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Article

Efficient Demand Side Management Using a Novel Decentralized Building Automation Algorithm

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Abstract: The building automation control is a crucial factor for improving buildings energy efficiency and management, as well as improving the electricity grid's reliability indices. This paper presents the methodology, describes the necessary technology requirements and presents the decentralized building automation novel algorithm for Efficient demand side management in a building. All these are applied in an experimental university microgrid and the results are presented in terms of energy saving in kWh, money in € and working hours.

Keywords: smart grid; building automation; energy efficiency; energy management

1. Introduction

The primary motivation for any energy management system is the economic gain. Pricing systems define the appropriate characteristics of smart household management systems (BMSs), which have a substantial impact on the complexity and dependability of BMSs [1]. Power-grid authorities recently changed the household electrical pricing to encourage proper demand-side control by homeowners. Furthermore, many countries support small-scale PV integration on residential or commercial rooftops and net metering [2,3].

On the other hand, RES-based electricity generation is unaffected by other conventional sustainable resources or variations in energy use. Sustainable generating is planned in accordance with expected load levels as well as some technological and environmental constraints. However, weather-dependent RES, such as PV facilities and wind farms, must run at maximum output whenever technically practicable in order to show a high proportion of RES in the electric energy production mixture. When considering limited or isolated energy networks (e.g., islands), these operating criteria cannot be met and may result in insufficient energy supply. Furthermore, as the proportion of renewable energy sources (RESs) in electricity generation grows, this problem becomes increasingly pressing.

All of the concerns listed above can be solved by integrating energy storage systems and controlled loads into the grid, as well as integrating enhancements to the control infrastructure and algorithms in a non-invasive manner for the distribution network. The microgrid, which is commonly characterized as a distribution grid incorporating distributed generators (DGs), energy storage units, and regulated loads [1], appears to be one of the most significant aspects of future power grid topologies. The auxiliary services that a microgrid's supply and demand sides could provide are predicted to improve the value of the future smart grid [2–7]. In general, load leveling and demand-side management are widely employed to provide services such as voltage regulation and energy management for isolated microgrids [3,7,8].

Because they are programmable, these authorized automation devices are typically put at the low-voltage sector of the grid and have numerous capabilities for controlling electric energy use. Their operation is based on a shared data bus, which allows simple binary signals to be transmitted to activate their varied capabilities. Accurate assessment and proper control of the State of Charge (SoC) of energy storage devices are critical during islanded operation of microgrids [12,13]. According to [14], faulty control architecture and algorithms can have a severe impact on grid

operation, resulting in inaccurate SoC estimate as well as a decrease in customer power supply reliability. As a result, it is obvious that the control architecture of a smart distribution grid must be compatible with and adequately interactive with energy storage devices and existing bus communication technologies.

The developers of [10] use the OPC server solution to address the compatibility issue between the microgrid's control system and bus communication technologies. This technique has significant drawbacks, including a relatively expensive cost, the requirement of permanent additional hardware installation, and software version compatibility concerns. Furthermore, in this scenario, the control algorithm of an experimental microgrid without bus technology, as described in [15], should be exposed to numerous changes. Because most DGs' principal energy sources (PV and wind) are stochastic in nature, incorporating weather prediction into microgrid control algorithms will be critical [6,7], however this is not a component of this paper.

In order to achieve optimal demand-side management, this paper describes the control infrastructure and algorithm of an experimental smart microgrid that is compatible with KNX bus systems [9,16,17] in a very simple and cost-effective manner. The first section describes the smart microgrid topology by emphasizing the unique control infrastructure components that transform the distribution network into a "smart grid.", the details of the suggested technique for integrating KNX bus devices into the microgrid and then, a brief overview of the microgrid's control method is offered, including interoperability with KNX bus systems. Finally, the experimental results of the microgrid's operation are shown. According to the findings, incorporating smart cities (bus) systems might greatly improve consumer reliability performance and the supply/demand balance of microgrid-based smart grid topologies.

