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Article

Intelligent Reasoning Rules for Home Energy Management (IRRHEM): Algeria Case Study

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Abstract: Algeria is characterized by extreme cold in winter and high heat and humidity in summer. This leads to an increase in the use of electrical appliances, which has a negative impact on electrical energy consumption and its high costs, especially with the high price of electricity in Algeria. In this context, artificial intelligence can help to regulate the daily consumption of electricity, by optimizing the exploitation of natural resources and alerting the individual to avoid energy wasting. This paper proposes a decision-making tool (IRRHEM) for managing electrical energy at smart home. The IRRHEM solution is based on three elements: the use of natural resources, the notification of the inhabitants in case of resources misuse or wasting behavior, and the aggregation of similar activities at same time. Additionally, based on the proposed intelligent reasoning rules, residents' behavior and activities are represented by OWL (Ontology Web Language) and written and executed through SWRL (Semantic Web Rule Language). Finally, the (IRRHEM) solution is tested in a home located in Algiers city inhabited by a family of four persons. The IRRHEM performance evaluation results are very promising and show a 3.60% rate of energy saving.

Keywords: decision-making tool; intelligent reasoning rules; energy saving; energy domain ontology; smart home; protégé software; ontology web language; semantic web rule language

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1. Introduction

A smart home allows its residents to control and manage the different home appliances through the Internet [1]. The first developments in home automation appeared in the 1980s thanks to the reduction of electronic and computer systems [2]. Therefore, the industry has focused its experiments on the development of controllers, interfaces, and tools providing comfort, security, and assistance within a building. Additionally, smart home management systems use several technologies, such as the IoT, cloud computing, Internet, GSM, and GPRS [3,4]. With a smart home, the indoor and outdoor surroundings of the dwelling can be monitored remotely. Recently, thanks to smartphones and the development of new technologies (for instance, apps and connected devices), the installation of smart homes becomes easier as all electrical devices are connected through the Internet.

The term smart energy management has spread in recent years and it is associated with several aspects of life, such as heating, cooling, and lighting systems [5]. This type of management aims to save daily energy consumption through the use of AIT, such as

MAS, and knowledge representation techniques, such as ontology [6–8]. Generally "energy efficiency" is achieved by putting devices into sleep mode or by activating them only when necessary. Electricity bills can be reduced to a much lower level, such as turning off lights when a person can leave the room or adjusting a temperature according to a person's identity or preference. In addition, it becomes possible to track the amount of energy consumed by various appliances at home and obtain forecasts for the future [9]. However, the issue of electric energy has become a priority in most countries due to the increasing need for energy in daily life, as a lot of research has been conducted to find suitable energy management solutions [10]. Some of them have worked to find solutions for energy sources that depend on clean energy sources, such as solar and wind energy [11]. Other research works have taken an interest in moving electricity from the source to the place of storage or consumption, seeking to find the shortest and least wasted electricity distance [12]. Djamel Saba et al. [13] focused on the consumption process by explaining to consumers how to use home appliances, as well as relying on smart solutions for energy consumption.

From an architectural point of view, there are many methods by which we can save more energy at home, whether by insulating the walls and floors, as this process can reduce between 20% and 25% of the heat loss at home [14]. The second method is to use double-glazed windows, as the windows are a major source of heat loss and savings. The third method relates to the use of a shared solar system for heating the water and the house.

In this paper, we focus on the development of an intelligent energy management solution applied to the smart home. This latter is an open and complex system, it includes some geographically distributed elements. In addition, the proposed solution is based on three elements: the first concerns the exploitation of natural resources, the second concerns the correction of occupants' errors and notification of occupants, and the third item concerns the grouping of similar activities at the same period. More precisely, the main contribution of this paper can be summarized in developing a smart solution to choose the most efficient energy sources as well as the best optimization technique that allows obtaining the best configuration of the hybrid energy system.

The remainder of this document includes the energy-saving elements at home in Section 2. Section 3 is reserved to present an IRRHEM design and development. The case study and its simulation are presented in Section 4, followed by the analysis and discussion in Section 5, and, finally, we conclude the paper.

2. IRRHEM Design and Development

In this section, we present the design, the development, and the scenarios on the simulated environment of our IRRHEM proposed method. We begin with a presentation of the used method, followed by a study of the work environment. The results of this study will be used to develop the main elements of ontology (for instance, concepts, relations, and rules of reasoning). The following steps are reserved for editing the ontological data, testing, and validating the ontology. This section ends with the presentation of the scenarios of the simulation of the solution and the display of the results.

2.1. Method Principle

Using the aforementioned elements, such as the building materials or specific electrical devices, energy savings can be obtained, but they remain insufficient, whether due to the random operation of the devices or to errors made by residents. Therefore, it is very important to include automatic or smart solutions to achieve more energy savings. In this context, this research work proposes an intelligent solution based on the ontology of energy and intelligent reasoning rules. Through the interaction between intelligent reasoning rules and the use of information stored in the knowledge base in the form of concepts (objects). It is possible to regulate the use of household appliances, as well as to make the best use of natural resources. Finally, the home occupants can be alerted to organize simultaneously similar activities. To achieve the main objective, which is the ideal saving of electrical energy consumption, a method has been developed, which includes many steps (Figure 1):

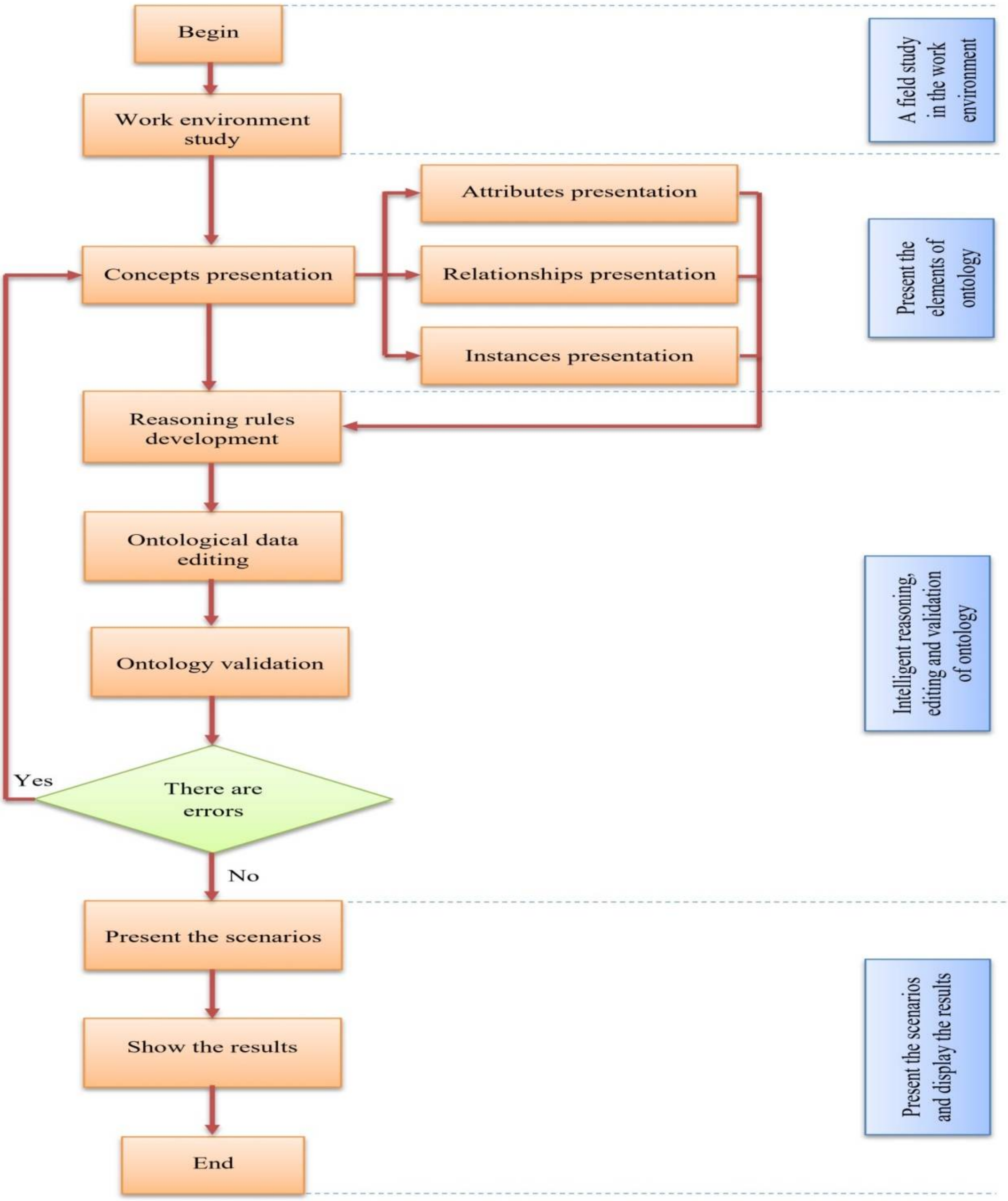

Figure 1. The proposed IRRHEM method.

