentiometer present on the controller of the terminal units allowing a -3°C or +3°C deviation of the setpoint. No inoccupation hour's setpoint were found from the inspection procedure leading to observation that occupation setpoints were operational all year long even though it appeared as in as-built file the setpoint was 16°C and 28°C in winter and summer.

The humidity setpoint is according to as-built data fixed 40% and 60% +/-5%.

3. BES Model

3.1. Simulation tool

In a building, monthly energy bills cannot accurately analyze the behavior of a building. It is particularly difficult to distinguish the power consumption due to HVAC systems from the other items consumption. BES models, as mentioned before, give a large range of possibilities at the different phases of an audit. In the frame of two different projects, AUDITAC and HAMONAC, a simplified BES model called "SIMAUDIT" has been developed (Bertagnolio, 2012) and tested on a few test cases (Bertagnolio et al., 2008) (Bertagnolio and Lebrun, 2008). SIMAUDIT is a quasi-steady state hourly simulation where cooling, heating and latent loads computed by the building multi-zone model (Fig. 1) are summed and converted into system loads and then, into final energy consumptions (Fig. 2).

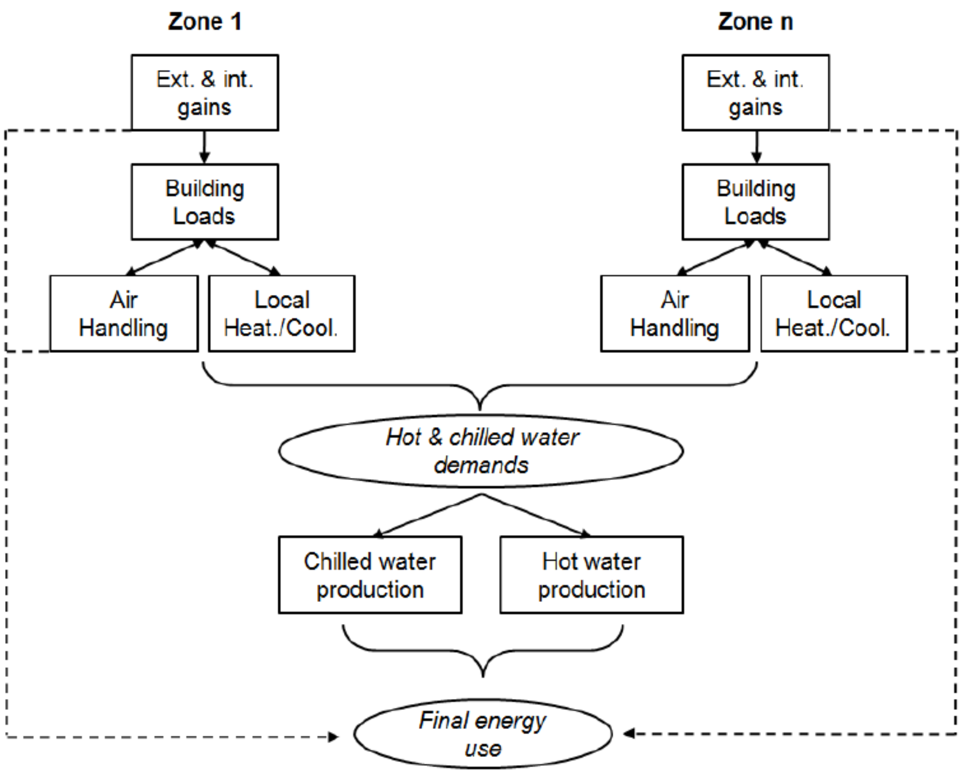

Fig. 1. Multi-zone modeling scheme

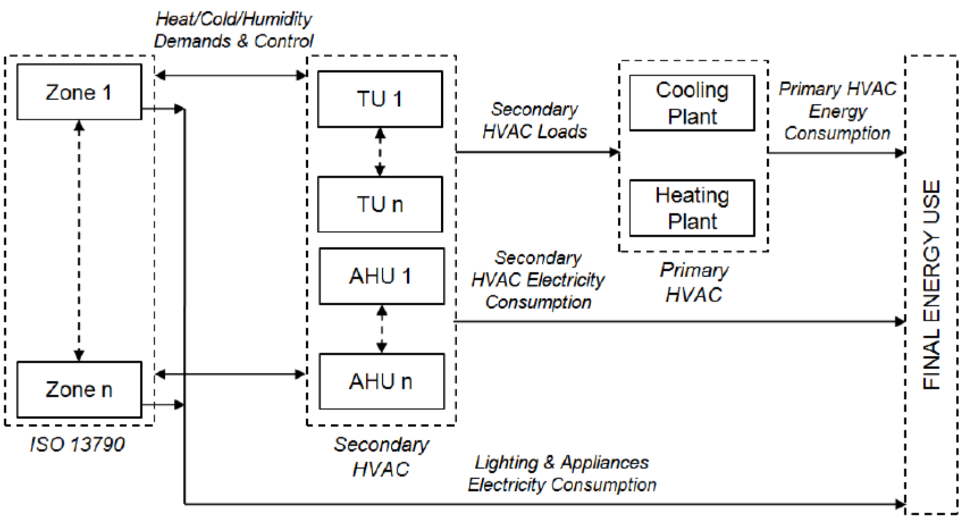

Fig. 2. Global building-HVAC model block diagram

Disaggregation between different items of power consumption can be achieved by means of the tool SIMAUDIT representing the actual behavior of building and HVAC systems.

The first phase of the audit concerns the calibration of the tool. This calibration uses monthly energy consumption, as well as the characteristics of the building envelope, HVAC equipment and their regulation obtained during the inspection of the installation. Other parameters, such as ventilation rates should be adjusted iteratively if no objective information is available. Iterations required to calibrate the simulation model are part of the audit process and to identify the variables to measure or quantify in priority and to highlight important features of the building.

