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# Impact of Smart Monitoring on Energy Savings in a Social Housing Residence

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**Abstract:** Energy consumption in the social housing sector constitutes a major economic, social, and environmental issue, because in some countries such as France, social housing accounts for about 19% of the housing sector. In addition, this sector suffers from ageing, which results in high energy consumption, deterioration in the occupant quality of life, and high pressure on the budget of low-income occupants. The reduction of the energy consumption in this sector becomes a "must". This reduction can be achieved through energy renovation and innovation in both energy management and occupant involvement by using smart technology. This paper presents a contribution to this goal through the investigation of the impact of smart monitoring on energy savings. The research is based on monitoring of comfort conditions in an occupied social housing residence in the North of France and the use of building thermal numerical modeling. Results of monitoring show that the indoor temperature largely exceeds the regulations requirements and the use of a smart system together with occupant involvement could lead to significant savings in heating energy consumption. The novelty in this paper concerns the use of comfort data from occupied social housing residence, occupation conditions, and building thermal modeling to estimate energy savings. The proposed methodology could be easily implemented to estimate heating energy savings in social housing buildings that lack individual energy consumption monitoring.

**Keywords:** Social housing; smart; monitoring; heating; energy; consumption; comfort; numerical modeling

## 1. Introduction

Energy consumption in the social housing sector constitutes a major economic, social, and environmental issue, because in some countries such as in France, this sector accounts for about 19% of the housing sector. In addition, this sector suffers from ageing, which results in high energy consumption as well as in high running expenses, degraded quality of life, and high pressure on the budget of low-income occupants. Energy consumption in social housing has been explored in Australia, the Netherlands, the United Kingdom, and Spain [1–4]. This research confirms the necessity to reduce energy consumption in this sector in order to meet national and regional environmental strategies as well as to improve the quality of life for occupants and to reduce the pressure on the budget of low-income residents.

Analysis of the impact of buildings renovation on energy savings in two renovation programs in Grenoble, France showed that building renovation did not meet the expected energy savings, because of insufficient consideration of occupant behavior and lack of building monitoring [5]. This result was confirmed by the research conducted by Juan et al. on the energy use in the social housing sector in Spain [6]. They showed that the building characteristics are not the most relevant factors in energy poverty, because of the important role of the resident behavior in energy use. Analysis of questionnaire to the residents of a Community Energy Saving Program in Nottingham showed that building retrofitting reduces carbon emissions to a certain extent [3]. The achievement of higher energy performance requires emphasis on the occupant behavior and policy interventions. Research conducted by Kavgic et al. showed that consideration of the buildings operating conditions constitutes a major issue in energy saving [6].

Research presented in this paper concerns energy savings in a social housing residence in the North of France. Despite a recent renovation of this residence, energy expenses remained high regarding the renovation program expectations. This result seems to be coherent with the findings of research conducted by (Enertech 2012), (Juan et al. 2018) and (Elsharkawy and Rutherford 2015) [3–5]. To understand the cause of the high energy expanses and to find solutions to reduce these expenses, a monitoring program was deployed in the residence to follow the comfort conditions. Collected data together with user energy practices were used in a buildings thermal modeling to explore the possibility of energy savings [7]. The novelty in this paper concerns the use of indoor comfort data in occupied social housing, occupation practices, and thermal building modeling with ArchiWIZARD software to estimate energy savings. The proposed methodology could be easily implemented to estimate heating energy savings in social housing buildings that lack individual energy consumption recording.

In the following, the paper presents the method used in this research including both smart monitoring and numerical modeling, then it discusses the major results and proposes some recommendation to reduce energy expanses.

## 2. Method and Material

### 2.1. Research Methodology

This research is based on a smart monitoring of three apartments in a social housing residence in the North of France, which includes (i) use of smart sensors to record the indoor temperature and humidity in the different rooms of each apartment and (ii) and a questionnaire for the volunteer occupants to estimate energy production related to their presence in the apartment.

Due to the old equipment of this residence and the complexity of the heating system, the energy consumption was not recorded at short time interval. It was obtained from the manager of the social housing for the period of heating. To estimate energy savings, the software ArchiWIZARD was used for establishing a numerical model for each apartment [7,8]. The parameters of the thermal model were determined from the records of indoor and outdoor temperatures as well as from the global heating consumption provided by the social housing manager. The thermal parameters were used to explore energy savings which could be obtained by control of the indoor temperature according to the French regulations.