2.2. Work Environment Study

In this study, the internal environment of the home is affected by many negative aspects that have a direct relationship with the residents, in particular:

- Random setting of the electric air conditioner;
- Leaving the water heater on continuously without setting the timer at night to use it in the morning;
- Not turning off lights when they are not needed, and not using natural light instead of electricity (at specific times of the day);
- Not unplugging electrical devices when not in use;
- Not exploiting renewable energy resources;
- Not using the refrigerator efficiently to avoid wasting electricity, for example, by avoiding continuously opening and closing it so that cold air does not escape;

- χ Not using electric ovens correctly, for example, opening the oven door several times to check the cooking level. It should also be noted that not using utensils that are the same size as the stove, results in heat loss. Finally, a common mistake is not turning off the stove minutes before the end of cooking, although the residual heat after turning it off may be sufficient to complete the food cooking;
- χ Putting hot food in the refrigerator causes an increase in energy consumption;
- χ Keeping a lot of leftover food in the refrigerator may lead to an increase in power consumption;
- χ Cooking food without a "pot" lid, which increases the cooking time and therefore increases the amount of electrical energy consumed;
- χ Using the microwave to boil water instead of an electric kettle, although the first appliance consumes a greater amount of electrical energy compared to the second appliance;
- χ Using the electric cooker instead of the electric kettle because the cooker needs time to heat up also the cooker stays hot for up to twenty minutes even after the task is completed and it is a waste of energy;
- χ Failure to use modern electrical devices that do not require a lot of electrical energy during their operation, as well as not consulting the technical side when purchasing electrical devices (for example, not reading the label of the device, which explains its classification in terms of consumption and energy efficiency);
- χ Frequent use of the hot water cycle and not choosing the cold water cycle over hot water (for example, uncertainty as to operating dishwashers at full capacity);
- χ Not changing the air conditioning filters, because the accumulation of dust in the filters causes the air conditioner to work twice as hard to push in cold air, and therefore the consumption of a greater quantity of electric energy;
- χ Not using LED bulbs that consume less energy;
- χ Operating a clothes dryer instead of drying clothes with natural air and sun, which leads to the additional consumption of electrical energy;
- χ Opening the curtains when the air conditioner is on, causing heat to spread in the room, resulting in an increase in work for the air conditioner and therefore higher energy consumption;
- χ Increasing the temperature of the washing machine, although heating the water does not significantly affect the cleanliness of the clothes;
- χ Failure to reduce the brightness of the TV screen, which may cause the TV to consume more electricity;
- χ Not using thermal insulation in buildings;
- χ Failure to group similar activities at the same time, which causes additional uses of electrical devices and thus the additional consumption of electrical energy;
- χ Not using modern technologies to run the house and energy in particular, such as artificial intelligence techniques, knowledge capitalization tools, and rules-based reasoning tools linked to resident behavior.

After analyzing and studying previous work, the following propositions can be suggested:

- ✓ Air conditioning accounts for about half of the electrical energy consumption in homes. It should be remembered that 24 degrees Celsius is the perfect temperature to balance comfort and energy saving at home [15]. In addition, it is necessary to ensure that the air conditioning system is working efficiently;
- ✓ Instead of letting the water heater run constantly, it is better to turn it on only half an hour before showering, or set the automatic timer switch to heat the water at night, so that the water is ready in the morning [16];
- ✓ Individuals should have an awareness of turning off the lights at home when they do not need them. It is also better to replace traditional lamps with modern ones; of course, it is preferable to use natural light rather than bulbs [17];

- ✓ Freezers and refrigerators must be used efficiently to avoid wasting electricity by avoiding the constant opening and closing of the refrigerator door so that the cold air does not escape;
- ✓ The process of opening the oven door several times to check the cooking stage of the food results in heat escaping from inside the oven. When cooking on the stovetop, it is recommended to use pots of the same size as the stovetop to retain heat. It is also a good idea to reduce the heat so that the food is cooked evenly on all sides and the utensils do not burn. Finally, the stove can be turned off a few minutes before the food is fully cooked, as the heat will continue to cook the food for a while after being turned off;
- ✓ It is important to make sure to buy electrical appliances with low power consumption, and they usually carry the consumption class "A" or "A+", because these appliances are energy efficient [18];
- ✓ Dishwashers use the most energy in a home, so it is important to make sure they are at a full capacity before operating them. It is recommended to not use the hot water cycle and to opt for the cold water cycle. Additionally, it is recommended to use the eco cycle option if the devices are equipped with this function;
- ✓ The use of thermal insulation in buildings, where studies have shown in this regard that the use of insulation in walls and balconies can save up to 60% of electricity, in particular in very hot regions;
- ✓ Use of high-efficiency air conditioning systems [19];
- ✓ Avoid continuously opening the refrigerator or freezer during the day;
- ✓ Closing the blinds when the air conditioner is operating state;
- ✓ Avoid opening the lid of the "pot" while cooking food;
- ✓ Disconnecting electrical appliances when not in use;
- ✓ It is better to use the electric kettle instead of the microwave;
- ✓ Avoid leaving the oven door open, because leaving the oven door open during cooking leads to 50% more loss of electricity cooking;
- ✓ It is not necessary to increase the temperature of the washing machine since heating the water practically does not affect the cleanliness of the clothes. It is best if the temperature is between 30 and 40 degrees Celsius, which saves a lot of energy that the washer uses to heat the water [20];
- ✓ It is important to reduce the brightness of the TV screen, where it is possible to reduce the brightness of the image without affecting its quality. In addition, the bigger the TV screen, the more electricity it consumes, and the lower the picture brightness, the less the energy consumption;
- ✓ Take care to cook with the lid on the pot, as this helps reduce energy consumption. In addition, the size of the utensils used should also be suitable for the size of the meal being cooked;
- ✓ Making sure that the cooling degree of the food in the refrigerator is not more than 7 degrees Celsius and the cooling temperature in the freezer is not more than 18 degrees Celsius [21]. It is also recommended to place these devices in a cool place and avoid placing them next to the oven, dishwasher, or heating devices.

All these proposals are really interesting to achieve energy savings without neglecting the comfort of the inhabitants. However, there are other issues related to the characteristics of forgetfulness and neglect that characterize the individual, which make the implementation of the above suggestions really difficult. On this basis, a suggestion was presented to develop automatic (semi-automatic) and intelligent solutions, and conducted to ensure the completion of the previous proposals. The proposed work is an intelligent solution based on the ontology of energy management. This choice is justifiable due to the nature of the system that is open, complex, and distributed. Then, the system concerned by this study is characterized by a significant informational volume that requires flexibility in the presentation of knowledge of the ontology web language (OWL), which will be exploited to create intelligent reasoning using the semantic web rules language (SWRL). The ontology carried out is applied to a house located in the city of Algiers. Finally, following a comparison between two scenarios of energy consumption, the solution shows their importance from the efficient energy saving viewpoint.

2.3. IRRHEM Architecture

IRRHEM offers an intelligent techniques energy management system based on an Intelligent Context-Awareness Management (Intelligent-CAM). Intelligent-CAM uses contextual awareness ontology and intelligent reasoning to provide contextual information to simulate the behaviors of a population and its surroundings.

From an architectural point of view, the architecture for the IRRHEM system is proposed (Figure 2). IRRHEM is capable of better controlling the home environment (occupants, equipment, and environment), all this is to ensure the main objective that concerns energy optimization. Then, to obtain correct information and make appropriate decisions about current situations, the Intelligent-CAM detects various situations related to the home and its surroundings to provide full Context-Awareness to obtain the minimum number of personnel interventions, as well as avoiding the wastage of energy. Finally, the structure of the proposed solution is formed into seven models, namely:

2.3.1. Data Aggregate Model

This unit receives data from devices and sensors, such as temperature sensors and lights. Moreover, it is responsible for modifying the environmental conditions by sending a command to the operator's infrastructures, such as the switch or any existing services. This unit then sends the data collected from the smart building to the Intelligent-CAM model for processing.

2.3.2. Intelligent CAM Model

This module provides Context-Awareness about what is happening in the smart home. This Context-Awareness is useful for energy efficiency inference techniques to provide the best services at the right time and place. Intelligent-CAM is responsible for managing the Context lifecycle in the IRRHEM system. The context life cycle consists of five phases. The first is "Context acquisition", where contexts need to be obtained from different sources, which may be physical (e.g., physical sensors) or virtual (e.g., virtual sensors and software). The second is "Context-Awareness Constructor", where the collected data must be modeled and represented in a meaningful way. In this section, the ontology technique is used. The third is the "Temporal Context", in which the typical contexts are preprocessed. This step improves the thinking stage and leads to a better result. The fourth is "Context reasoning", where the modeled data needs to be processed to extract new information and generate high-level context information from low-level contextual data. Finally, the "Context dissemination" distributes high- and low-level content text to interested consumers (such as, energy-saving logical engines, user interfaces, or any external services).

2.3.3. Energy Reasoning Engine Model

This is the part of the system that generates conclusions and decisions from the available knowledge about the smart building, and plays an important role in implementing the proposed solution by discovering the causes and contexts of energy waste using a set of smart reasoning rules (presented in the next sections). The first step for this unit is to arrange the positions in descending order. The benefit of this arrangement lies in dealing with the most important and most wasted states of energy. It also provides measures to save energy and eliminate energy waste by using SWRL rules, where those rules are represented as conditional logic. Rulesets can also be managed and applied separately to other functions, and each parent clause association rule can be linked to a list of executable actions.

