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Artificial Intelligence Protocols for Improving Efficiency and Sustainability in Energy Processes

Carlos Armenta-Deu*

Facultad de Físicas. Universidad Complutense, 28040 Madrid (Spain)

***Corresponding Author**
Carlos Armenta-Deu, Facultad de Físicas. Universidad Complutense, 28040 Madrid (Spain).

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Abstract
This work aims to develop a new protocol for improving sustainability in current applications like household heating, air conditioning, and sanitary water use. The paper introduces a new protocol focused on reducing energy consumption, improving energy conversion process efficiency, and minimizing carbon emissions. The developed protocols apply to three relevant topics: energy management, water heating, and space conditioning in the domestic sector. The methodology focuses on saving energy without reducing performance by developing a specific protocol for the three analyzed topics. Experimental tests prove the protocol's validity in household facilities. Tests running under variable conditions show an energy consumption reduction between 39.6% and 52.3%, depending on operating conditions. Experimental tests for two consecutive years with alternating operational modes, AIP and conventional, show a high agreement between current data and expected values, with 98% accuracy. The reduction in carbon emissions is between 397.4 and 660.5 kilograms per year, depending on the appliance use. The obtained results from the proposed protocol application improve the sustainability, proving the beneficial effects of the applied methodology.

Keywords: Artificial Intelligence Protocol, Control System, Sustainability, Energy saving, Carbon emissions, Efficiency

1. Introduction

In present days, the transition to a more respectful energy use with the environment requires the implementation of green and renewable energy sources to reduce fossil fuel dependence and minimize carbon emissions [1-4]. Thermal power plant replacement with renewable energies for heavy industry, aircraft, trains, and high-capacity transport vehicles is difficult due to the low energy density, intermittency, and variability of the natural power sources [5-8]. Renewable energies are a perfect fit for domestic applications and private transportation [9-13]. These settings don't demand a powerful energy source, and we can easily manage any intermittency and variability with small storage units [14-18].

The continuous population growth and the improvement in the standard of living lead to an energy demand increase, representing a challenge for the renewable energies sector [19-22]. Modern policies trying to implement the energy transition at a fast rate represent a problem for the new energy mix people acceptance [23-27]. The false expectation of full energy demand coverage by renewable energies increases the population's reluctance to adopt a more sustainable energy policy [28-31]. People used to get easy access to energy without constraints are not prone to accept restrictions due to the renewable energy's limitations, perceiving that new power source implementation will reduce their standard of living.

The complete energy demand coverage factor derives from appropriate design and adequate planning of human activities if renewable energies are the principal or unique household power source [32-35]. While the grid supplies all the required energy within the limitation forced by the maximum contracted power, the renewable facility has the limit imposed by the natural resource [36-38]. In the case of solar thermal, photovoltaic, wind, geothermal, or any other renewable power source, the available surface limits the maximum power supply in domestic facilities, representing a barrier for household inhabitants to decide on a change [39-40].

Another problem that creates a barrier to using renewable energies in the domestic sector is the request for more powerful household appliances [41-42]. Indeed, in modern society, people's attitudes toward current activities have changed from past times. Today, people do things at a fast rate since we consider developing activities at a low rate to be a waste of time [43-44]; therefore, we ask for power systems that reduce the time used for developing daily activities like ironing, dish and clothes washing, recharging mobile phones, and some others.

This work gives directions through a detailed protocol to avoid excessive energy use in current applications, like house heating and air conditioning. The proposed protocol reduces fuel consumption and contributes to a more sustainable society. The paper describes current practices and how to focus them from a more conservative point of view without reducing performance, security, or comfort.

1.1 Fundamentals

Energy use depends on power and time; therefore, power should increase proportionally to maintain energy when time reduces. In applications connected to the grid, power is a factor of minor importance since the consumer may ask for an increase in power supply by simply modifying the limited client power contracted with the electric distribution company. This easy process only requires a change in the installed limit power device [45-47]. In this way, the client automatically increases the Maximum Import Capacity (MIC) associated with the facility [48].

In domestic renewable energy systems, the problem is more difficult to solve since the input power depends on the installation characteristics, number and unitary power of PV panels or wind turbines, size of the geothermal installation, and biomass system capacity, only to mention some of the renewable energy systems that may power a domestic facility. Power generation change means modifying the system layout, adding new elements, PV panels, wind turbines, or enlarging the geothermal or biomass system capacity, which in most cases is not feasible.

Despite renewable energy systems being scalable and maintaining energy efficiency when enlarging facilities, the associated enlargement cost is often unaffordable by the customer. This situation produces an unsatisfactory reaction in people, maintaining fossil fuel power systems as primary sources for domestic services. As a consequence, carbon emissions increase, and the sustainability index reduces.

On the other hand, many domestic appliances operate at reduced efficiency due to low maintenance or inadequate design, generating extra energy consumption and additional carbon dioxide emissions to the atmosphere. Additionally, current customer practices provoke inefficient use of power sources for heat and electricity appliances, increasing energy demand with the consequent increase in carbon emissions. A similar situation occurs with car driving since drivers tend to speed and accelerate faster than necessary, increasing fuel consumption and GHG emissions.

All the above statements reinforce the need for specific protocols to manage energy use more appropriately so energy consumption and carbon emissions are reduced. Because of the many situations, we focus our attention on the following problems: household space and water heating, air conditioning, and city car driving. We selected these configurations because we can easily power them with renewable energies: solar, wind, geothermal, and biomass for household facilities and battery or fuel cells for vehicles.

1.2 Energy Management and Carbon Emissions

➢ *Electric energy supply*

The household power supply should cover the peak point derived from the simultaneous domestic appliance's connection. The situation does not represent a problem in grid-connected facilities, but in renewable systems, we should size the installations to cover the peak power point. Although the daily energy consumption remains unchanged, the hourly distribution is relevant for the renewable system size; as an example, we refer to the following cases (Figure 1), where global daily energy consumption is the same, but the peak power demand is different. The graphics of Figure 1 derived from statistical developed analysis [49].