### 2.2. Monitoring Program and Data Collection

The social housing residence was built in 1973 and renovated in 2012. The residence is composed of 15 apartments distributed in 5 floors. The monitoring program concerned three occupied apartments. The first one is located on the 1st floor, while the others are located on the 4th floor. The residence is heated by a central heating system. Heating regulation is conducted by manual valves at the radiator level.

The monitoring system is composed of a central unit, wireless sensors, and user interface. The central unit consists of a Raspberry Pi, which uses the open-source Linux operating system and a SD Card for data storage. Figure 1 illustrates the architecture of monitoring system. Indoor temperature and humidity were recorded using SI7021 sensors. Table 1 provides the characteristics of these sensors. The temperature sensor has an accuracy of ±0.4 °C within the range of (−10 °C–65 °C), while the relative humidity sensor has an accuracy of 0.6% within the range (0–80%). Sensors were associated with Panstamp programmable module and connected to the Raspberry Pi with radio frequency protocol. Temperature and humidity sensors were installed in the salon and the bedrooms. Data were recorded at 30 minutes time interval. The outdoor temperature and humidity were obtained from the weather Observatory Lesquin, which is located at 5 km from the residence.

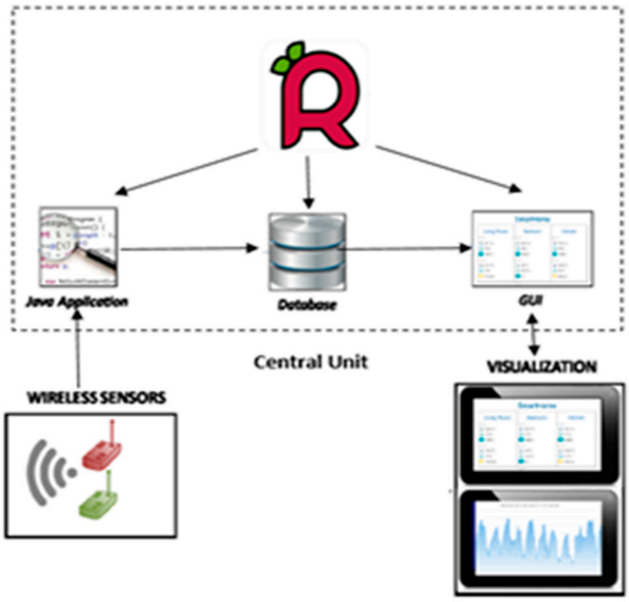


**Figure 1.** Architecture of the monitoring system.

**Table 1.** Characteristics of temperature and relative humidity sensors.

| Sensors | Type | Interval | Precision |
|---|---|---|---|
| Temperature | SI7021 | −10 to 85 °C | 0.4 °C |
| Relative Humidity | SI7021 | 0 to 80% | 3% |

### *2.3. Numerical Modeling*

Estimation of the heating energy savings in the apartments was conducted using the software ArchiWIZARD. This software allows determination of energy need for given indoor and outdoor temperatures. It requires physical characteristics of the building and appliances as well as the occupant activity.

The building's installations and technical equipment were provided by the residence manager. The occupant activity was obtained through a questionnaire. Global energy consumption was provided by the residence manager. Over the heating period, the heating energy consumption for the apartment of the first floor was equal to 95 kwh/($m^2$·an).

A trial-by-trial data analysis using ArchiWIZARD software was conducted for the estimation of the overall loss coefficient of the apartment envelope. This analysis was based on the indoor and outdoor recorded temperatures, the thermal characteristics of the building and energy consumption. It gave an overall loss coefficient of the envelope Ubat = 0.7.

ArchiWIZARD software was then used with the overall loss coefficient of the envelope (Ubat = 0.7) to estimate energy need for the recorded indoor and outdoor temperatures. It gave an energy need of 101 kwh/($m^2$·an), which is about 6% higher than that provided by the manager. According to Yan et al., this difference between estimated energy need and energy consumption is acceptable [9].

## 3. Results and Discussion

### *3.1. Indoor Temperature Variation*

Indoor temperature was recorded during the period 1 October 2016 to 14 April 2017. Figure 2 illustrates the variation of the temperature in the living room of the apartment of the first floor as well as the variation of the outdoor temperature. The indoor temperature varied around an average value of 23.8 °C with some peaks, which could reach 29.3 °C. For the same period, the outdoor temperature varied between −5 °C and 23° C with an average value of 5.1 °C.