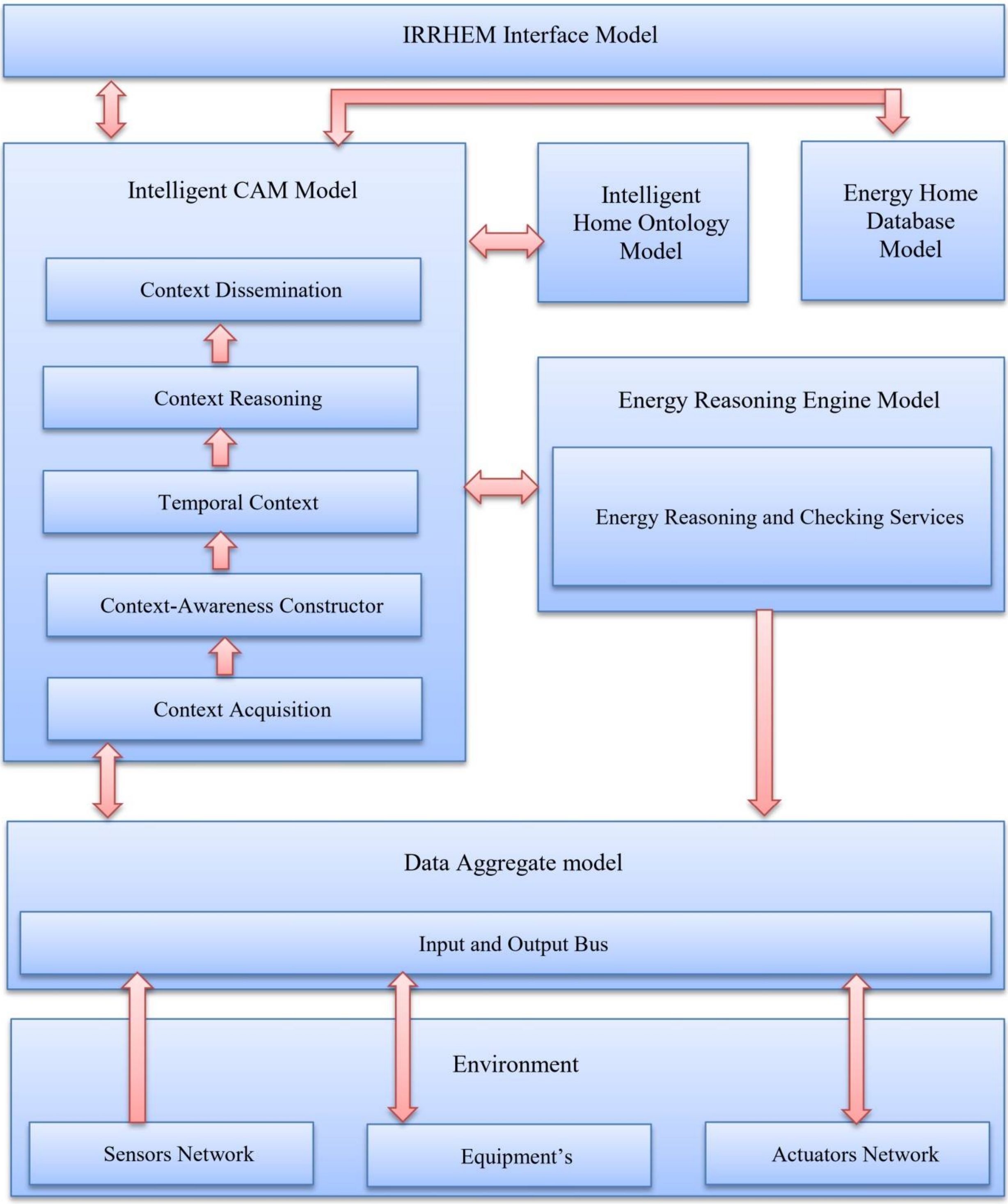

Figure 2. Architecture of IRRHEM.

2.3.4. Intelligent home Ontology Model

Ontology is one of the best tools for representing the field of knowledge, particularly in the management of energy in homes. Many works have been interested in this field, the most important of which are the works of Degha et al., most of which, in their entirety, suggest a structural framework for organizing smart building data [22]. It includes machine-interpretable definitions of the basic concepts of the smart building field and the relationships between them. These works include an important number of concepts, namely human, environment, services, devices, places and Context-Awareness. The ontology-based formal context model can play a vital role in facilitating reasoning by representing the knowledge of the home energy domain. The Semantic Web Rules Language (SWRL) is used, where the rules are applied for different purposes; in addition, the Web Ontology Language (OWL) is used to represent concepts, properties, and relationships. The names of concepts and relationships taken from the ontology (described in detail in the Sections 2.4–2.6) are represented.

2.3.5. Energy Home Database Model

A database is a systematic collection of data to support electronic storage and data processing, and to make data management easier. In this paper, a central database was used to store information about the building, such as hardware statistics, climate information, or any events that occur inside the building. It provides different ways to access the data and history, and it is used to automatically provide services if the same situation is repeated.

2.3.6. IRRHEM Interface Model:

A user interface module is used to interact with users and exchange information. The goal of the user interface design is the ease of use in operating a device or software to achieve the desired result. This generally means that the operator must provide minimum inputs to achieve the desired output in the form of notifications and feedback, and this interface can be a web-based application or the smartphone application.

2.3.7. Home Environment Model

The home environment is a space consisting of a group of objects and programs that interact with each other (for instance, occupants, sensors, actuators, and appliances). The creation of this environment and the selection of its components are carried out according to systematic studies to achieve certain goals, such as saving energy. In general, the elements of this environment belong to the passive category related to constructions and the active category, which pertain to the programs and solutions that apply to the first category of objects.

2.4. IRRHEM Concepts Presentation

An ontology is a formal and explicit representation of knowledge in a given domain (e.g., the home environment), with the aim of efficiently using the data and ensuring flexibility in the sharing and updating of ontologies [23,24]. However, a concept (classes) is the basic element for an ontology; it represents a hardware or software object of the studied environment.

2.4.1. "Call" Concept

There are many similar individuals' activities that can be grouped in a single time (for example, eating meals), so that there is the joint use of devices that consume electricity, and thus benefit from an important energy saving method. It is only a reminder that the process of grouping activities can be carried out without neglecting the comfort of the residents. To ensure the latter, it is necessary to first collect the activities in a unified and short time, and if this process causes harm to an individual, the time is expanded to be slightly longer and therefore electricity consumption can also be obtained, but in a smaller amount than in the first case (Figure 3).

2.4.2. "Sensor" Concept

The "sensor" concept is an essential element of the IRRHEM ontology; it detects the information coming from the physical environment and reacts to it. The information captured can be light, heat, movement, humidity, pressure, or other environmental phenomena (Figure 4). The output is typically a signal that is converted to an operator-readable display at the location of the sensor, or transmitted electronically over a network for reading or processing.

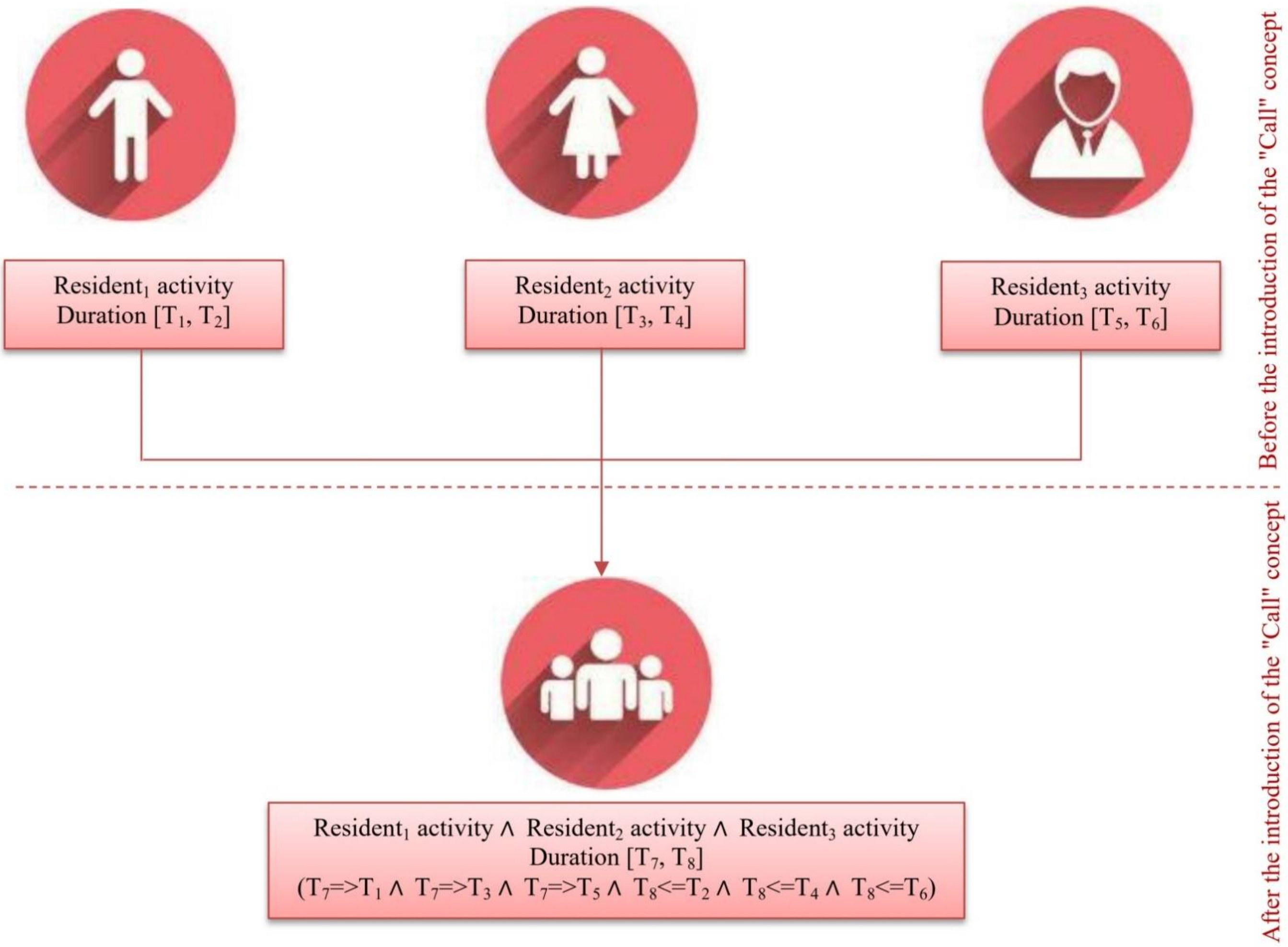

Figure 3. Impact of the introduction of the "Call" concept in IRRHEM.