Once calibrated, SIMAUDIT must be able to reproduce with a given precision the monthly electricity consumption according to ASHRAE 14-2002 guidelines (ASHRAE (2002)) by two distinct criteria: on one hand, the criterion of "Mean Bias Error" (MBE) and on the other the criterion of "Coefficient of Variation of the Root Mean Square Error" CV (RMSE). The second criterion is inseparable from the first because of its possible compensation differences (positive and negative) skew the results.

$$MBE = \frac{\sum_{i=1}^{n}(Q_{pred,i} - Q_{data,i})}{n\,Q_{data}}$$

$$CV(RMSE) = \frac{\sqrt{\frac{\sum_{i=1}^{n}\left(Q_{pred,i} - Q_{data,i}\right)^2}{n}}}{Q_{data}}$$

Q_{data} is the average measured value (here on a monthly basis) during the period, $Q_{data,i}$ is the measured value for the “i” period and $Q_{pred,i}$ is the predicted value for the “i” period. It is obviously desirable to minimize the value of these two parameters, the MBE and CV (RMSE) to refine the calibration. In the case of an assessment on a monthly basis, ASHRAE recommends limits of + / - 5% for MBE and + / - 15% for the CV (RMSE).

3.2. Calibrated model and results

The data collected on site and as-built files (plans, technical sheet...) allowed defining the zoning of the building according to its geometry, orientation, HVAC system configuration and use of the various areas. After setting the 9 zones of the building, the geometric description of each zone has been entered in the simulation program.

Available information on the components of the HVAC system and internal loads (occupancy, lighting, computer equipment ...) and on-site measurements were then used to calibrate the model parameters gradually and approach profiles consumptions recorded in 2009.

Figure 3 and Table 3 shows a comparison of monthly predicted and measured consumption values and the corresponding MBE and CV (RMSE) criteria.

Table 3: MBE and CV (RMSE) criteria

	[%]
MBE	3.7
CV(RMSE)	1.1

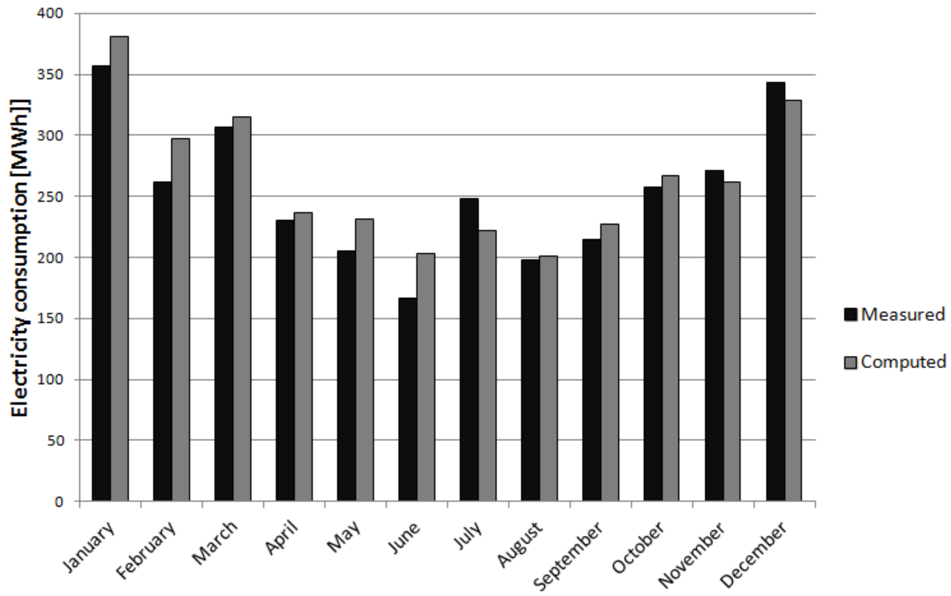

Fig. 3. Monthly measured and computed consumption values comparison

From Table 3, it can be seen that MBE and CV (RMSE) criteria are under recommended limit according to ASHRAE Guideline.