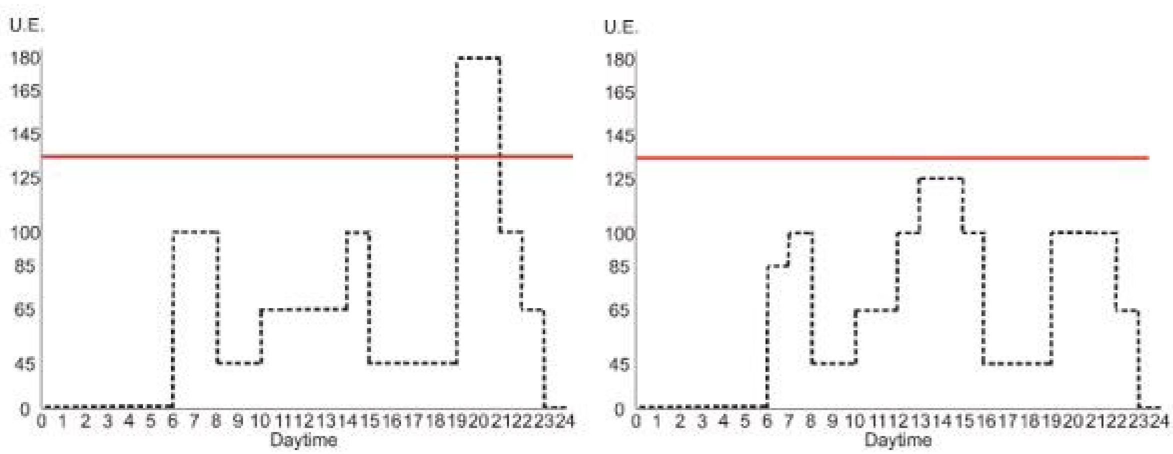

Figure 1: Daily energy consumption for two power distributions. Left side: conventional; right side: improved

The left side of Figure 1 shows a conventional daily energy distribution in generic units (U.E.), where the peak power occurs in the late afternoon when people return home and connect powerful appliances like the clothes washer, the dishwasher, and the iron machine, which require high power from the electric supply system.

In a household facility powered by renewable energy, the recommended size corresponds to a power generation that produces the same daily energy as the required one by the home installation. In the studied case (Figure 1), considering an average daily solar time of 10 hours, yields:

$$P = \frac{\sum_{i=1}^{24} \xi_i}{24} = \frac{1355}{10} = 135.5 \qquad (1)$$

This value, the red line in Figure 1, covers all periods except the interval from 7 to 9 pm, where the power demand exceeds the maximum power supply by the renewable energy source. During this period, the household facility imports energy from the grid, equivalent to 270 U.E.

If we redistribute the energy demand to make it more homogeneous throughout the day, on the right side in Figure 1, the same renewable installation covers all day energy demand, avoiding energy import from the grid. The new configuration reduces the dependence on the grid, avoiding carbon emissions if electric energy comes from a fossil fuel power plant. Considering the average value of the daily energy consumption for a four people family, 29-30 kWh in USA [50-51], 19 kWh in Western Europe [52], 47.2 kWh in Northern Europe [52], and 11.5 kWh in Eastern Europe [52], and comparing to the normalized values in Figure 1, the ratio for every region is (Table 1):

Region	USA	Western Europe	Northern Europe	Eastern Europe
Ratio (kWh/UE)	0.022	0.014	0.035	0.009

Table: 1 Energy consumption ratio

According to these values and retrieving the CO2 rate generation, 0.39 kgCO2/kWh from the literature the carbon dioxide emission reduction to the atmosphere for the presented case is (Table 2) [53].

Region	USA	Western Europe	Northern Europe	Eastern Europe
CO2 reduction (kg/year)	845.6	538.1	1345.2	326.7

Table 2: Reduction of CO2 emissions

1.3 Analysis of The Renewable Installation

The renewable installation must match the peak power demanded by the household facility. In case of a complete power demand coverage, considering a standard renewable energy resource, and according to energy distribution in Figure 1, the power is (Table 3):

Region		USA	Western Europe	Northern Europe	Eastern Europe
Peak power (W)	Left	5940	3780	9450	2430
	Right	4125	2623	6558	1686

Table 3: Renewable energy installation peak power for a complete energy coverage

If we compare the daily energy distribution values from the left and right sides in Figure 1, we observe a peak power reduction of 30.6%. This value represents a significant size and investment saving, which may decide the user to reduce the renewable installation power and import energy from the grid with the consequent increase in fossil fuel consumption and carbon emissions.

1.4 AI Protocol for Energy Management

Since people, either through ignorance, laziness or forgetfulness, most of the times do not use the household appliances according to the optimum daily energy distribution, which leads to a reduction in the peak power demand, an automatic procedure should take the system control and proceed to manage the energy demand situation. This procedure bases on Artificial Intelligence protocol as shown in Figure 2.

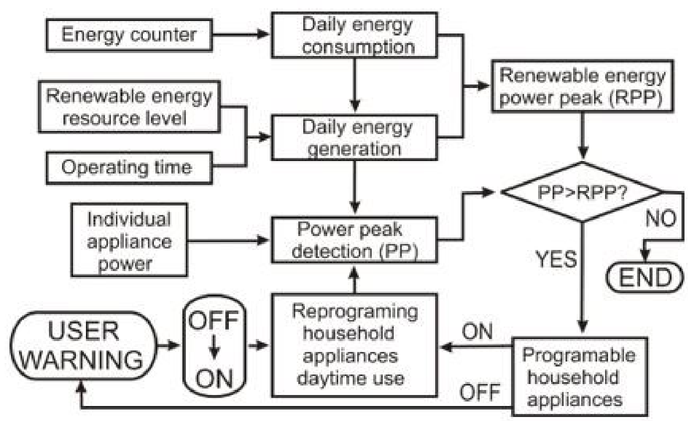

Figure 2: Artificial Intelligence Protocol for Electric Household Appliances Optimization Use

The Artificial Intelligence Protocol (AIP) sequence is:

- A control system computes the daily energy consumption from the household appliance power and operating time through an energy counter.
- The control system calculates the energy generation from the renewable installation power and working time using an energy integrator device.
- The control system detects every household appliance's power and calculates the household facility's peak power at any time (PP).
- The control system evaluates the renewable installation power peak (RPP).
- The protocol compares both values, PP and RPP; if PP is higher than RPP, it gets access to programmable household devices; if not, the protocol ends.
- If programmable devices are ON, the protocol reprograms the daytime use for every device, following the sequence of matching the highest power device with the maximum renewable output power and continuing the process until the sequence ends.
- After reprograming the household devices for daytime use,

the protocol compares PP and RPP again; if PP is still higher, the reprogramming protocol restarts; if not, the process ends.