2.4.3. Other Concepts

The ontology model includes any hierarchy of concepts rooted in the "Home" concept, which represents the residential environment. The model also includes disjoint secondary hierarchies describing the categorizations of subdomain objects of the application domain (such as, sensor, equipment, and activities) (Table 1).

Table 1. IRRHEM concepts.

Concept	Description
Home	Represents the place of residence
Resident	Represents the home resident
TaskResident	Represents the resident task
EquipmentHome	Represents the electrical equipment
ActionEquipment	Represents an action performed by the equipment
BehaviorResident	Represents the resident behavior
WeatherHomeEnvironment	Represents the climate that characterizes a home environment

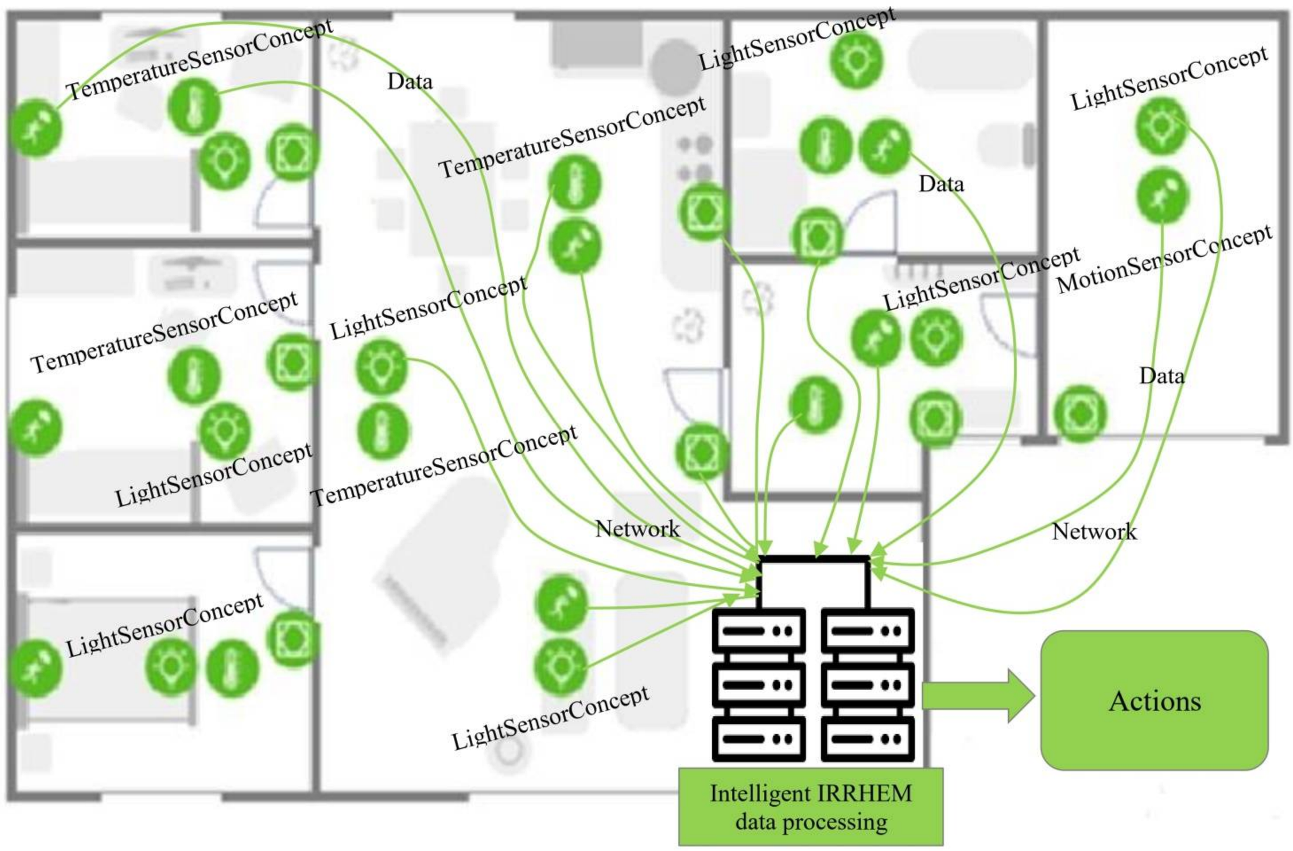

Figure 4. "Sensor" concept architecture in IRRHEM.

2.5. Attributes for IRRHEM Concepts

The attributes or properties are the functionalities, characteristics, or settings that objects can own and share [25]. Each IRRHEM concept includes a set of attributes (Table 2).

Table 2. Some examples of the attributes for IRRHEM concepts.

Attribute	Description	Concept
ResidentName	Resident name	Resident
ResidentProfile	Resident profile	Resident
EquipmentAction	Actions of equipment	EquipmentHome
EquipmentPlace	Place of equipment	EquipmentHome

2.6. IRRHEM Relations

Relationships are the links that objects can have with each other [6]. An ontological relation (hierarchical or descriptive) is a relation linking ontological concepts, constructed from termino-ontological relations, and described in a formal language. A hierarchical relationship expresses an inheritance of the properties of the concept (Table 3).

Table 3. Some examples for IRRHEM relationships.

Relation	Description	Related Concepts
ResidenttHasTask	Everyone at home performs activities	Resident, TaskResident
ResidentHasProfil	Home resident possesses a profile	Resident, ProfileResident
EquipmentHasAction	Equipment can perform actions	EquipmentHome, ActionEquipment
EquipmentHasPlace	Equipment is located in place the of the home	EquipmentHome, PlaceEquipment

2.7. IRRHEM Instances

The use of ontology will depend on the ability to reason about individuals [26]. To achieve this in a beneficial manner, it is necessary to have a mechanism for describing the classes to which individuals belong and the properties they inherit due to their membership in these classes. We can always assert specific properties about individuals, but the great strength of ontologies lies in class-based reasoning. Finally, the extension of the class is the set of individual members of a class (Table 4).

Table 4. Some examples for IRRHEM individuals (instances).

Individual	Concept
TV	EquipmentHome
Refrigerator	EquipmentHome
Living room	Place
Breakfast	TaskResident

2.8. Intelligent Reasoning of IRRHEM

Regardless of the tools, their formalisms, or methods of inference, knowledge-based systems, such as expert systems, are based on a clear separation between knowledge and methods of inference [27]. Thus knowledge, instead of being nested in the structure of the program (such as, the “if . . . then . . . else . . . ” commands of a programming language), is considered as interchangeable data, susceptible to change [28]. It can be corrected, updated, and exploited by programs (inference engines), which simulate reasoning mechanisms and provide the interface with users [29]. Then, in any knowledge-based system or expert system, the following components will be found at the base:

- The knowledge base is domain-specific and, unlike databases, is not limited to factual knowledge, or data [30]. It brings together all the types of knowledge relevant to the domain considered, namely, the description of objects and their relationships (for example, in the form of ontology), rules to be applied to make a diagnosis or solve a problem, and meta-knowledge making it possible to choose which rules apply.
- The system remains at all times, in its working memory, a base of known facts (or instances of ontology). Thanks to it, the inference engine can choose the elements of its knowledge base, for example, the rules to be used effeciently and according to the facts available, and adapted to the problem posed [31]. The fact base grows as the inference engine infers new facts by applying knowledge to the already known facts.
- The inference engine is the program that builds reasoning by drawing its materials from the knowledge base and the fact base. By examining the fact base, it detects interesting knowledge that can be applied to certain facts, connects them, and builds a resolution plan. It deduces new facts from those provided at the start or during the interaction by the user. Independent of the domain, the inference engine brings together the reasoning mechanisms that will exploit the knowledge base.
- To these three essential components are added the interface modules, which are also independent of the field of knowledge. Thanks to them, the expert can easily access the knowledge base, modify it by correcting unnecessary or erroneous information, or by adding precision. The user can follow the reasoning of the system in a language that is natural to him, ask questions, and ask for explanations, without having to acquire in-depth knowledge of expert systems or computing [32].

IRRHEM is based on intelligent reasoning rules formulated by predicate logic and facts, whereby all the rules are loaded for the accomplishment of the tasks (Figures 5–7).

- Rule 1 (R1) is concerned with adjusting the temperature in a specific place at home according to the wishes and the desires of residents. The use of this rule allows the cooling to stop when the temperature becomes less than 28 degrees Celsius.