2. Materials and Methods

In the experimental microgrid of UoWM, every DC load, generator, or energy storage device in a microgrid-based smart distribution grid architecture is equipped with individual DC-AC inverters and is connected to the AC microgrid via KNX actuator and multi tariff energy meter.

The microgrid is made up of two 1.1 kW PV-inverter with six connected PV panels each, three loads with a maximum consumption of approximately 1500 W (1 AC-motor, incandescent lamps).

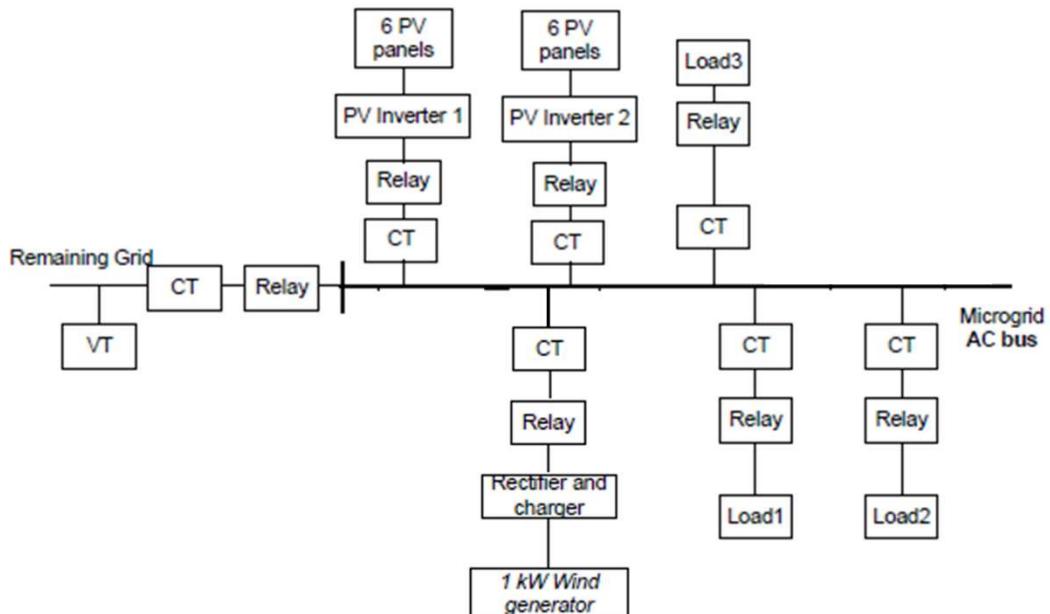


Figure 1. Implementation of a smart distribution grid topology.

Interoperability with KNX system

In this paper we have installed some KNX devices: a KNX power supply 160mA, a switch on/off actuator of 2 channels, a dimmer actuator of 4 channels, an energy 3 channels multi-tariff meter, a basic weather station, a push button with room temperature control, a presence detector with light control and a KNX server for the visualization.

The KNX server (HomeLynk from Schneider Electric) is required to incorporate KNX bus technologies into real-time measurements and decision systems in general. In the case of the experimental microgrid, in addition to the KNX devices the KNX HomeLynk sever, as illustrated in Figure 2, should be installed on the microgrid. Load 1 in Figure 2 represents the motor (heating/cooling pump), while Load 2 and Load 3 represent a 500W incandescent light group.

Table 1. Lab appliance types.

Component	Load/source type	Rating
PV modules	Source	2 kW
Light 1	Managed load	250W
Light 2	Managed load	250W
Heating/cooling pump	Managed load	1 kW