- If programmable devices are in the OFF or STANDBY position, the protocol warns the user who should turn the OFF or STANDBY position to ON.
- Once all programmable household devices are ON, the protocol continues with the control process until optimization completes.

➢ Thermal Power Supply

In thermal applications, we use energy to heat water or space air conditioning; the expression that rules the process is:

$$\xi_i = m_j c \Delta T_j \quad (2)$$

m is the fluid mass, currently water, c is the specific heat, and ΔT is the temperature difference. The subscript j accounts for water or air, depending on water or space heating.

Domestic water heating is produced using gas or electricity in a boiler, an electric heater, or a heat pump. Depending on the used system, the efficiency is higher or lower; for instance, a boiler has a typical efficiency of 90% [54], an electric heater of 100% [55], and the heat pump efficiency reaches 300% in heating mode [56-57].

An electric heater is designed only for water heating; however, gas boilers or heat pumps are more appropriate for combined water and space heating household facilities. On the other hand, we must consider the power plant type that generates electricity, thermal or renewable. In the first case, direct carbon emissions are present in the energy conversion process; in the second case, we should consider the carbon footprint of the generated electricity due to the renewable power plant building.

Discarding the electric heater, whose use is outdated, gas boilers and heat pumps compete as the power system for household water heating and space air conditioning. Regarding efficiency, neglecting the extraction process and refinery, electricity for heat pump power supply should consider the conversion process efficiency at the thermal power plant, whose maximum current value is 80% in a combined cycle thermal power plant. Therefore, water and space heating operate at 90% efficiency when using a gas boiler and 80% in the case of a heat pump.

It looks like the gas boiler is a better option; however, if we use the Coefficient of Performance (COP), which considers only the useful to consumed energy ratio, neglecting the energy exchange with the environment, a heat pump operates with a Global Performance Coefficient (GPC) of 2.4 for space heating and 3.3 for air conditioning. Water heating using a heat pump has a 1.7 GPC value on average [58]. On the other hand, the gas boiler operates at a GPC equal to 0.9 since it does not exchange energy with the environment.

We define the Global Performance Coefficient as:

$$GPC = \eta\left(COP\right) \quad (3)$$

COP is the Coefficient of Performance, and η is the energy conversion efficiency.

For gas and electricity generated at thermal power plants, the values are (Equation 4). *HP* and *AC* are the acronyms for heat pump and air conditioning.

$$GPC = \begin{cases} 0.9x1 = 0.9\,(gas) \\ 0.8x2.15 = 1.7\,(HP - water\ heating) \\ 0.8x3.0 = 2.4\,(HP - space\ heating) \\ 0.8x4.1 = 3.3\,(HP - AC) \end{cases} \quad (4)$$

Now, using the standard daily water consumption for a four people family, 80 liters per person, considering a water temperature increase of 43º C, from the yearly average water network servicing at 12º C to the heated water operating temperature at 55º C, applying equation 2, we have:

$$\xi_i = (80x4)(4180)(43) = 57.52\ MJ = 16\ kWh \quad (5)$$

If we combine results from Tables 2 and 3, we obtain the primary energy source value:

$$\xi_i = \begin{cases} 16/0.9 = 17.78\ kWh\,(gas) \\ 16 = 7.37\ kWh\,(HP) \end{cases} \quad (6)$$

The heat pump system is 2.4 times more efficient than the gas boiler and saves 1480.44 kg of CO2 emissions every year.

The configuration, however, is not optimized since heating water at 55º C wastes energy for many household applications like sanitary services like showering and washing (37-40º C) [59], clothes washing (30-40º C) [60], floor scrubbing (30º C)[61], even dishwashing (43º C) [62]. The reason to set up the standard domestic hot water at 55º C is the temperature drop due to thermal losses in water ducts, estimated at 10º C.

A way to reduce the temperature drop and operate at optimum conditions is recirculating hot water from the supply to the service point. Nevertheless, maintaining hot water recirculation 24 h a day generates thermal losses and consumes energy without benefiting effects since hot water demand is not constant. Therefore, hot water recirculation activates only at specific daily periods, early morning, midday, and late afternoon. A statistical study, developed for detached and semi-detached houses, shows that the most adequate time intervals for hot water recirculation are 6.30 to 8.30 am, 1.30 to 3.30 pm, and 8 to 10 pm. Figure 3 shows the average daily hot water demand and the recirculation periods.

If we operate at the appropriate temperature, the energy saving is:

$$\Delta\xi_i = \begin{cases} (a) \quad (160)(4180)(15) = 10\ MJ = 2.79\ kWh \\ (b) \quad (160)(4180)(20) = 13.4\ MJ = 3.72\ kWh \\ (c) \quad (160)(4180)(25) = 16.72\ MJ = 4.64\ kWh \\ (d) \quad (160)(4180)(12) = 8.03\ MJ = 2.23\ kWh \end{cases} \quad (7)$$

a, b, c, and d account for showering and washing, clothes washing, floor scrubbing, dishwashing, respectively.

The carbon emissions saving in a year is:

$$\Delta CO_2 = \begin{cases} (a) \quad 397.2\,kg \quad (b) \quad 529.5\,kg \\ (c) \quad 660.5\,kg \quad (d) \quad 317.4\,kg \end{cases} \qquad (8)$$

1.5 Control system and Artificial Intelligence Protocol for Thermal Supply

The control system that manages domestic hot water operations searches to reduce the temperature drop by controlling the water servicing temperature for every application. To this goal, the control system activates hot water recirculation when necessary, currently just before or when the consumers open the faucets. If we apply this procedure, there is no delay in hot water servicing, minimizing thermal losses. Figure 3 shows the hot water demand (red line) and the water recirculation (black dashed line).