- Rule 2 (R2) is concerned with adjusting the temperature in a specific place at home according to the residents' desire. The use of this rule allows for the heating system to be stopped when the temperature becomes greater than 29 degrees Celsius.
- Rule 3 (R3) is concerned with adjusting the lighting of a specific place inside the home to benefit from the external lighting, and thus turning off the lamps lead to the gain of a large amount of energy. However, by measuring the internal lighting, estimated at (10), and the external lighting, rated at (50), where we notice strong lighting outside, can be used by opening the windows and curtains.
- For rule 4 (R4), in many cases, the light bulbs are left on despite the absence of people from the home. This rule turns off all the light bulbs, except for the refrigerator, because it contains food items, and a home security camera.
- Rule 5 (R5) is concerned with correcting some negative traits of individuals, such as forgetfulness or neglect. For example, in many cases, electrical appliances are left to operate despite the absence of individuals from the home. In this instance, when people are absent from the home, this rule turns off all the electrical appliances, except for the refrigerator, because it contains food items, and a home protection camera.
- Rule 6 (R6) allows the temperature of a particular place in the house to be adapted according to the wishes of the inhabitant.
- Rule 7 (R7) is related to the process of grouping similar activities of the individuals. In this example, the activity of the individual that takes the least time (50 min) is chosen.

R1: TempSensor(?T) ∧ Equipment- Value(?T, ?V) ∧ swrlb:lessThan(?VAL, 28) ∧ EquipmentLocateInPlace (?Z, ?T) ∧ Cooling-Equipment (?H)∧ EquipmentLocateInPlace (?Z, ?H) ⇨ Equipment-State(?H, "off")

R2: TempSensor(?T) ∧ Equipment-Value(?T, ?VAL) ∧ swrlb:greaterThan(?VAL, 29) ∧ EquipmentLocateInPlace (?Z, ?T) ∧ Heating-Equipment (?H)∧ EquipmentLocateInPlace (?Z, ?H) ⇨ Equipment-State(?H, "off")

R3: illumination_Sensor(?X) ∧ Equipment_location(?X , ?LOC) ∧ swrlb:equal(?LOC, "INDOOR") ∧ Equipment_Values(?X, ?VAL) ∧ (?VAL <= 10) ∧ Illumination_Sensor(?Y) ∧ Equipment_location(?Y , ?LOC2) ∧ swrlb:eqyal(?LOC2, "OUTDOOR") ∧ Equipment_Values(?Y, ?VAL2) ∧ swrlb:greaterThan(?VAL2?,50) ∧ EquipmentHasLocation(?X,?Z) ∧ EquipmentHasLocation(?y,?z) ∧ Illumination(?L) ∧ IlluminationHasLocation(?L,?Z) ∧ Window(?W) ∧ Curtain (?C) ∧ ThingHasLocation(?W,?Z) ∧ ThingHasLocation(?C,?Z) ⇨ Equipment_Stat(?L, "OF") ∧ Window_state(?W,"OPEN") ∧ Curtain_state(?C,"OPEN")

Figure 5. Rules 1–3.

2.9. Ontological Data Editing

In computer science, ontology is a technical term that denotes an artefact designed to be able to model the knowledge of a real or imaginary domain [33]. One of the first objectives of developing ontology is to share the same understanding of the structure of information between people. There are different reasons why it is necessary to develop ontology [34]:

- Allow the reuse of knowledge in a field;
- Make explicit the hypotheses of a domain;
- Separate domain knowledge from operational knowledge;
- Analyze the knowledge of a domain;

- Facilitate the interoperability between two systems;
- Ensure the reliability of knowledge;
- Facilitate the communication between users.

R4: Moving-Sensor (?X) ∧ Equipment-State (?X , ?STAT) ∧ swrlb :equal (?STAT , "ON") ∧ Equipment -Value (?X , ?VAL) ∧ swrlb:equal (?VAL , "0") ∧ EquipmentLocateInPlace (?X , ?Z) ∧ EquipmentLocateInPlace (?L , ?Z) ∧ Place (?Z) ∧ Light(?L) ∧ Equipment-State (?L , ?STAT 2) ∧ swrlb :equal (?STAT 2, "ON ") ∧ Fridge-Equipment (?F)∧ Camera-Equipment (?C) ⇨ Equipment-State (?L , "OF") ∧ Turn - Of (?L) ∧ Equipment-State (?F , "ON") ∧ Equipment-State (?C , "ON")
R5: Moving-Sensor(?X) ∧ Equipment-State(?X, ?STAT) ∧ swrlb:equal(?STAT, "TRUE") ∧ Equipment-Value(?X, ?VAL) ∧ swrlb:equal(?VAL, "0") ∧ EquipmentLocateInPlace(?Z, ?X) ∧ EquipmentLocateInPlace(?Z, ?L) ∧ Equipment(?L) ∧ Equipment-State(?L, ?STAT2) ∧ swrlb:equal(?STAT2, "ON") ∧ Fridge-Equipment (?F)∧ Camera-Equipment (?C) ⇨ Equipment-State(?L, "OFF") ∧ Equipment-State (?F , "ON") ∧ Equipment-State (?C , "ON")

Figure 6. Rule 4 and Rule 5.

R6: Place(?P) ∧ Place-Is-Owned-By-Person(?P, ?H) ∧ Human(?H) ∧ Zone-Has-Devices(?P, ?T) ∧TemperatureSensor(?T) ∧ Equipment-Values(?T, ?VAL1) ∧ Human-Has-Behaviors(?H, ?B) ∧ BehaviorsTemperatureLike(?B) ∧ BehaviorsTemperatureVal(?B,?VAL2) ∧ swrlb:greaterThan(?VAL1,?VAL2) ∧ Place -Has-Equipment(?P,?C) ∧ Cooling(?C) ⇨ Equipment - State(?C ,"ON") ∧ Equipment-Values(?C,?VAL 2)
R7: Resident (?R) ∧ Profil (?P) ∧ Task (?T) ∧ DurationTask (?DA) ∧ hasValue (?DA, ?DAV) ∧ swrlb : greater than or equal (?DAV, "50") ⇨ choice (?DAV)

Figure 7. Rule 6 and Rule 7.

There are many free editors, such as Protégé 3.5, SWOOP, Ontolingua, KMgen, IsaViz, and DOE. In this category of publishers, the best known and the most used is Protégé. It is an open-source tool developed by Stanford University [35]. Since its first version, it has significantly evolved and continues to evolve rapidly (Figure 8).

The "Protégé" software is employed to edit and read the "IRRHEM" ontology, where all hierarchical categories are created for each concept with its properties and relationships. Intelligent thinking rules are also an important part of implementing the proposed solution, as additional components are used, such as SWRLTab for Protégé 3.5, which provides the SWRL and SQWRL rule execution environment [36]. The next step is to use the debugger in "Protégé" to check the correctness and consistency of the information entered in the previous stages. In addition to that, we relied on previous ontology solutions, through the process of importing them, which allowed us to save a lot of time and effort. Finally, the language "JAVA", can be used to develop IRRHEM modules.

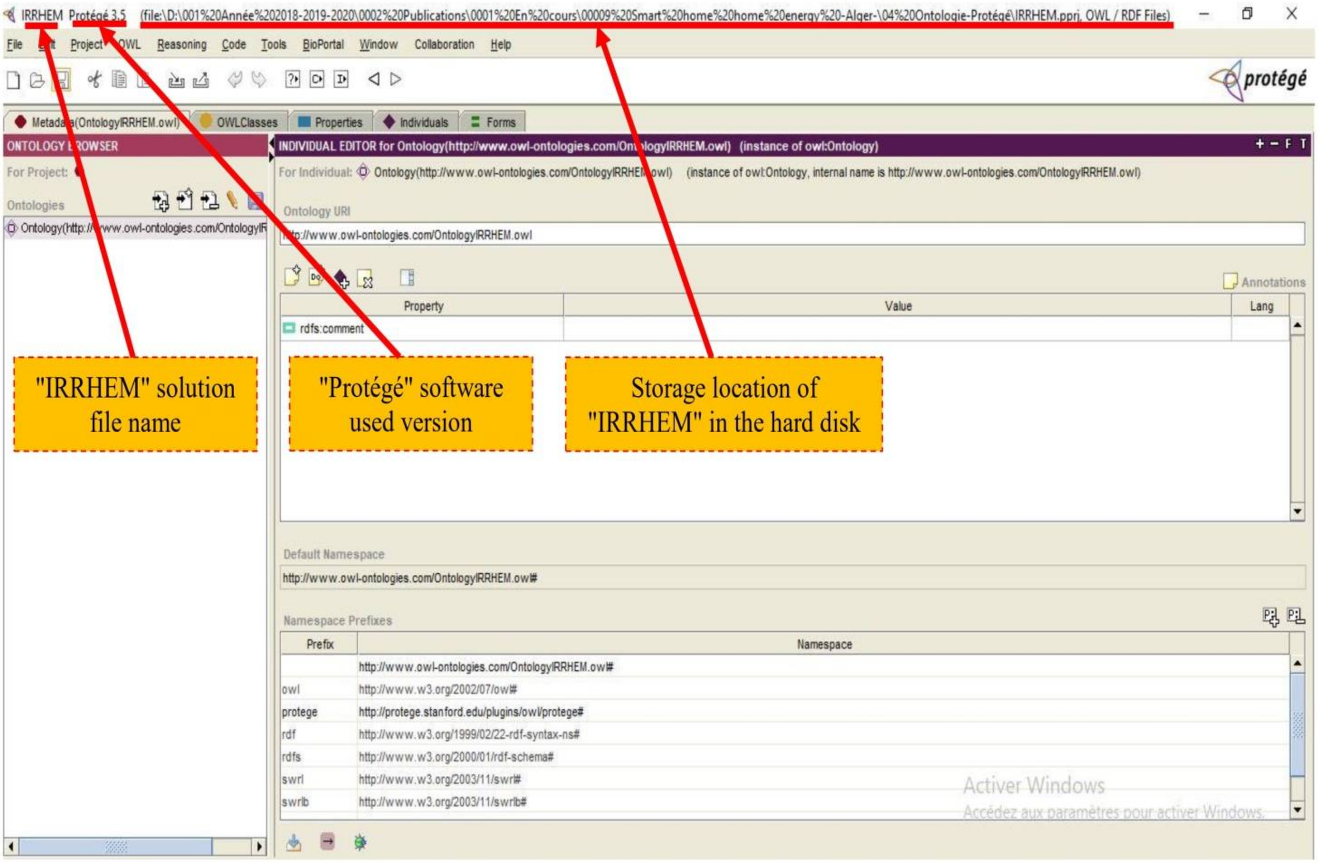

Figure 8. Editor "Protégé" graphical interfaces.