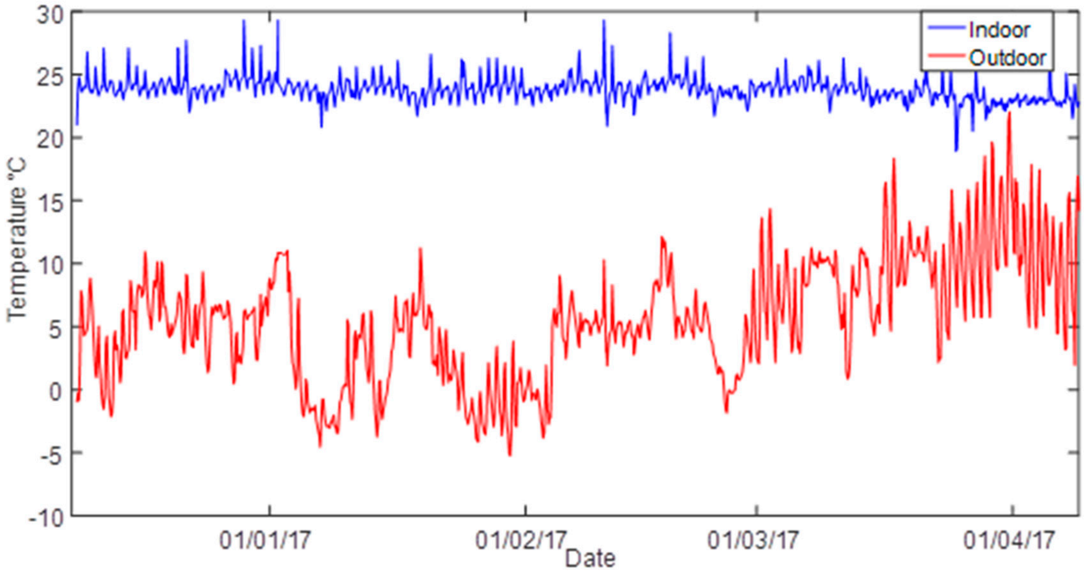


**Figure 2.** Variation of the indoor and outdoor temperatures (December 2016–April 2017).

Figure 3 shows the variation of the temperature during the period 21–23 December 2016. The indoor temperature exceeded 23.7 ° C, with a maximum of 29.3 °C and an average of 24.8 °C. This high temperature is to be compared with the French thermal regulation, which recommends limiting the indoor temperature to 19 °C during occupation time and to 16 °C during unoccupied time.

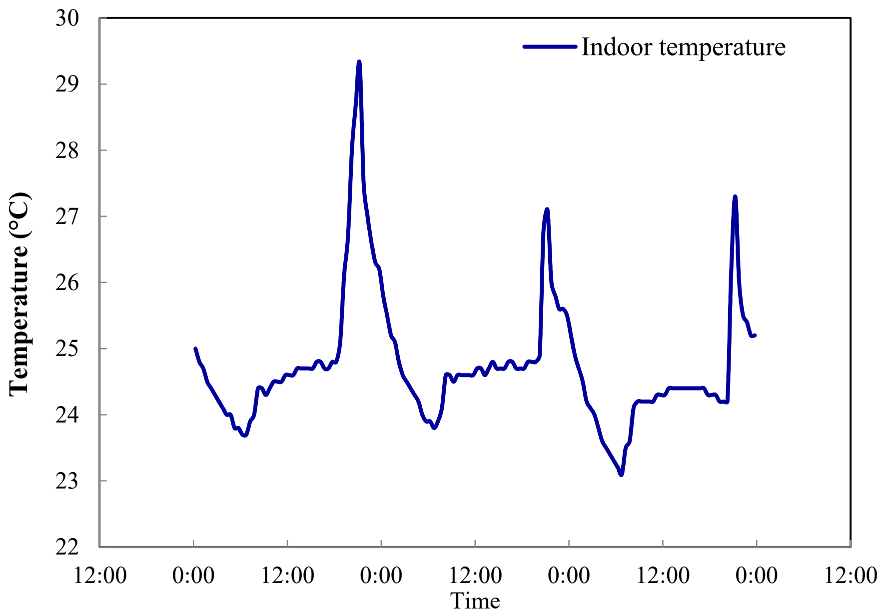


**Figure 3.** Variation of the temperature in the period 21–23 December 2016 (Max = 29.3 °C, Min = 23.7 °C, Average = 24.8 °C).