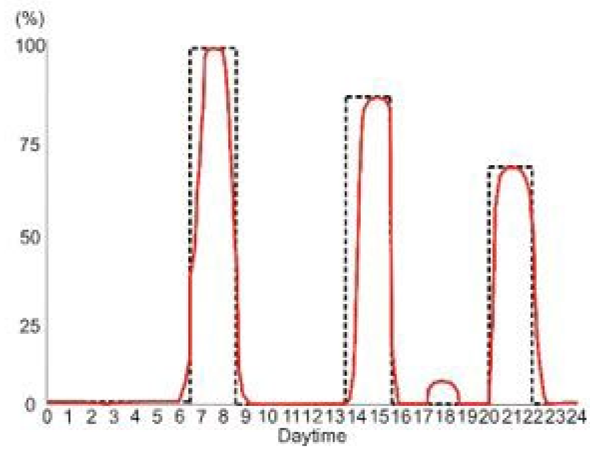

Figure 3: Daily Distribution of Domestic Hot Water Demand (Red Line) and Water Recirculation Periods (black dashed line)

We observe a good match between hot water demand and recirculation. The control system regulates the water recirculation flow, to adapt to the water demand. We notice that the water recirculation period is wider than the hot water demand; we design the operational time to ensure hot water arrives on time when needed with no delay that may cause energy losses and efficiency reduction.

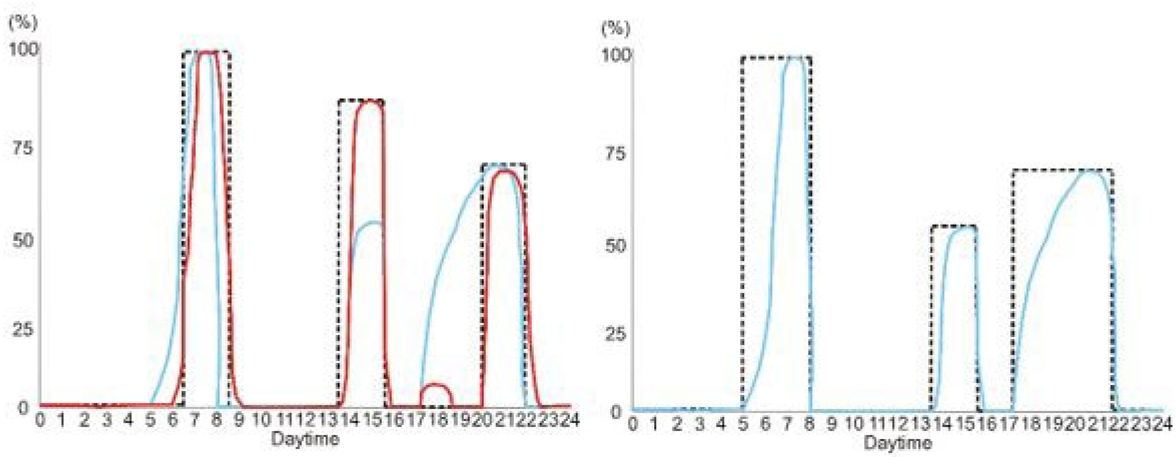

Figure 4: Water Demand Distribution Changes (Left Side) and Water Recirculation Periods Adaptation (right side)

Despite the scheduled water recirculation periods, the daily hot water demand may change because of human habit modification (Figure 4, left side). In such a case, the Artificial Intelligence Protocol (AIP) detects variations in the daily hot water demand distribution. The AIP reacts by activating the water recirculation software routine, and the control system modifies the recirculation periods (Figure 4, right side).

Figure 5 shows the Artificial Intelligence Protocol routine for hot water management.

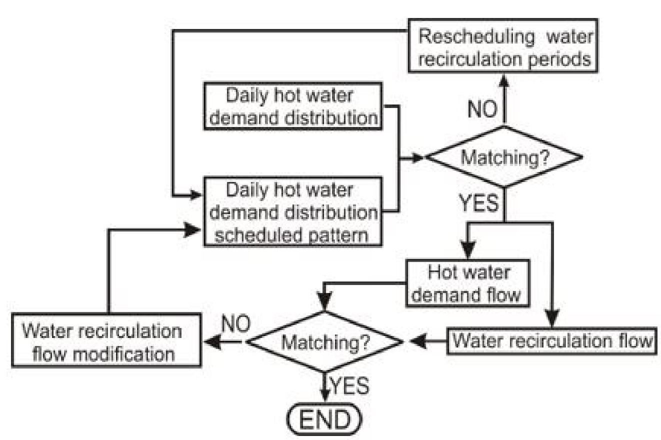

Figure 5: Artificial Intelligence Protocol For Domestic Hot Water Management

The Artificial Intelligence Protocol (AIP) sequence is:

- The control system computes the daily hot water demand distribution through an appropriate flowmeter.
- The control system compares the obtained water demand distribution with the scheduled pattern stored in the database bank.
- If both distributions do not match, the AIP reschedules the water circulation periods and restarts the process.
- If both distributions match, the control system evaluates the water flow demand at every interval and compares it to the programmed water recirculation flow periods.
- If the comparison succeeds, the sequence ends, and the control system takes no further action; if not, the control system modifies the water recirculation flow wherever necessary.
- After the water recirculation flow modification, the AIP returns the sequence to the initial statement, and the process restarts.

➢ **Space Heating and Air Conditioning**

Regarding space heating and air conditioning, the situation reminds us of hot water management with specific differences due to the influence of climate and meteorology.

Space heating and air conditioning depend on the energy balance between the conditioning room and the outside and the human comfort feeling. Based on a setup comfort temperature, the energy balance is given by:

$$mc\frac{dT_r}{dt} = \tau\alpha GS + P_{ext} - \frac{T_r - T_{amb}}{R_t} \qquad (9)$$

m is the air mass inside the conditioning room, c is the air-specific heat, T_r and T_{amb} are the room and ambient temperature, τ is the windows glass transmission coefficient, α is the average room absorption coefficient, G is the solar radiation, S is the windows global surface, R_t is the room's wall thermal resistance, and P_{ext} is the heating power.