In the first step, the concepts of IRRHEM are introduced. The following steps concern editing the relationships and instances. The final step concerns the editing of the intelligent reasoning rules.

3. Case Study and Simulation

It is important to present the elements that are directly related to the consumption of electrical energy in a home, such as climatic data, household appliances, and the activities of residents. Then, to know the importance of the proposed solution (IRRHEM), two energy consumption scenarios are presented (with and without the intervention of the proposed solution).

3.1. Presentation of the IRRHEM Environment

The energy consumption scenarios were carried out on a family house located in the city of Algiers in Algeria. Algiers is located in the north-center of the country and occupies an interesting geostrategic position, both from the point of view of economic flows and exchanges with the rest of the world, and from a geopolitical point of view. It extends over more than 809 km^2. The city of Algiers is bounded to the north by the Mediterranean Sea with a coastline of 80 km, to the south by the Blida city, and to the west and east by the cities of Tipaza and Boumerdes, respectively [37] (Figure 9). It is characterized by a latitude of 36°45′08″ N, a longitude of 3°02′31″ E, and an elevation above sea level of 186 m. The home in the study was inhabited by a family of four members (a father, mother, boy, and girl) (Table 5).

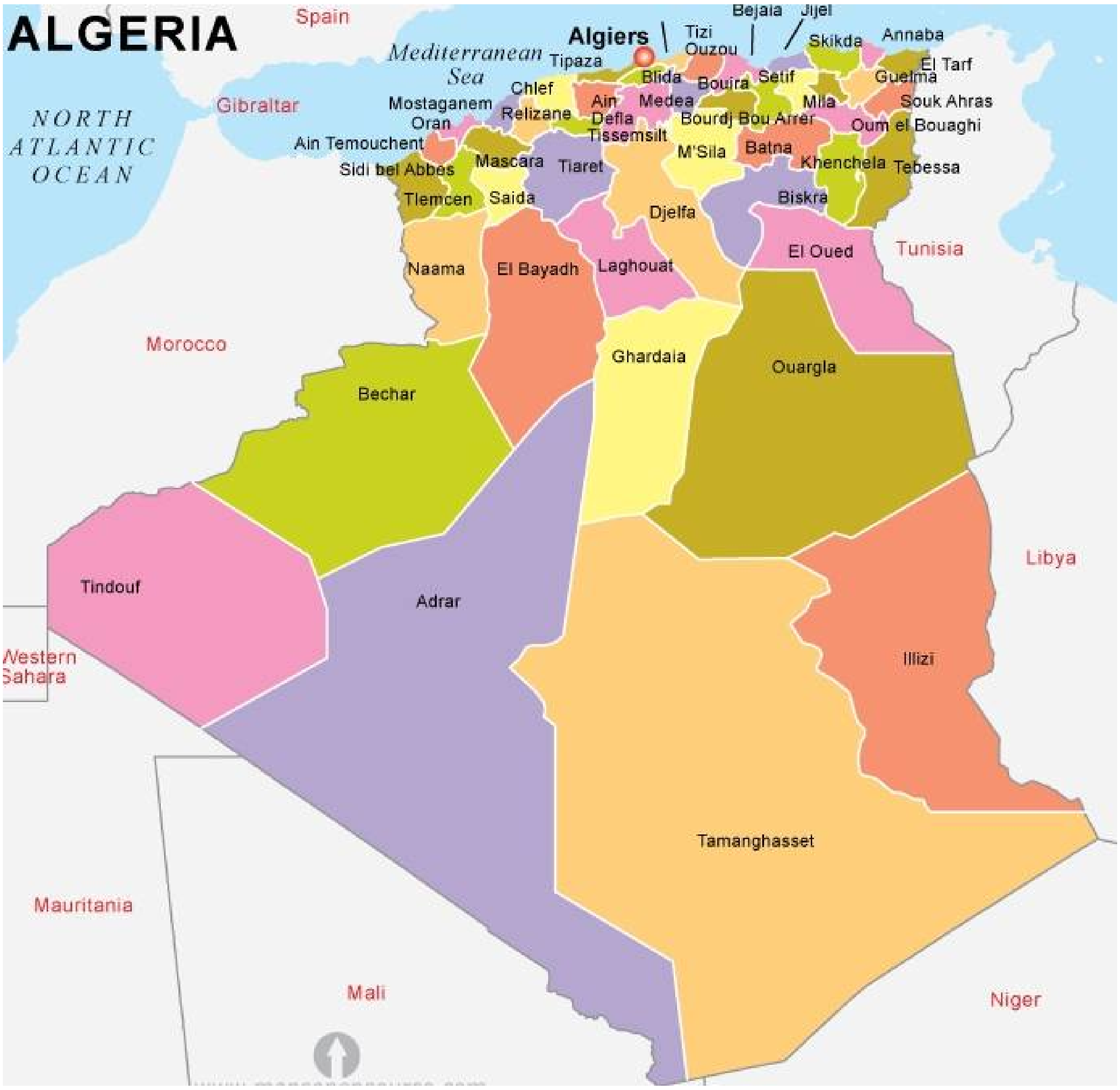

Figure 9. Geographic map of Algiers city [38].

The climate in Algiers is warm and temperate. In winter, the rains are much more important in the city of Algiers than they are in summer. The annual average temperature in the city of Algiers is 18.2 °C. The mean annual precipitation is 615 mm. The driest month is July, with an average of 1 mm of rain. In addition, the record precipitation level is recorded in November with an average of 94 mm of rain. The warmest month of the year is August with an average temperature of 26.7 °C. The coldest month of the year is January with an average temperature of 11.0 °C. The difference in precipitation between the driest and wettest months is 93 mm. A variation of 15.7 °C is recorded over the year [39].

The family home contains a set of appliances that depend on electrical energy to operate. Table 6 presents a number of electrical appliances, their electricity consumption characteristics, and their location.

3.2. IRRHEM Scenarios

To know the effectiveness of IRRHEM, two scenarios were proposed: the first without the intervention of IRRHEM (electricity consumption in a normal state) and the second deals with the electricity consumption with the intervention of IRRHEM. In addition, 1 May

2020, was selected to test IRRHEM. To measure the amount of energy consumed during that day, we divided that day into units of time of one hour.

Table 5. Family members concerned with the study.

Family Member	Age	Function	Preference	Event/Activity
Father	45	Employee	• 25 °C ≤ Temperature ≤ 28 °C • Illumination ≥ 20 Linux	• Sleeping • Waking up from sleep • Going to the bathroom • Going to the bathroom
Mother	40	Housewife	• 21 °C ≤ Temperature ≤ 26 °C Illumination ≥ 20 Linux	• Sleeping • Fajr prayer • Reading the Koran • House cleaning
Boy	16	High school student	• 27 °C ≤ Temperature ≤ 29 °C Illumination ≥ 15 Linux	• Sleeping • At school • Returning from school and going to the dining room
Girl	13	A student in middle school	• 27 °C ≤ Temperature: ≤ 30 °C Illumination ≥ 15 Linux	• Sleeping • At school • Going to the kitchen

Table 6. Electrical equipment.

Place	Electrical Equipment	Number (N)	Power (P_{ap})
Bathroom	Electric water boiler	1	1800
	Washing machine	1	240
	Economic lamp	2	25
Hall	Economic lamp	3	25
Living room	Air conditioner (8000 BTU)	1	900
	Economic lamp	3	25
	Home internet router	1	7
Kitchen	Refrigerator combi (250 L)	1	175
	Economic lamp	2	25
	Microwave	1	1125
Garage	Camera	1	20
	Electric car	1	3000
	Economic lamp	4	25
Room	Air conditioner (6000 BTU)	1	700
	Iron	1	800
	Economic lamp	2	25

3.2.1. First Scenario (Without IRRHEM Intervention)

The amount of energy consumed is directly related to the activities of family members, thanks to which it is possible to know the electrical devices used. What distinguishes the energy consumption in this scenario is the presence of many disadvantages, such as the non-exploitation of natural resources (e.g., sunlight) as well as the random exploitation of electrical devices (Tables 7 and 8). Additionally, to calculate the energy consumption (P_{ap} (W)) by family members over a period (T (hours)), there are mathematical formulas in the literature such as:

$$E_{ap}(Wh) = P_{ap}.T \quad (1)$$

It is also possible to calculate the energy consumed by a number of devices of the same type using the following rule:

$$E_{apt}(Wh) = E_{ap}.N \quad (2)$$

The total power is calculated by the following mathematical rule:

$$E_t(Wh) = \sum_{i=1}^{n} E_{apt}(i) \quad (3)$$

where "i" is the equipment type.