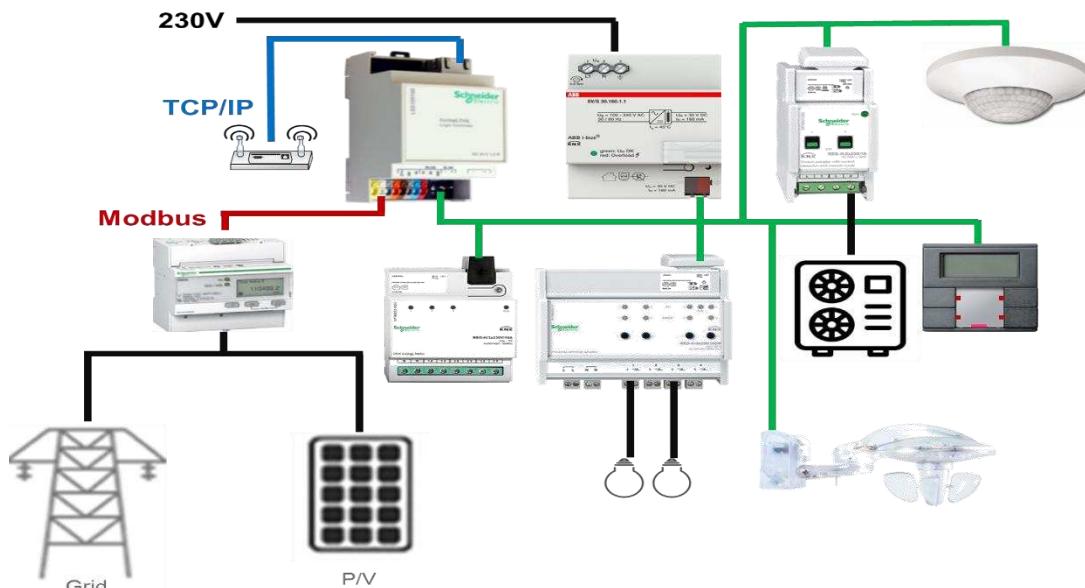


Figure 2. diagram of the BMS.

The BMS, checks the PV energy, the real time energy price and the average energy price through the multi tariff energy meter continuously every 15 minutes. Recent smart homes have several possibilities of room occupants. According to this study, the optimal schedule of occupant rooms, i.e., the comfort zone, is defined and suggested to home owners. The system checks the internal and external brightness of the room, the room temperature, the photovoltaic energy flow according to the weather prediction the electricity real time price and the average electricity price According to all these parameters the system dims up or down the light in the room, changes the temperature setpoint and activates the heating or cooling and activates the electric vehicle (EV) charge station.

Cost effective demand side-management

As previously stated, a simple and low-cost alternative option for integrating KNX-controlled loads into the microgrid control strategy is devised. KNX is the global standard for all building and smart city applications control.

The majority of KNX-compatible load control devices are activated by KNX switches as well as traditional push buttons, the manipulations of which can be converted into binary signals. When the push button on a KNX dimmer is pressed briefly, the signal is translated into a pulse in the dimming mechanism. The inbuilt KNX program in the gadget transforms this pulse to full power for the lamps, and the lamps consume full power. On the other hand, sustained switch pressure indicates that the KNX device gets 1 bit signals sequentially. In this situation, the device begins lowering the voltage of the lamps until the pressing stops or the voltage is reduced to the final value set by the dimmer's original program. The lights and electricity usage are both lowered. If the button is held down for an extended period of time, the brightness is increased, and so on.

There are two main scenarios according to the flow chart in Figure 3. In scenario 1 the photovoltaic energy is greater than the demand energy, while in scenario 2 the photovoltaic energy is less than the demand power and the real time electricity price is greater than the average electricity price. In scenario 3 the photovoltaic energy is less than the demand energy and the real time electricity price is less than the average electricity price.

When the photovoltaic power is greater than the demand power, then the power source is the photovoltaic, otherwise the power source is the grid.

The technical features of the multi-tariff energy meter are presented below:

Table 2. Multi-tariff energy meter characteristics.

Direct measurement (up to 63 A)	✓
Active Energy measurements	✓
Four Quadrant Energy measurements	✓
Electrical measurements (I, V, P, ...)	✓
Multi-tariff (internal clock)	4
Multi-tariff (controlled by digital inputs)	2
Measurement display	✓
Digital inputs	1
Programmable digital outputs	1
Overload alarm	✓
Modbus communication	✓
MID (legal metrology certification)	✓

The control algorithm's inputs are real-time measurements that are updated by the HomeLynk at each duty cycle and output variables that are supplied back into the iterative control method at the end of its execution period.