From equation 9, we obtain:

$$\frac{dT_r}{dt} + \frac{T_r}{mcR_t} - \frac{1}{mcR_t}\left[T_{amb} + R_t\left(\tau\alpha GS + P_{ext}\right)\right] = 0$$

Air mass and specific heat, thermal resistance, global windows surface, and transmission and absorption coefficient can be considered constant; therefore:

$$\frac{dT_r}{dt} + aT_r - C_o = 0$$

$$a = \frac{1}{mcR_t}; C_o = a\left[T_{amb} + R_t\left(\tau\alpha GS + P_{ext}\right)\right] \qquad (11)$$

The coefficient Co evolves with daytime since ambient temperature and solar radiation change throughout the day.

Solving equation 11, yields:

$$P_{ext} = \frac{1}{R_t}\left[\left(T_r - T_{amb}\right) - \exp\left(-\frac{t}{mcR_t}\right)\right] - \tau\alpha GS \qquad (12)$$

Since Rt, m, c, α, τ, and S are constant, the heating power depends on solar radiation and ambient temperature for a given room temperature. Considering the daily average values for these two parameters, we notice that the heating power only depends on time; the shorter the room heating, the higher the heating power.

Room heating can be done by one of the following mechanisms: conduction, convection, and radiation. In residential areas, the current way for space heating is through radiation from wall radiators or radiant floors. In both cases, a water flow circulates through an inner duct, exchanging heat with the radiator or the floor, which emits thermal energy and heats the room. Room refrigeration, however, is produced by forced convection created by cold air flow injected into the room from an air conditioning unit.

Forced convection develops at a faster rate than radiation, resulting in a shorter time to condition the room; therefore, we can use a heat pump for heating or refrigerating residential spaces since the heat pump operates under a reversible thermodynamic cycle, which injects or extracts thermal energy from a space depending on the cycle work direction.

Conventional heat pump units are inadequate for radiant floors or wall radiators because they operate with air as a working fluid, whose thermal capacity is much lower than water. In such a case, if we want to use the existing heating installation, we have to use an aerothermal unit so that it uses water as a heat carrier.

Coupling an aerothermal unit in a house without a built-in radiant floor is a complex and expensive task since we need to lift the entire house floor to install the underfloor heating, therefore, it is good practice to couple the wall radiators to the aerothermal unit.

For an efficient management of the heating process, we can apply an Artificial Intelligence Protocol, specifically developed for this purpose. Indeed, aerothermal units can operate at variable heating flow rate and temperature, adjusting the heating time to the consumer needs. Figure 6 shows the heating curves for the aerothermal unit.

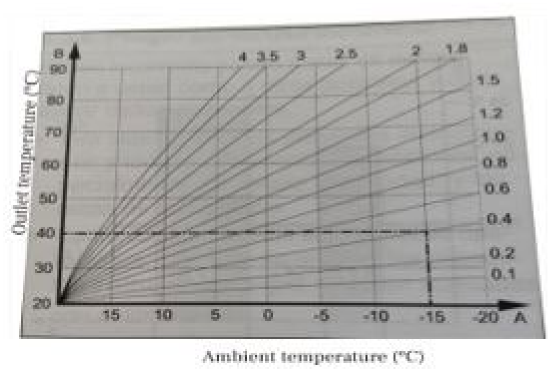

Figure 6: Heating and air conditioning curves fort the aerothermal unit [63]

1.6 Control System for Space Heating

The control system for space heating operates following the next sequence:

- It collects information on solar radiation and ambient temperature from the internal database, where the average daily values of these magnitudes have been obtained from the National Meteorological Service.

- It also collects structural element characteristic values like window glass transmission and wall thermal resistance from the building workbook recorded in the inner database. It also evaluates the average room absorption coefficient from the database.
- It calculates the room air mass and global windows surface from the building descriptive plans and retrieves air-specific heat from the database.
- Once all data are collected, the control system retrieves data from the aerothermal unit heating curves (Figure 6), which are recorded in the inner database.

The control system applies equation 12 for specific ambient and room temperatures and determines the heating power for a given time using heating curves and collected data. The energy use derives from the calculated power and time.

1.7 Artificial Intelligence Protocol for Space Heating

The Artificial Intelligence Protocol retrieves the programmed user's daily room temperature distribution (Figure 7) and compares data with values extracted from the control system database.

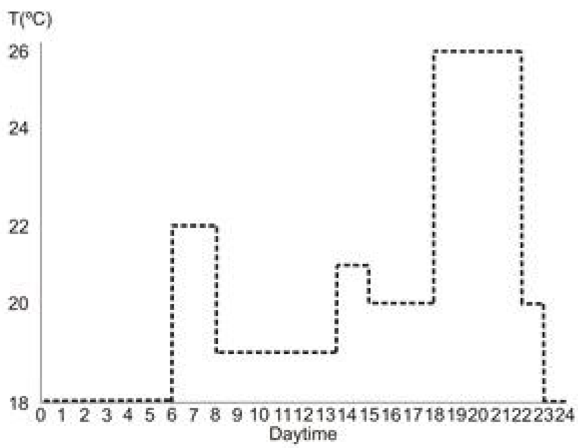

Figure 7: Programmed Daily Room Temperature Distribution

If the temperature matches at all hourly ranges, the AIP sends the order to take no further action to the control system. If the temperature does not match, the AIP sends an order to the control system to modify the heating curve (Figure 6) to match the current room temperature and programmed value.

The AIP also evaluates human activities out of programmed intervals because of changes in people's habits (red line in Figure 8) and reprograms the control system to adapt the heating process to the new configuration. The dynamic process continues whenever the AIP detects deviations from the original schedule programming.

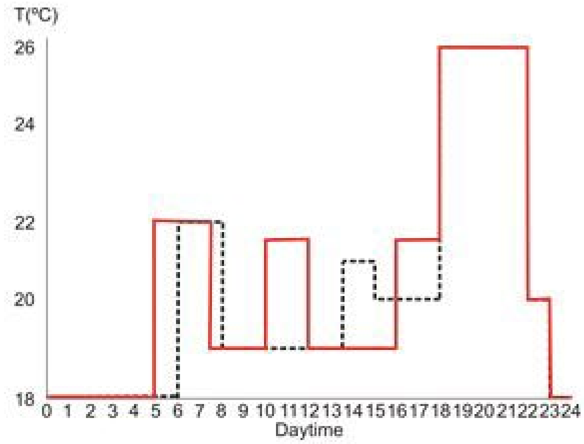

Figure 8: Programmed Daily Room Temperature Distribution (Black Dashed Line) And Current Human Activity (solid red line)

Figure 9 shows the AIP programming flowchart.
The control system operation and AIP management for the room air conditioning is similar to the one described for the space heating, with the only difference being that the control system commutes the aerothermal unit from heating to refrigerating mode.