A comparison on an hourly basis, on Figure 4 for the month of January, shows the good representation of the BES model compared to actual measured values.

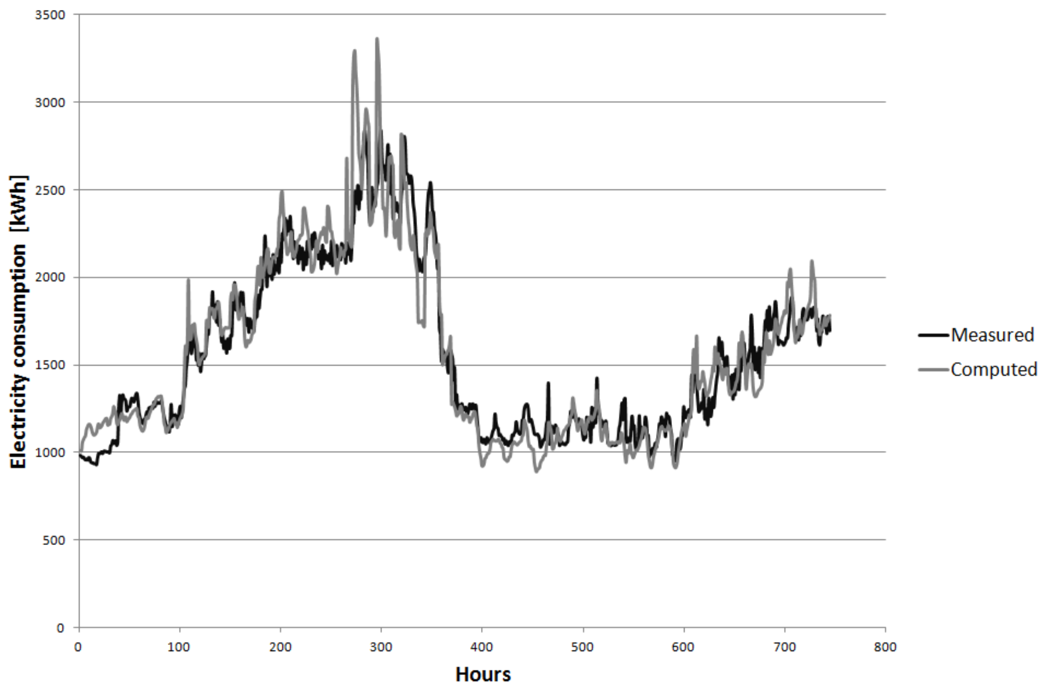

Fig. 4. Hourly measured and computed consumption values comparison

Once the model is calibrated, the consumption of the building can be disaggregated into its different main consumers and analyzed for further potential energy savings phases. Figure 5 shows the disaggregation of annual electricity consumption into the main consumer. It shows the importance of the heat pumps, the distribution, humidification and the ventilation in the building, which all together account for more than 70% of the whole building consumption.

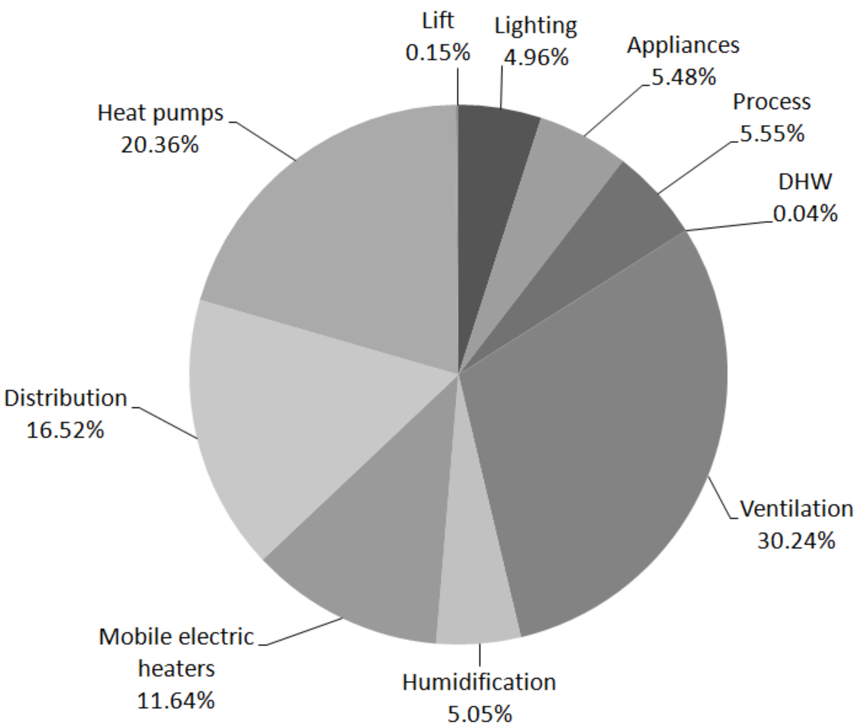

Fig. 5. Desegregation of annual electricity consumption of the building into main items