The algorithm's real-time measurement inputs are:

- the PV energy
- the signal for multi-tariffs
- the L1 energy in channel 1 of the dimmer
- the L2 energy in channel 1 of the dimmer
- the motor (heating/cooling) energy
- the internal lux in the lab
- the external lux
- the room temperature
- the room temperature setpoint

The HomeLynk algorithm

The HomeLynk algorithm is presented in Figure 3. PV energy is the energy from photovoltaic panels, Dem is the demand energy, T is the room temperature, L is the internal brightness, REP is the real time energy price, and AP is the average energy price. According to the algorithm in the Figure 3 there are the cases below:

- The photovoltaic energy is greater than the demand energy, the room temperature is less than 22 °C (winter) or greater than 27 °C, and the internal brightness is less than 200 lux, then energy source is the PV, the temperature setpoint is 24 °C (winter) or 25 °C (summer) and the heating/cooling pump is on and the lamps L1 and L2 are dimmed up at X % brightness as follows: internal brightness + X% brightness = 200 lux.
- The photovoltaic energy is greater than the demand energy, the room temperature is less than 22 °C (winter) or greater than 27 °C, and the internal brightness is greater than 200 lux, then energy source is the PV, the temperature setpoint is 24 °C (winter) or 25 °C (summer) and the heating/cooling pump is on and the lamps L1 and L2 are switched off.
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and the lamps L1 and L2 are switched off.

- The photovoltaic energy is less than the demand energy, the real time energy price is less than the average price, the room temperature is less than 22 °C (winter) or greater than 27 °C (summer), and the internal brightness is less than 200 lux, then energy source is the grid, the temperature setpoint is 24 °C (winter) or 25 °C (summer) and the heating/cooling pump is on and the lamps L1 and L2 are dimmed up at X % brightness as follows: internal brightness + X% brightness = 200 lux.
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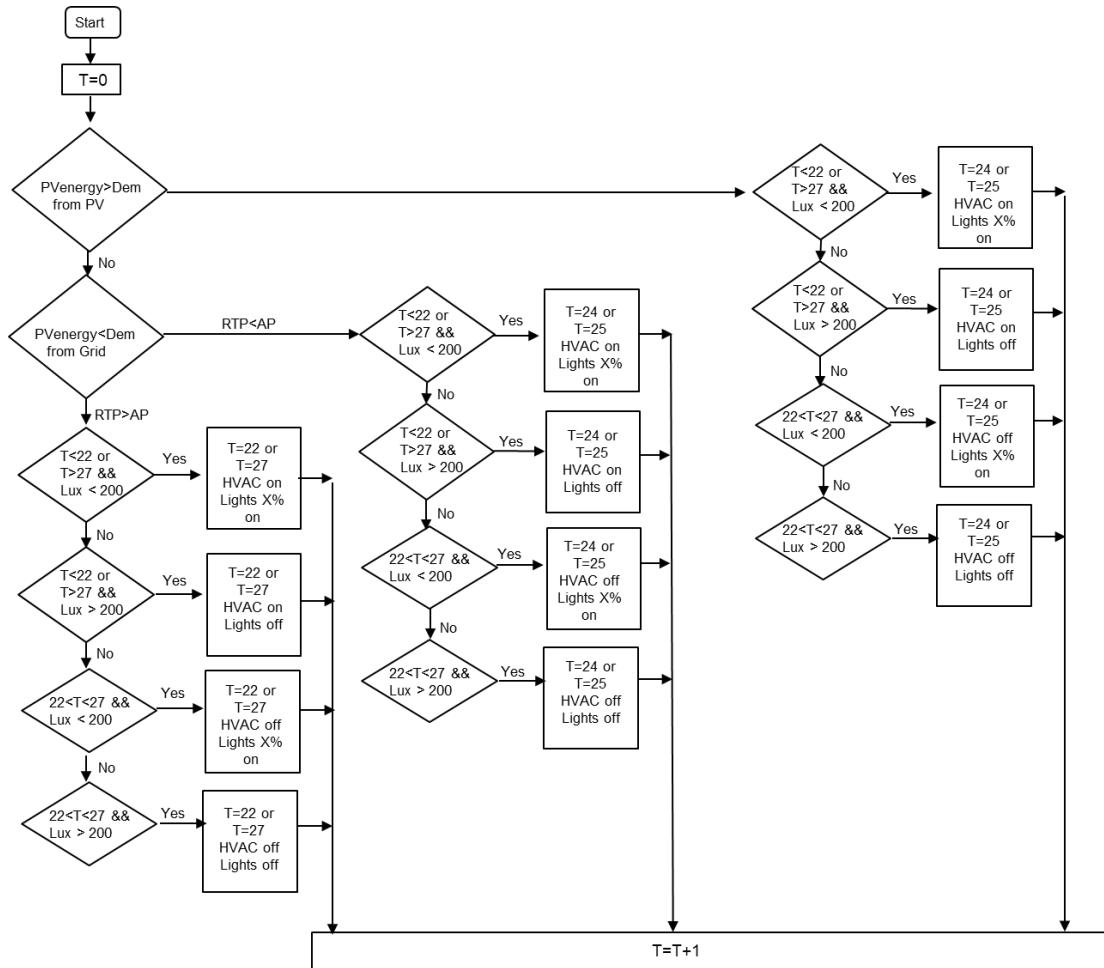