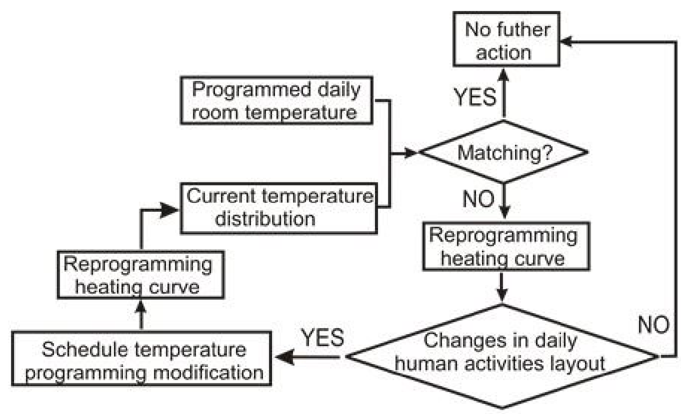

Figure 9: Artificial Intelligence Protocol for Domestic Space Heating or Air Conditioning Management

2. Energy Efficiency

An additional objective of the AIP is energy efficiency improvement. The control system evaluates the heating and air conditioning system efficiencies. Because forced convection is faster than radiation in conditioning the room, if there is any change in the heating or air conditioning schedule programming, the AIP sends an order to the control system to activate electric fans placed under every wall radiator, accelerating the heating or air conditioning process. At the same time, the AIP forces the control system to move from a heating or air conditioning curve to a more conservative one, saving energy and improving efficiency. Figure 10 shows the AIP flowchart for energy efficiency improvement.

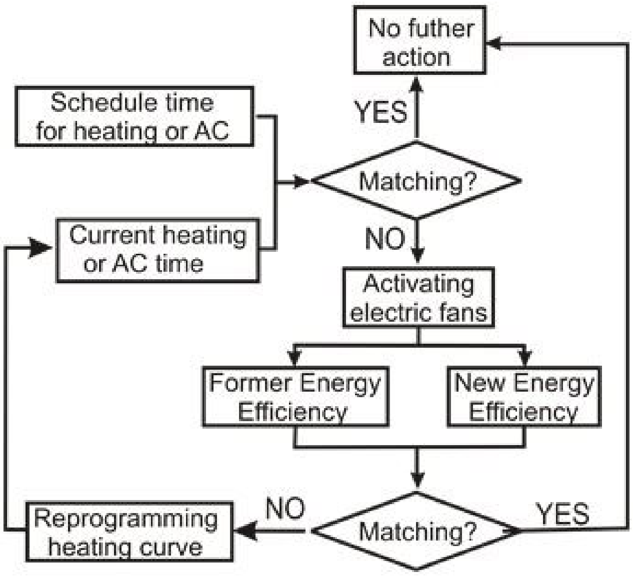

Figure 10: Artificial Intelligence Protocol for Energy Efficiency Improvement Management

3. Experimental Tests

We run experimental tests to validate the Artificial Intelligence Protocol application for energy management and efficiency improvement. We divided the tests into three groups: the first was devoted to power supply management, the second to hot water, and the third to space heating and air conditioning.

Tests run on a semi-detached house powered by grid electricity, gas, and a photovoltaic system. The PV system comprises two sets of 11 panels each for a global power supply of 8.85 kWp. The PV power, however, should be reduced by a factor of 0.75 due to the East-West orientation of the PV sets; therefore, the maximum available power is 6.64 kWp. Considering the average daily solar radiation, the PV output power reduces to 3.15 kWp.

Electric power is supplied by the photovoltaic system, with the grid assisting whenever the energy demand exceeds the PV power generation. We produce hot water in two ways: from a gas boiler or an aerothermal unit. A similar situation occurs for space heating, where the gas boiler or the aerothermal unit supplies heating power to condition the house. Regarding refrigeration, two options arise an aerothermal system or air conditioning units, either wall or portable.

Space heating runs on wall radiators since the building structure does not allow underfloor heating. We use the aerothermal system or the air conditioning units for space refrigeration due to the impossibility of installing underfloor heating. Electric fans, placed under the wall radiators, help the heating or refrigeration process, accelerating the heat exchange due to the forced convection.

Figure 11 shows a schematic view of the household facility.

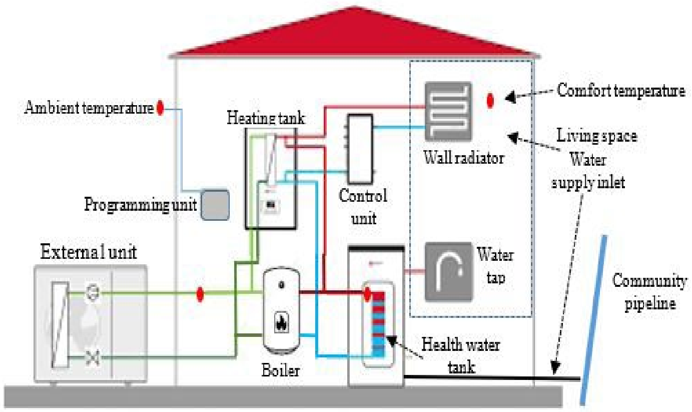

Figure 11: Schematic View of the Household Facility

Tests for Energy Management

We run tests for energy management for more than four months under variable operating conditions, connecting and disconnecting household appliances and alternating programmed configurations with manual operation. Table 4 shows the appliances list.

Table 4 List of appliances

Appliance	Power (kW)	Power factor use	Eff.power (kW)
Oven	3,20	0,5	1,60
Microwave	1,00	1	1,00
Washer	1,60	0,6	0,96
Dishwasher	2,30	0,4	0,92
Cooking plate	1,80	0,5	0,90
Coffee maker	0,45	1	0,45
Television	0,30	1	0,30
Iron machine	2,60	1	2,60
Vacuum cleaner	2,20	0,75	1,65
Lighting	0,50	0,25	0,13
Computer	0,70	1	0,70
Accessories	0,85	0,4	0,34
Electric tools	1,30	0,1	0,13
Garden tools	1,20	0,1	0,12

The power column indicates the appliance's maximum power, while the power factor used shows the percentage of the maximum power at which the appliance currently works. The Eff. Power column corresponds to the appliance power demand in manual mode.