The average values of the climate data in the period from 00 h: 00 m: 00 s to 00 h: 59 m: 59 s are: horizontal radiation (W/m^2) 0, temperature 20 °C, and humidity 65% [40].

The average values of the climate data in the period from 11 h: 00 m: 00 s to 11 h: 59 m: 59 s are: horizontal radiation (W/m^2) 0, temperature 29 °C, and humidity 80% [40].

3.2.2. Second Scenario (With IRRHEM Intervention)

Table 9 presents the results related to the IRRHEM intervention. These results are based on the rules of intelligent thinking.

Table 7. Energy consumption scenario in the period: 01 h: 00 m: 00 s to 01 h: 59 m: 59 s.

Time (h, m, s)	Family Member	Place	Event/Activity	Action	Equipment in Operation	Number (N)	Operating Time (Minutes)	Power (W)	Energy Consumed by Event (W)	Energy Consumed per Hour (W)
00 h:00 m:00 s–00 h:59 m:59 s	Father Mother	Bedroom Bedroom	Sleeping Sleeping	Nothing Nothing	Air conditioner (6000 BTU)	1	60	700	700	2205
	Boy	Room 2	Sleeping	Nothing	Air conditioner (6000 BTU)	1	60	700	700	
	Girl	Room 3	Sleeping	Nothing	Air conditioner (6000 BTU)	1	60	700	700	
	/	/	/	/	Refrigerator combi (250 L)	1	60	170	170	
	/	/	/	/	Camera	1	60	20	20	
	/	/	/	/	Intercom	1	60	40	40	
	/	/	/	/	Light (outside)	2	60	25	50	

- In the periods from 00 h: 00 min: 00 s to 01 h: 00 min: 00 s and from 01 h: 00 min: 00 s to 02 h: 00 min: 00 s, there is no activity for all family members, and therefore it is impossibile to apply the rules of intelligent reasoning (because the execution of the solution rules is linked mainly to the activity of individuals and the mistakes they commit).
- In the periods from 05 h: 00 min: 00 s to 06 h: 00 min: 00 s and from 06 h: 00 min: 00 s to 07 h: 00 min: 00 s, energy savings of 1225 watts and 1341.67 watts, respectively, were observed through the intervention of rule "R1", which relates to switching off refrigeration equipment; rule "R4", which relates to switching off electrical equipment (except for the appliances that are necessary to operate constantly, such as refrigerators and security equipment); rule "R5", which relates to correcting the mistakes committed and forgetfulness that characterize the family members of the home in many cases; rule "R6", which relates to the process of air-conditioning or heating a room in the home according to personal choice; and rule "R7", which relates to the process grouping the similar activities of the family members.

- From 07 h: 00 min: 00 s to 08 h: 00 min: 00 s, there is an energy-saving amount of 1395 watts, through the intervention of rule "R1", the turning off of cooling equipment; rule "R3", the adjusting of indoor lighting according to the availability of light outside the home; rule "R4", the turning off of electrical equipment when a room is absent of family members; rule "R5", related to correcting errors and forgetfulness that characterizes the members of the home; rule "R6", hich relates to adjusting the air conditioning according to individual preference; and rule "R7", which relates to grouping the similar activities of the members of the home.
- In the periods from 09 h: 00 min: 00 s to 10 h: 00 min: 00 s and from 11 h: 00 min: 00 s to 12 h: 00 min: 00 s, energy savings of 16.6 watts and 108.33 watts, respectively, were observed through the intervention of rule "R3", related to adjusting the lighting of a place in the home by taking advantage of external light; rule "R4", related to turning off electrical equipment (except for some equipment); rule "R5", related to correcting some negative characteristics of the family members, such as forgetfulness; and rule "R7", regarding the grouping of similar activities of individuals.
- In the periods from 12 h: 00 min: 00 s to 13 h: 00 min: 00 s, 15 h: 00 min: 00 s to 16 h: 00 min: 00 s, 16 h: 00 min: 00 s to 17 h: 00 min: 00 s, 17 h: 00 min: 00 s to 18 h: 00 min: 00 s, and 18 h: 00 min: 00 s to 19 h: 00 min: 00 s, energy-saving figures of 8.33 watts, 54.17 watts, 66.17 watts, 8.33 watts, and 8.33 watts, respectively, are observed through the intervention of rule "R3", which relates to the optimum use of sunlight for room lighting; rule "R4", which concerns the switching off of electrical equipment in the case of the absence of family members in the room; and rule "R5", related to correcting some errors committed by the family members, such as operating some devices without using them, or forgetting about a device that is in use state.

Table 8. Energy consumption scenario in the period: 11 h: 00 m: 00 s to 11 h: 59 m: 59 s.

Time (h, min, s)	Family Member	Place	Event–Activity	Action	Equipment in Operation	Number (N)	Operating Time (Minutes)	Power (W)	Energy Consumed by Event (W)	Energy Consumed per Hour (W)
11 h:00 m:00 s–11 h:59 m:59 s	Father	Out of the house	/	/	/	0	0	0	0	367.50
	Mother	Kitchen	He is out of the house (at work)	Lunch	Light_Kitchen	2	45	25	37.50	
		Dining room	Going to the kitchen	Lunch	Light_DiningRoom	2	15	25	12.50	
	Boy	Dining room	Returning from school and going to the dining room	Lunch	Light_DiningRoom	2	10	15	8.33	
		Room 2	Going to Room 2	Preparation of homework	Light_Room2	2	15	25	12.50	
					Laptop	1	35	50	29.17	
	Girl	Dining room	Returning from school and going to the dining room	Lunch	Light_DiningRoom	2	15	25	12.50	
		Room 3	Going to Room 3	Preparation of homework	Light_Room3	2	30	25	25.00	
	/	/	/	/	Refrigerator combi (250 L)	1	60	170	170	
	/	/	/	/	Camera	1	60	20	20	
	/	/	/	/	Intercom	1	60	40	40	
	/	/	/	/	Light (outside)	0	60	25	0	

Table 9. The obtained results using IRRHEM intervention.

Time (h, min, s)	Energy Consumption without IRRHEM Intervention (W)	Energy Consumption with IRRHEM Intervention (W)	Energy Saved (W)	Rules Used by IRRHEM
00 h: 00 min: 00 s–01 h: 00 min: 00 s	2380.00	2380.00	0.00	/
01 h: 00 min: 00 s–02 h: 00 min: 00 s	2205.00	2205.00	0.00	/
…	…	…	…	…
05 h: 00 min: 00 s–06 h: 00 min: 00 s	1505.00	280.00	1225.00	R1, R4–R7
06 h: 00 min: 00 s–07 h: 00 min: 00 s	2365.00	1023.33	1341.67	R1, R4–R7
07 h: 00 min: 00 s–08 h: 00 min: 00 s	1625.00	230.00	1395.00	R1, R3–R7
08 h: 00 min: 00 s–09 h: 00 min: 00 s	396. 67	396.67	0.00	/
09 h: 00 min: 00 s–10 h: 00 min: 00 s	1231.67	1215.00	16.67	R3–R5, R7
10 h: 00 min: 00 s–11 h: 00 min: 00 s	535.00	535.00	0.00	/
11 h: 00 min: 00 s–12 h: 00 min: 00 s	367.50	259.17	108.33	R3–R5, R7
12 h: 00 min: 00 s–13 h: 00 min: 00 s	1138.33	1130.00	8.33	R3–R5
13 h: 00 min: 00 s–14 h: 00 min: 00 s	930.00	930.00	0.00	/
14 h: 00 min: 00 s–15 h: 00 min: 00 s	230.00	230.00	0.00	/
15 h: 00 min: 00 s–16 h: 00 min: 00 s	2796.67	2742.50	54.17	R3–R5
16 h: 00 min: 00 s–17 h: 00 min: 00 s	1221.67	1155.00	66.67	R3–R5
17 h: 00 min: 00 s–18 h: 00 min: 00 s	238.33	230.00	8.33	R3–R5
18 h: 00 min: 00 s–19 h: 00 min: 00 s	238.33	230.00	8.33	R3–R5
…	…	…	…	…
22 h: 00 min: 00 s–23 h: 00 min: 00 s	84,980.00	84,980.00	0.00	/
23 h: 00 min: 00 s–00 h: 00 min: 00 s	2380.00	2380.00	0.00	/

4. Analysis and Discussion

Through the obtained results, it can be seen that the value of the energy consumed by the IRRHEM solution intervention is less than or equal to the value of the energy consumed without the intervention of this solution, which proves the IRRHEM solution efficiency in many cases, including (Figure 10):

- Energy savings of 81.39% and 56.73% are obtained during the periods of 05 h: 00 min: 00 s to 06 h: 00 min: 00 s and from 06 h: 00 min: 00 s to 07 h: 00 min: 00 s, respectively, based on:
  - Turning off the “air conditioner 6000 BTU” in the parent’s room;
  - Turning off the “air conditioner 6000 BTU” in the boy’s room;
  - Turning off the “air conditioner 6000 BTU” in the girl’s room;
  - Switching off all the electrical equipment in the event of the absence of occupants;

- Contributing to the correction of negative characteristics of the family members, such as making mistakes in the use of electrical equipment, as well as forgetting to turn off equipment that is in a working state and not in use;
- Adapting the rooms of the home according to the family members' wishes;
- Grouping similar activities for adapting the rooms of the home according to the wishes of members (for example, "Fajr" prayer in congregation).