This high level of temperature is due to several factors, in particular the absence of an indoor heating regulation system, the absence of a monitoring system that informs occupants about the high level of indoor temperature and its consequences on energy expanses and finally the lack of involvement of occupants in energy management.

Figure 4 illustrates the distribution of the indoor temperature according to 4 daily periods [6:00–12:00; 12:00–18:00, 18:00–22:00 and 22:00–6:00]. It could be observed that the temperature distribution over the 4 periods is close with a concentration in the temperature interval [23 °C–25 °C]. High values observed in the afternoon [14:00–18:00] and in the evening [18:00–22:00] could be related to the occupant activity. According to the French thermal regulations, the maximum indoor temperature during this time should not exceed 19 °C, while that at the sleeping time should be limited to 16 °C. As can be seen in Fifure.4, indoor temperature highly exceeds the regulation values all over the day.

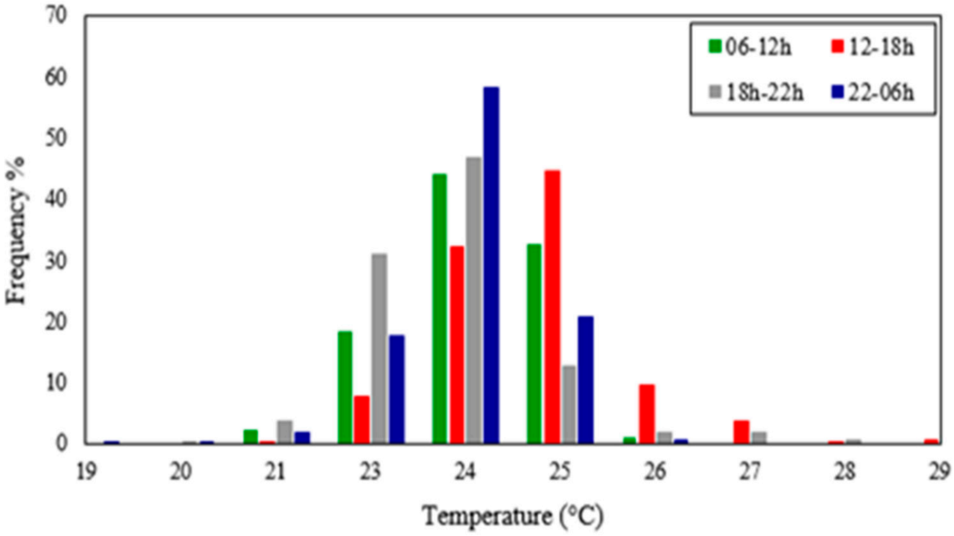


**Figure 4.** Temperature distribution according to time slots during the heating period (A).

Table 2 shows the mean values of the temperature in the salons of the three apartments: A in the first floor and B and C in the third floor. It shows that mean values of the temperature in these apartments are very close, with a mean value over the period December–March between 23.8 for building A and 23.6 for buildings B and C. This result confirms the global overheating observed in building A.

**Table 2.** Mean values of the temperature in the salons of three apartments (A in the first floor and B and C).

| Month | Apartment A | Apartment B | Apartment C |
|---|---|---|---|
| December | 24.1 | 23.6 | 22.5 |
| January | 23.8 | 23.2 | 22.5 |
| February | 23.9 | 23.8 | 24.1 |
| March | 23.4 | 23.7 | 25.2 |
| December–March | 23.8 | 23.6 | 23.6 |

Results in Figures 2–4 and Table 2 clearly show that the indoor temperature in the three apartments highly exceeded the French thermal regulations, which limit the indoor temperature to 19 °C during occupation time and 16 °C during inoccupation period. This result outlines both difficulties and shortage in energy management in the social housing sector. It recommends the generalization of temperature and humidity indoor monitoring for energy savings as well as for occupant comfort and health survey. It also indicates the necessity to involve the occupants in energy management through data sharing and regular information about the consequences of overheating on both energy expanses and health.

### 3.2. Heating Energy Savings

The energy need of each apartment is estimated according to the following regulations scenarios:

Scenario1: The indoor temperature is controlled according to the social landlord's regulations.

Scenario 2: The indoor temperature is controlled according to the thermal regulations RT 2012.

Results of scenario 1: $T_{indoor}$ is controlled according to the social landlord's regulations

This scenario is based on the French social landlord's regulation, which could be resumed as follows:

The indoor temperature is limited to 19 °C.

The internal generated energy is equal to 5.7 W/m$^2$ when the apartment is occupied and to 1.14 W/m$^2$ when it is unoccupied.