Considering the household power limit from the grid is 5.5 kW and retrieving the maximum PV output power, we realize that we can cover the maximum power demand (11.80 kW) with the PV installation and grid supply combined (12.14 kW).

Test to verify the validity of the energy management runs under the below procedure:

➢ First test: AIP not available

We program the control unit to block the access to the AIP routine; therefore, the system operates under conventional premises, which are:

- Control system collects energy from the PV installation as the primary power source
- When energy demand exceeds PV maximum output power, the control system automatically connects to the grid and collects the necessary power to equalize energy demand
- When energy demand exceeds the combined maximum PV output power and grid injection the power limiter device disconnects both power sources and energy supply is interrupted

Table 5 shows the process development under the above-mentioned premises. Table 6 indicates the programmed appliances and energy demand.

Household appliance configuration (experimental)		Control system action (experimental)
1.	The user programs household appliances connection for a global power below the maximum PV output	a. PV connected b. Grid connection deactivated
2.	The user programs additional appliances connection to exceed the maximum PV output power	a. PV connected b. Grid connection activated
3.	The user programs appliances connection for current power beyond the household power sources limit	a. The power limiter disconnects PV installation and deactivates the grid connection

Table 5: Energy Management Test for AIP Not Available

Conf.	Programmed appliances	Action	Power demand (kW)
1	Washer; Diswasher; Lightning; Computer	a	2.71 (PV)
		b	2.71 (PV)
2	Washer; Diswasher; Lightning; Computer; Oven	a	3.15 (PV)
		b	1.15 (grid)
3	Washer; Diswasher; Lightning; Computer; Oven; Microwave; Cooking plate; Garden tools; Electric tools; Accessories	a	***9.56*** Disconnected (Max. allowed: 8.65)

Table 6: Programmed Appliances and Power Demand

Values in italic bold type indicate we have exceeded the power limit; therefore, the installation is disconnected. This statement applies for all tests.

➢ Second test: AIP engaged

We left the AIP engaged so the control unit gets access when necessary. In this situation, the system operates under the following premises:

- The control system collects energy from the PV installation as the primary power source.
- When energy demand exceeds the maximum PV output power the PV power limiter disconnects the PV installation and the energy supply from PV panels is interrupted.
- After the power supply is interrupted, the control system disconnects the necessary appliances to reduce energy demand below PV maximum output power. Once the demanded power lowers, the control system automatically reactivates the power supply.
- If the point 2 configuration continues, the AIP reprograms the scheduled appliance operation to avoid overpassing the PV maximum output power.
- If AIP reprogramming cannot avoid the power supply surplus, the control system activates the grid connection and allows power injection from the grid to equalize energy demand and power supply

Table 7 shows the process development under the above-mentioned premises. Table 8 indicates the programmed appliances and energy demand.

Household appliance configuration (experimental)		Control system action (experimental)
4.	The user programs household appliances connection for a global power below the maximum PV output	a. PV connected b. Grid connection deactivated
5.	The user programs additional appliances connection to exceed the maximum PV output power	a. PV power limiter disconnects PV installation b. Control system disconnects some appliances. c. Control system reactivates PV power supply
6.	The programmed appliances operation continues exceeding PV maximum output power	a. AIP reprograms schedule appliance operation

Table 7: Energy Management Test for AIP Engage

Conf.	Programmed appliances	Action	Power demand (kW)
4	Washer; Diswasher; Lightning; Computer	a	2.71 (PV)
		b	2.71 (PV)
5	Washer; Diswasher; Lightning; Computer; Oven	a	4.31 PV disconnected
	Washer; Diswasher (disconnected)	b	1.88
	Computer; Lightning; Oven	c	2.43 (PV)
6	Computer; Lightning; Oven	a1	2.43 (PV)
	Washer; Diswasher	a2	1.82 (PV)

Table 8: Programmed Appliances and Power Demand

Steps a1 and a2 correspond to different time periods.

4. Tests for Hot Water Management

The experimental tests for hot water management focus on evaluating the servicing water temperature at any house tap. To this goal, we installed a temperature sensor inserted in a tap adaptor connected to the tap (Figure 12).

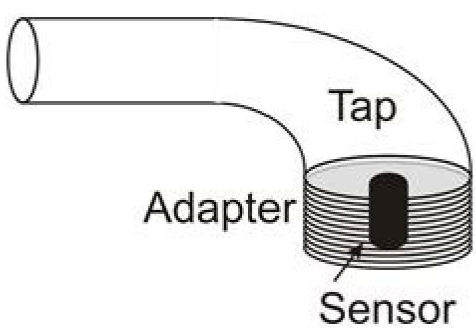

Figure 12: View of The Tap with the Temperature Sensor

Because in the current operation, there is a delay from the moment the user opens the tap until hot water arrives, we measured the time delay for activated and deactivated AIP. The time interval for temperature measuring is 5 seconds. Figure 13 shows the water temperature response with AIP activated (dashed line) and deactivated (solid line).

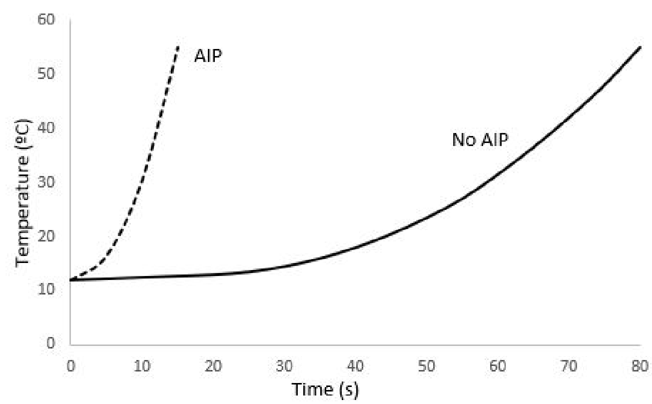

Figure 13: Water Temperature Response with AIP Activated and Deactivated

We observe the time reduction in reaching the maximum temperature when the AIP is activated, from 80 to 15 seconds, representing a significant reduction in time, water use, and energy.