- Energy savings of 85.84% were obtained during the period of 07 h: 00 min: 00 s to 08 h: 00 min: 00 s, based on:
  - Turning off the "air conditioner 6000 BTU" in the rooms of the parents, boy, and girl;
  - Turning off the electric light bulbs in the rooms of the home (except in special cases) and taking advantage of the sunlight coming from outside of the house;
  - When the family members are absent from a room, all electrical equipment is turned off (except in special cases, such as the refrigerator or security equipment);
  - Correcting some negative actions of individuals, such as leaving a device running without it being needed, or forgetting to turn off a working device. In addition, through this solution, a room in the home can be adapted according to the personal preferences of the individuals, and also the similar activities of family members can be grouped together to be conducted at the same time (for example, the activity of eating meals together).
- Energy savings of 1.34% and 29.47% were obtained during the periods of 09 h: 00 min: 00 s to 10 h: 00 min: 00 s and from 11 h: 00 min: 00 s to 12 h: 00 min: 00 s, respectively, based on:
  - Exploiting the external lighting by opening windows and curtains and turning off some (or all) of the lights bulbs;
  - Turning off electrical equipment in the absence of family members. This solution also addresses the case of an individual forgetting or operating equipment without exploiting it. Finally, this solution aggregates the similar activities of family members, simultaneously.
- Energy savings of 0.73%, 1.93%, 5.45%, 3.49%, and 3.49% were obtained during the periods of 12 h: 00 min: 00 s to 13 h: 00 min: 00 s, 15 h: 00 min: 00 s to 16 h: 00 min: 00 s, 16 h: 00 min: 00 s to 17 h: 00 min: 00 s, 17 h: 00 min: 00 s to 18 h: 00 min: 00 s, and from 18 h: 00 min: 00 s to 19 h: 00 min: 00 s, respectively, based on:
  - Turning off some or all of the light bulbs by taking advantage of the sunlight;
  - In case of the absence of all peoples from a room, the proposed solution take the turning off of electrical appliances (except for some appliances, such as refrigerators and security equipment);
  - Correcting some errors committed in the exploitation of electrical equipment, as well as cases of forgetfulness.

The employment of the IRRHEM solution in different regions results in energy-saving that differs from one region to another. Even if this solution is applied to the same family, we logically obtain different rates of energy consumption; this is due to three main reasons. The first is the climatic factor, which has a great impact on energy saving, thanks to the optimal exploitation of natural resources, such as temperature, lighting, wind. The second factor focuses on home construction that concerns several points, such as home orientation, the quality of the materials used in the construction, and home architecture. Finally, the factor linked to the habits, cultures, and activities of residents also has a significant impact on energy saving. However, for the IRRHEM solution to be universally applied in different regions, a good design of the following elements is necessary:

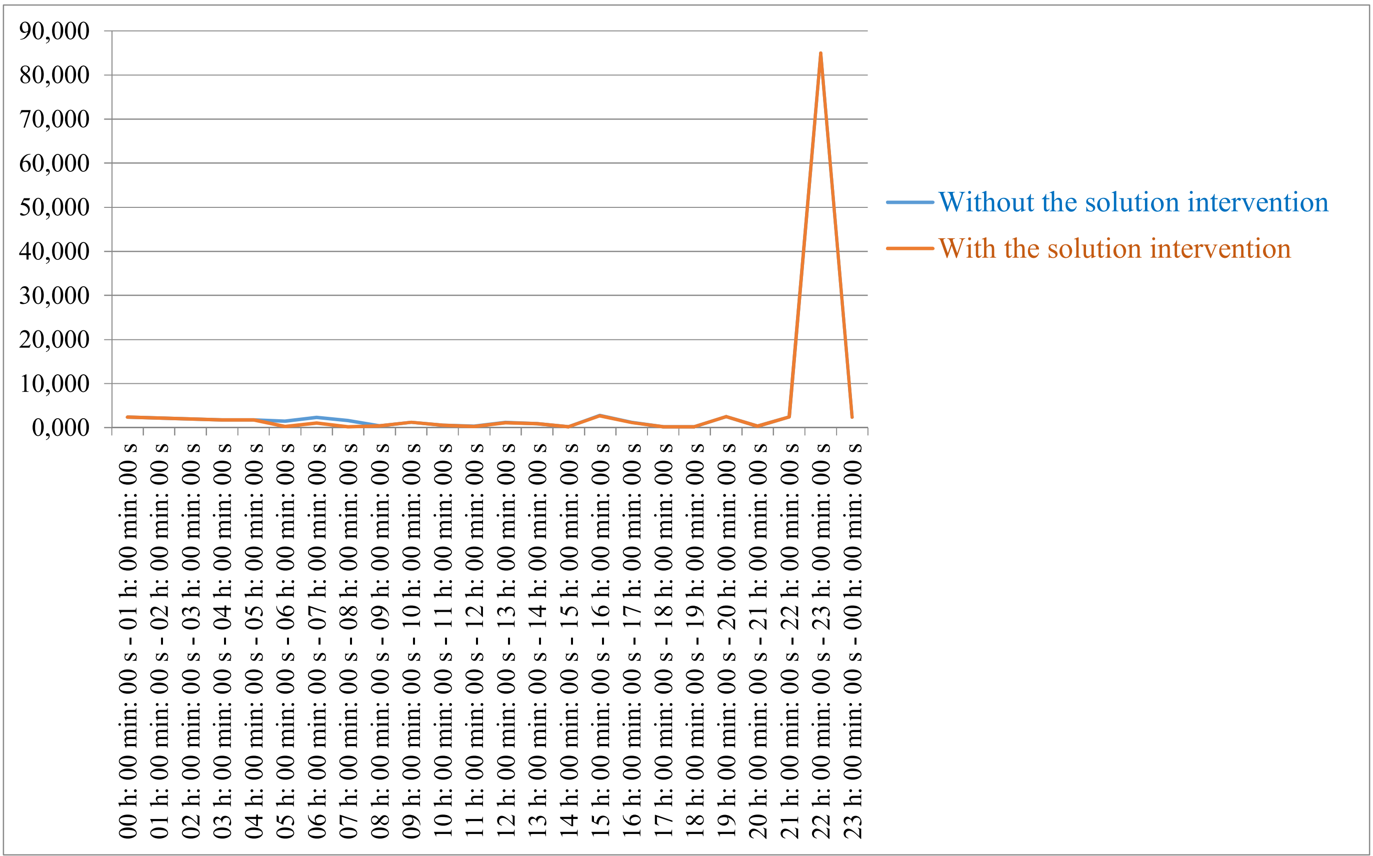

Figure 10. Energy consumption with and without the IRRHEM intervention.

- Profile: this concept is used to provide an explicit representation of many elements of a smart home in a structured information model. In the IRRHEM solution, the profile concept is divided into several subcategories to describe each concept in a particular category as "ResidentProfile" for "Resident". In addition, this concept is very important and used for several purposes, such as increasing the comfort of the residents and meeting the needs of the residents. Additionally, the category of the profile concerns the "Home" concept that is considered as the starting point for all other concepts, since this concept contains properties or information to describe the smart home, such as: "HomeID", "HomeLocation", and "HomeSurfaceSize".
- Activity scheduling: this concept presents a passive approach to energy efficiency based on determining the optimal schedule for resident activities. It is characterized by several advantages, among which is the optimization of energy consumption.

An important point that characterizes this solution concerns the possibility of extending this solution to future works (the flexibility in updating or exporting the ontology of this solution to develop others), due to the use of the ontological approach, where the latter presents one of the main reasons for choosing this approach.

5. Conclusions

Home automation is the binding between the various devices and systems at home, so that they can all be controlled from anywhere, and the interaction required between them. The intelligent system controls aspects such as lighting, heating, ventilation, air conditioning, safety, security, and energy-saving. The latter is the main objective of the IRRHEM solution.

To accomplish the IRRHEM solution, an energy ontology approach was chosen. This choice is linked to the nature of domestic systems, which are characterized by their possession of a large volume of information, mainly related to family members, household appliances, and climatic data. Therefore, to develop IRRHEM, a series of steps was followed. The first step concerned a detailed study on the home environment; the results of this step were used to build the conceptual model of the data. This model was edited using the "Protégé" software and syntactically checked. The last step concerned the test of the IRRHEM solution using two scenarios (with or without the IRRHEM solution intervention). The results obtained show the importance of IRRHEM by saving 3.60% of energy. In addition, IRRHEM made it possible to perform a set of actions, such as turning off electrical appliances without reducing the comfort of the residents of the home. Additionally, IRRHEM made it possible to:

- ✓ Group the residents' activities to one time period, which allows for the saving of a large amount of electrical energy through the unified use of electrical appliances;
- ✓ Switch off the heating systems (or switch on), according to the outside temperature and the preference of the residents;
- ✓ Switch off the cooling systems (or switch on), according to the outside temperature without neglecting the home residents' comfort;
- ✓ Open and close the windows, curtains, and doors to take advantage of the outdoor climate (sunlight, heat, and air);
- ✓ Turn off the lights in a certain area of the house (or all lights) when the residents of the house are away from that area (or the whole house);
- ✓ Turn off all the appliances in the house, except certain appliances, such as the refrigerator and protective devices, if all the residents are absent from the house.

In addition, among the advantages of the IRRHEM solution is the flexibility to use and update the knowledge base. Finally, the future works can be scheduled as follows:

- χ With the development of technology, especially for household appliances, it is important to update the information of the knowledge base;
- χ Take into account untreated cases, such as the operation of the cooling and heating system, before entering the house;
- χ Integrating renewable energies sources (such as, solar and wind) at home.

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