Analysis is conducted with a household composed of two members.

Figure 5 and Table 3 show a comparison between recorded heating consumption and heating energy needs according to this scenario. It could be observed that the respect of the social landlord's regulation leads to important savings in the energy consumption. The monthly energy saving varies between 218 kWh in April and 499 kWh in January. Over the period October – April, the heating energy saving is equal to 2953 kWh, which accounts to 41% of the recorded heating consumption. This result agrees well with the findings of (Enertech, 2012), Elsharkawy and Rutherford (2015) and Kavgic et al. (2012) [3,5,6].

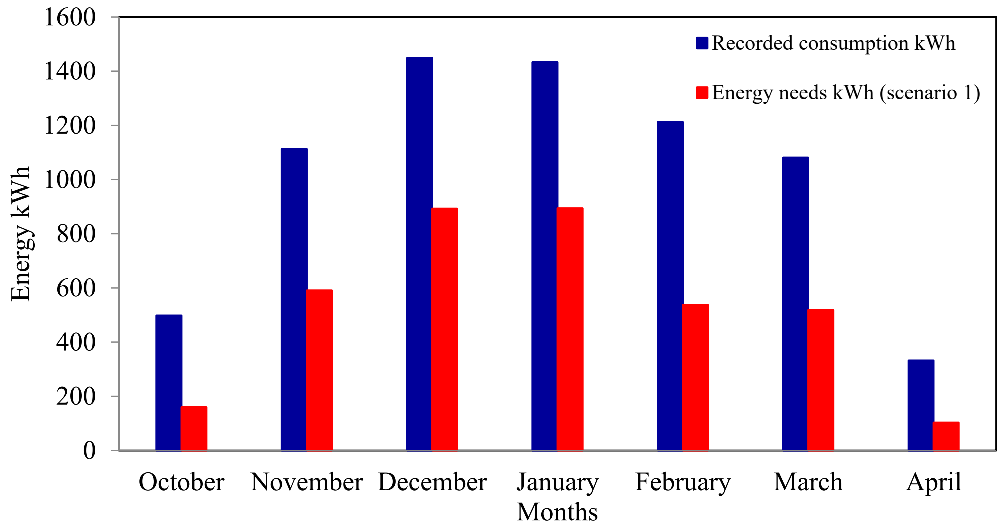


**Figure 5.** Comparison between recorded consumption and energy needs according to social landlord's regulations (Scenario 1).

**Table 3.** Comparison between recorded consumption and energy needs according to the social landlord's regulations (Scenario 1).

| Month | Recorded Consumption (kWh) | Estimated Energy need (kWh) | Over-Consumption (kWh) |
|---|---|---|---|
| October 2016 | 498 | 176 | 322 |
| November 2016 | 1113 | 637 | 476 |
| December 2016 | 1449 | 952 | 497 |
| January 2017 | 1433 | 934 | 499 |
| February 2017 | 1213 | 760 | 453 |
| March 2017 | 1081 | 593 | 488 |
| April 2017 | 332 | 114 | 218 |
| October–April | 7119 | 4166 | 2953 |

Results of scenario 2: $T_{indoor}$ is controlled according to French thermal regulations RT 2012.

This scenario is based on the French thermal regulations RT 2012, which includes the following conditions:

The indoor temperature is equal to 19 °C during the occupancy period and 16 °C in case of vacancy for a period inferior to 48 hours and 8 °C in a period of vacancy exceeding 48 hours.

Analysis was conducted with a household composed of two members. The occupancy rate of Apartment A is summarized in Table 4.

**Table 4.** Occupation of the Apartment A for the determination of internal generated energy.

| **Day/Hour** | **Occupancy Rate** | | | | |
|---|---|---|---|---|---|
| | **06h–10h** | **10h–14h** | **14h–18h** | **18h–22h** | **22h–06h** |
| Monday | 1 | 0 | 0 | 1 | 0.7 |
| Tuesday | 1 | 0 | 0 | 1 | 0.7 |
| Wednesday | 1 | 0 | 1 | 1 | 0.7 |
| Thursday | 1 | 0 | 0 | 1 | 0.7 |
| Friday | 1 | 0 | 0 | 1 | 0.7 |
| Saturday | 1 | 1 | 1 | 1 | 0.7 |
| Sunday | 1 | 1 | 1 | 1 | 0.7 |

Figure 6 and Table 5 illustrate a comparison between the recorded heating consumption and the heating energy needs according to the scenario RT2012. It shows that the application of the RT 2012 regulation results in energy savings, which are higher than that obtained with the social landlord's regulations. The monthly energy saving varies between 229 kWh in April and 675 kWh in February. Over the period October–April, the heating energy saving is equal to 3421, which is about 46% of the recorded heating consumption, to be compared with 41% obtained with the social landlord's regulations.