Considering an average current flow of 8 liters per minute when opening a tap, we may calculate the wasted water every time the user opens the tap, yielding:

$$\Delta m_w = \dot{m}_w \Delta t = \left(\frac{8}{60}\right)(80-15) = 8.67\ L \quad (13)$$

$\dot{m}_w$ is the average water flow when opening the tap, and Δt is the time saved applying the AIP?

Now, applying the average water consumption for the family house, 313.2 liters per day, obtained from the water distribution company [64], considering the sanitary services represent 25% of the global daily consumption, 78.3 L/day, the estimated daily wasted water is:

$$\Delta m_w\big|_{day} = \Delta m_w N = \Delta m_w \frac{m_w\big|_{day} f_{op}}{\dot{m}_w t_{op}} \qquad (14)$$

N is the number of times the user opens the tap, $m_w\big|_{day}$ is the daily water consumption, f_{op} is the fraction of water used for personal hygiene, and t_{op} is the time the tap remains open.

Applying data from the household facility:

$$\Delta m_w\big|_{day} = (8.67)\frac{(313.2)(0.25)}{(8)(2)} = 42.4\ L/day$$

If we compute over a year, we obtain a water waste of 15.5 m3, a significant value.

Regarding the energy wasted in heating the wasted water:

$$\Delta\xi = \begin{cases} (42.4)(4180)(43) = 7.62x10^6\ J/day = 2.11\ kWh/day \\ (365)(42.4)(4180)(43) = 2781x10^6\ J/year = 772.7\ kWh/year \end{cases}$$

5. Tests for Space Conditioning Management

Repeating the test procedure for space conditioning management, we determine the time to achieve a comfortable temperature in winter or summer, comparing the obtained values for the conventional configuration and the AIP-assisted system.

Applying the protocol described in Figure 9, we obtain the following results (Figure 14):

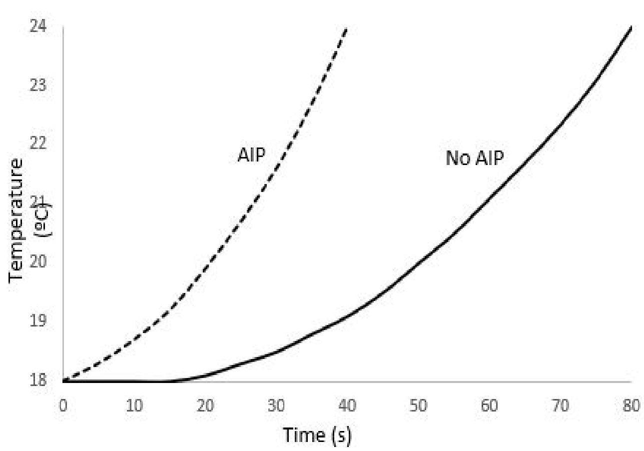

Figure 14: Room Temperature Response with AIP Activated and Deactivated

Analyzing data from Figure 14, we realize that the AIP reduces space heating by 50% in time, 40 versus 80 minutes, representing a significant energy saving.

For the space heating, we use a 6 kW aerothermal unit. Considering that AIP maximizes aerothermal performance, we retrieve the COP data from a previous study [58], with COP=3.64 for the optimum performance and COP=2.84 for the conventional operation. Using the COP difference, we obtain:

$$\Delta\xi = \Delta(COP)P_{aero}\Delta t = (0.8)(6)(40/60) = 3.2\ kWh/day \qquad (17)$$

The energy saving in space heating, applying the AIP, represents 16.8% of the daily energy consumption. These values are valid for Western Europe, where the tests take place.

6. Global Energy Saving

Combining the energy saving from hot water and space heating management, we obtain a significant 27.9 %, more than one-fourth of the daily consumption, showing the benefitting effects of the AIP application. Adding the energy saving due to the appropriate distribution of appliance use, we obtain an energy saving between 39.6% and 52.3%.

Experimental tests continue for more than two years to validate the energy-saving estimation from the AIP application. We developed household activities alternating AIP application and conventional operating mode. Global energy consumption is registered every month using an energy meter. Table 9 shows the monthly energy consumption for the tested facility.

		January	February	March	April	May	June
Energy (kWh)	Conv.	639	649	625	650	646	645
	AIP	354	323	347	343	347	346
Saving (%)		44.6	50.2	44.5	47.2	46.3	46.4
		July	August	September	October	November	December
Energy (kWh)	Conv.	643	614	622	606	635	646
	AIP	353	351	358	346	358	356
Saving (%)		45.1	42.8	42.4	42.9	43.6	44.9

Table 9: Monthly Household Energy Consumption

The data analysis in Table 9 shows that current energy-saving values are within the estimated interval for the AIP application, validating the developed methodology. If we average over the entire year, the energy saving is 45.1%, matching the half value of the estimated energy saving range (45.95%). The high agreement, with 98% accuracy, reinforces the method's validity.

7. Conclusions

Household facility's energy consumption can be improved using specific protocols focused on energy, hot water, and space heating management. The protocol based on the Artificial Intelligence application shows a significant reduction in energy consumption and an efficiency improvement.

Data from experimental tests run on a semi-detached house shows that the AIP application is interesting in household facilities powered by renewable energies with grid connection. The AIP warrants the correct operation of programmed appliances with no or minimum risk of blackout.

The AIP application is valid for any renewable power source and grid-connected houses or isolated dwellings, with specific relevance for this latter case. The AIP benefits are more significant as the household energy demand increases.

Experimental tests show that the AIP application may reduce up to 50.2% of daily energy consumption. The monthly energy saving falls within the expected range from the AIP application, with the yearly average energy saving matching the half point of the AIP application range with 98% accuracy. Besides, the AIP application reduces carbon emissions to the atmosphere between 397.4 and 660.5 kilograms per year, depending on the appliance use.

We remark that people should be taught about appropriate household energy use, either changing how to use appliances or implementing home automation systems assisted by Artificial Intelligence.

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