Figure 3. HomeLynk flow chart algorithm.

The change of the temperature setpoint from 22 °C to 24 °C (winter) or from 27 °C to 25 °C, when the real time energy price is less than the average energy price, leads to energy efficiency and to reduction of the energy cost. In Greece the average energy price for the homes is 0,18 €/Kwh, while the real time energy price is between 0,06 €/Kwh and 0,12 €/Kwh.

3. Results

The results show that none of the loads are totally rejected when KNX automation system is used for load control actions instead of traditional on-off control [18]. In this paper we present the results of the HomeLynk server trends application in a single day of summer when the environmental temperature is 35 °C. In the Figure 4 is presented the low and the high electricity price during the day. As one can see the low-price periods are 24:00 – 06:00, 15:00 – 17:00 and 19:00 – 24:00. In the remaining time during the day there is the high electricity price. In the next two figures (Figures 5 and 6) we present the temperature setpoint and the room temperature. As one can see, in the low-price periods the temperature setpoint is 25 °C and in the high-price periods the temperature setpoint increases automatically to 27 °C.



Figure 4. Low price signal.

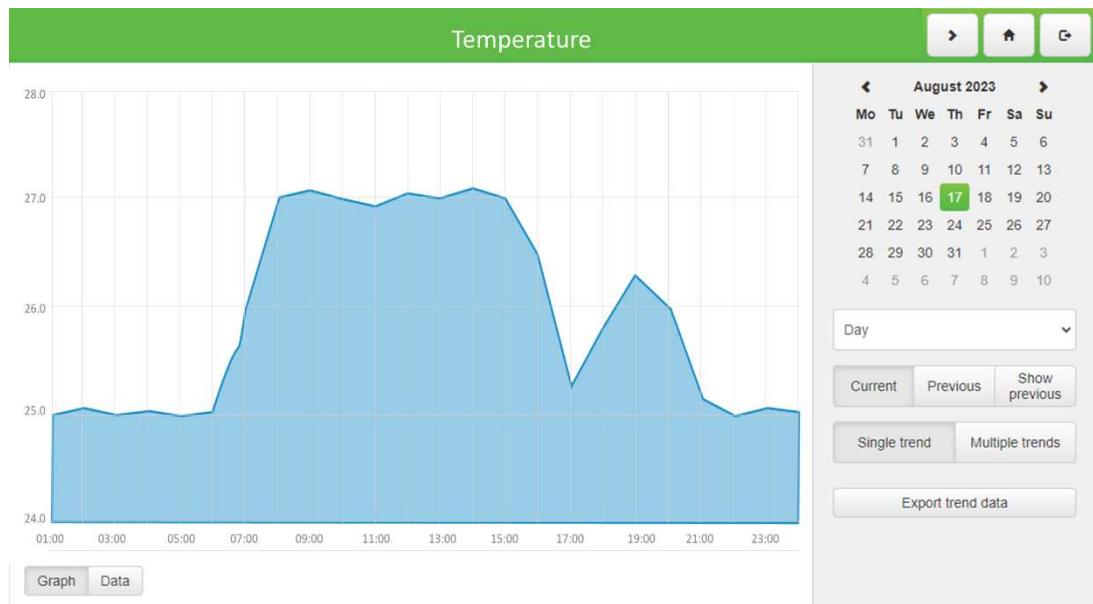


Figure 5. Room temperature.

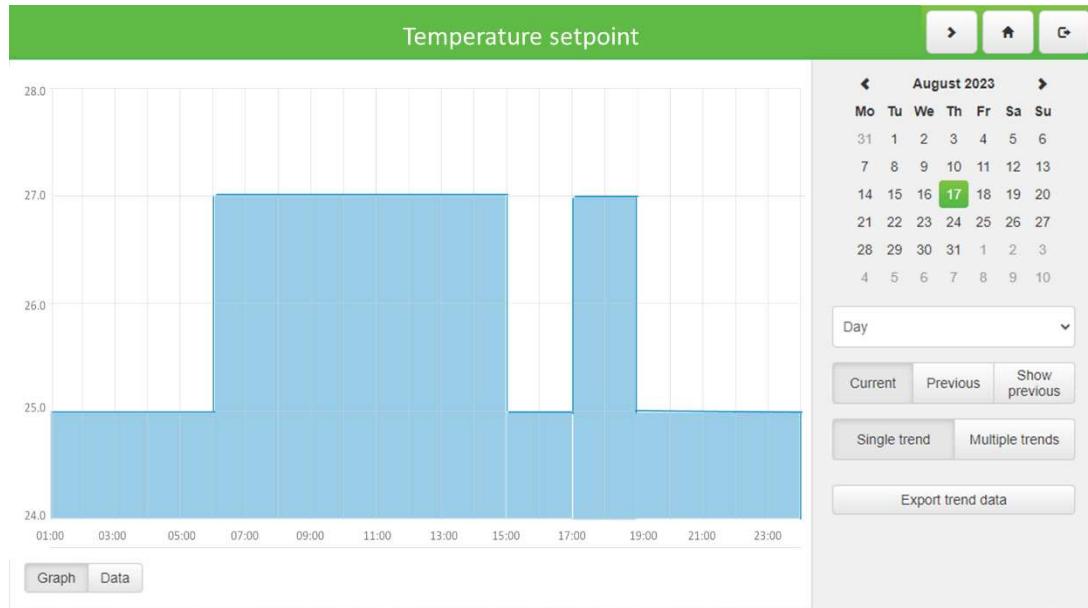


Figure 6. Room setpoint temperature.

In the next five figures (Figures 7–11) we present the room internal brightness according to the external brightness, the brightness of the lamps L1 and L2 and the energy consumption of the lamps L1 and L2. The lamps L1 and L2 are dimmed up. During the low price and the if the total room brightness is less than 200 lux the lamps are dimmed up at X % brightness as follows: internal brightness + X% brightness = 200 lux.