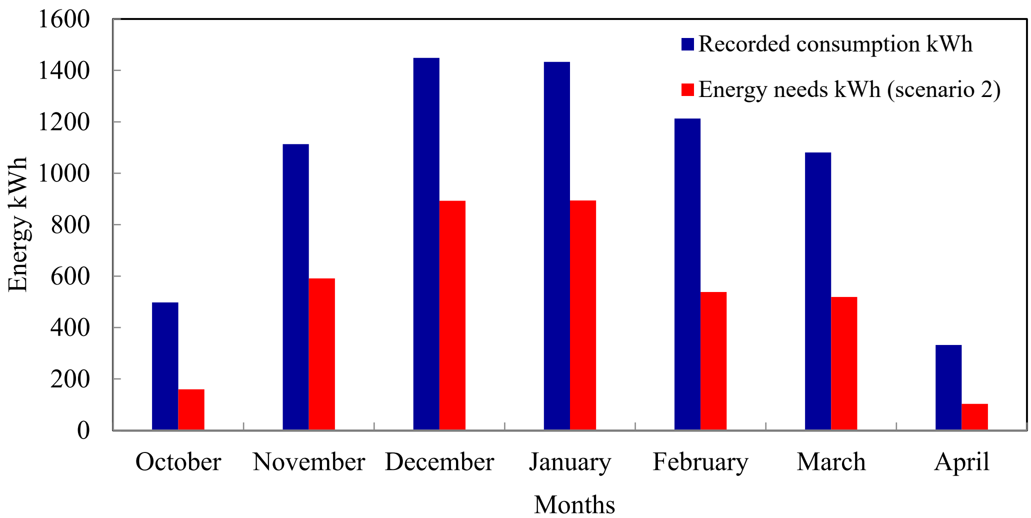


**Figure 6.** Comparison between recorded consumption and energy needs according to the French thermal regulations RT 2012 (Scenario 2).

These results confirm the high interest of indoor comfort monitoring in reducing heating energy consumption, which could attain around 46% of the global consumption. This reduction has important benefit for occupants as well as for the reduction of the global energy consumption and greenhouse gas emission.

**Table 5.** Comparison between recorded consumption and energy needs according to the French thermal regulations RT 2012 (Scenario 2).

| Month | Recorded Consumption (kWh) | Estimated Energy need (kWh) | Over-Consumption (kWh) |
|---|---|---|---|
| October 2016 | 498 | 160 | 338 |
| November 2016 | 1113 | 591 | 522 |
| December 2016 | 1449 | 893 | 556 |
| January 2017 | 1433 | 894 | 539 |
| February 2017 | 1213 | 538 | 675 |
| March 2017 | 1081 | 519 | 562 |
| April 2017 | 332 | 103 | 229 |
| October–April | 7119 | 3698 | 3421 |

## 4. Conclusions

This paper presented an investigation of potential heating energy savings in a social housing residence. This issue is of high concern, because the social housing sector suffers generally from low energy performance, which lead to high energy consumption and high pressure on the budget of low-income occupants. The study was conducted using a smart monitoring of some apartments in a social housing residence and a thermal modeling of these apartments by ArchiWIZARD software. Indoor temperature was recorded for the period December 2016–April 2017. The recorded temperature was generally high with an average value of 23.8 °C and some peaks close to 29 °C. Energy savings were estimated using the software ArchiWIZARD with regard to the application of two thermal regulations: the social landlord's regulations and the French thermal regulations RT 2012. Results show that the application of the social landlord's and RT2012 regulations could lead to 41% and 46% of energy savings, respectively. This result outlines difficulties and shortage in energy management in the social housing sector. It recommends the generalization of indoor comfort monitoring including both temperature and humidity for energy savings as well as for occupant comfort and health survey. It also shows the necessity to involve occupants in energy management through data sharing and regular information about the consequences of overheating on energy consumption and health. In addition, indoor comfort monitoring in the social housing sector leads to a better understanding of the heating operating conditions. It constitutes a valuable support for decision-makers to set up efficient strategies for the optimal energy management in old buildings through a smart transformation of the social buildings and occupant involvement.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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