Also, in Table 3, it can be seen that only 28% of the annual energy consumption comes from the working period. These observations lead to various energy savings scenarios.

Table 3: 2009 Electricty consumption period disaggregation according to SIMAUDIT model

	%	**MWh**	**Primary Energy [MWh]**	**CO2 [T]**
Post-work period (PoP)	50.16%	1591.10	4105.04	119.33
Pre-work period (PrP)	21.81%	691.78	1784.79	51.88
Work period (WP)	28.03%	889.05	2293.75	66.68
Total	100%	3171.93	8183.58	237.89

4. Retrofit options simulation

4.1. Individual technical solutions and ECOs

4.1.1. Efficient schedule implementation in BMS of air handling and fan coil units

The first energy conservation opportunity (ECO) presented here concerns the implementation of energy efficient schedule and setpoint for air handling units and fan coils into the BMS. This would allow a significant reduction of energy consumption in terms of ventilation, heat pumps, humidification and distribution especially for the PrP and PoP where some of the HVAC systems where still working 24/7.

The results presented in table 4 shows an impressing relative saving of 21% of annual electricity consumption.

Table 4: Efficient schedule implementation in BMS simulation results

	Unit	Reference	Solution	Relative Gain
Total electricity consumption	**MWh**	**3 770.18**	**2972.74**	**21.2%**
High peak electricity consumption	MWh	180.49	140.08	22.4%
Winter peak electricity consumption	MWh	1 042.33	842.35	19.2%
Winter off-peak electricity consumption	MWh	730.57	531.28	27.3%
Summer peak electricity consumption	MWh	1 098.85	904.61	17.7%
Summer off-peak electricity consumption	MWh	717.94	554.41	22.8%

Table 5: New functional organization simulation results

	Unit	Reference	Solution	Relative Gain
Total electricity consumption	**MWh**	**3 770.18**	**3577.33**	**5.1%**
High peak electricity consumption	MWh	180.49	172.22	4.6%
Winter peak electricity consumption	MWh	1 042.33	999.77	4.1%
Winter off-peak electricity consumption	MWh	730.57	691.41	5.4%
Summer peak electricity consumption	MWh	1 098.85	1041.50	5.2%
Summer off-peak electricity consumption	MWh	717.94	672.42	6.3%

4.1.2. New functional organization

The second ECO presented here show the possibility of SIMAUDIT to analyze the impact of a modification of the occupancy by zone. In the present ECO, the consulting firm has imagine a new functional organization of the building, regrouping the permanent worker into specific zones instead of leaving them all over the building as it was in the actual organization. This allowed the shutting off of some AHU and fan coil units. This ECO was analyzed independently, without any other changes in the building operation.

4.2. Overall scenario

The final scenario presented here incorporates the most interesting individual technical solution studied in the single retrofit simulation phase according to the consulting. This scenario contains new setpoint during occupation and inoccupation period, a complete implementation of schedule in the BMS, the replacement of some of the AHU with new ones with recovery systems, modification of the functional organization, replacement of some of the lighting and installation of solar shading device.

This scenario presents according to the BES model a potential energy savings of 48.7% of the annual electricity consumption.

Table 6: Scenario simulation results

	Unit	Reference	Solution	Relative Gain
Total electricity consumption	**MWh**	**3 770.18**	**1 932.64**	**48.7%**
High peak electricity consumption	MWh	180.49	92.36	48.8%
Winter peak electricity consumption	MWh	1 042.33	538.50	48.3%
Winter off-peak electricity consumption	MWh	730.57	309.28	57.7%
Summer peak electricity consumption	MWh	1 098.85	661.26	39.8%
Summer off-peak electricity consumption	MWh	717.94	331.25	53.9%

5. Conclusion

BES model can be a great help in energy audit for both analyzing the actual behavior and consumptions of a building and for evaluating the potential energy savings. Difficulties lie in the calibration of the model to the actual building behavior, calibration directly linked to the quality of the data available but also the communication between the consulting firm and the modeling team. The present study demonstrates the usefulness and the range of possibility of such study but has also met difficulties due to the lack of knowledge of both the building operator and the building owner leading to an important energy waste from mismanagement of installations in theory yet effective.

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