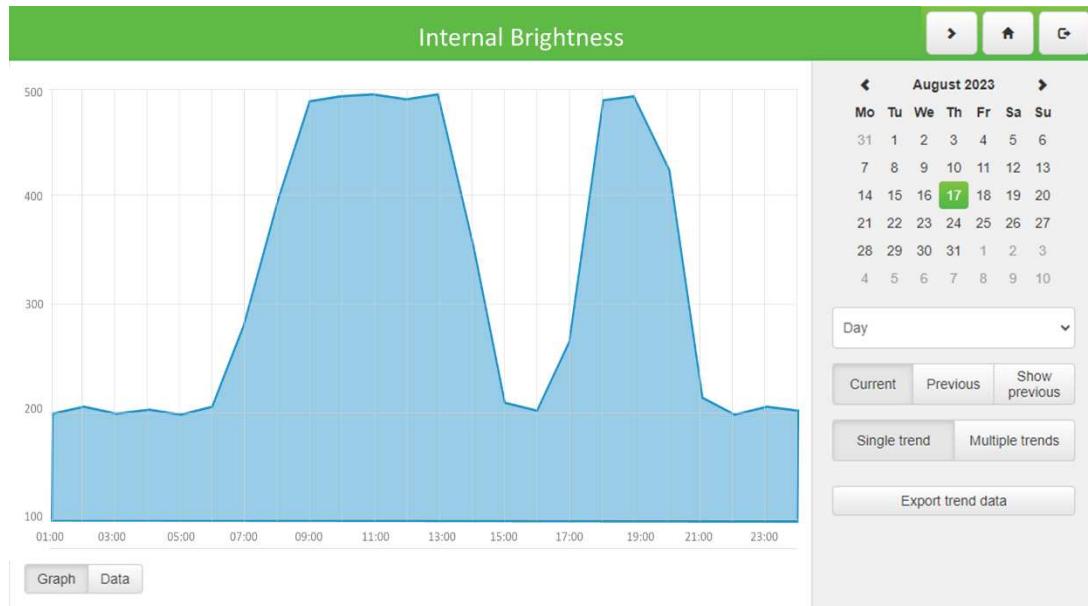


Figure 7. Room internal brightness.



Figure 8. L1 brightness value.

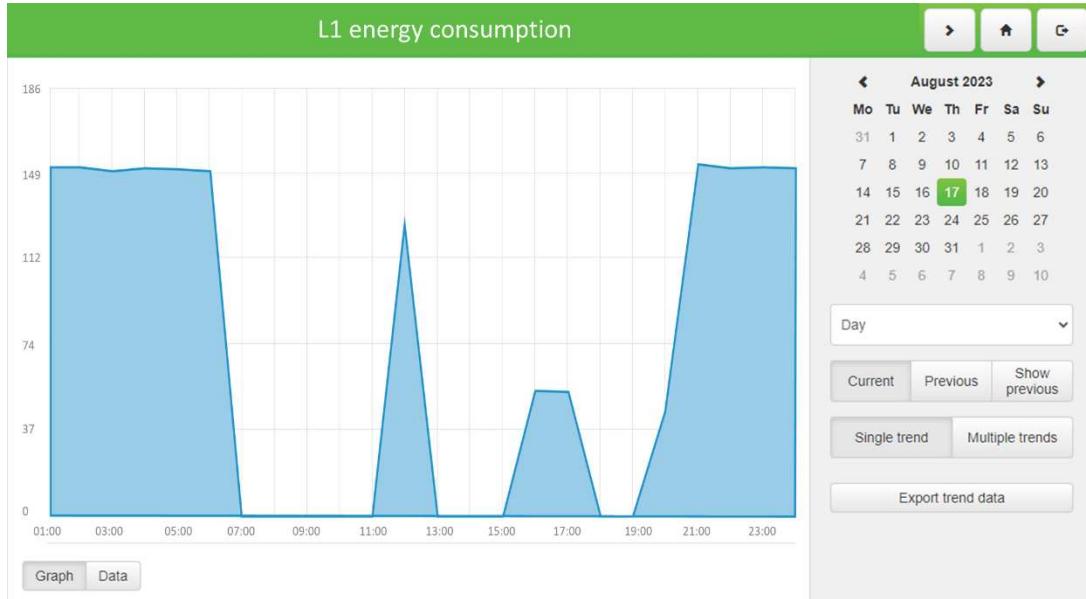


Figure 9. L1 energy consumption.

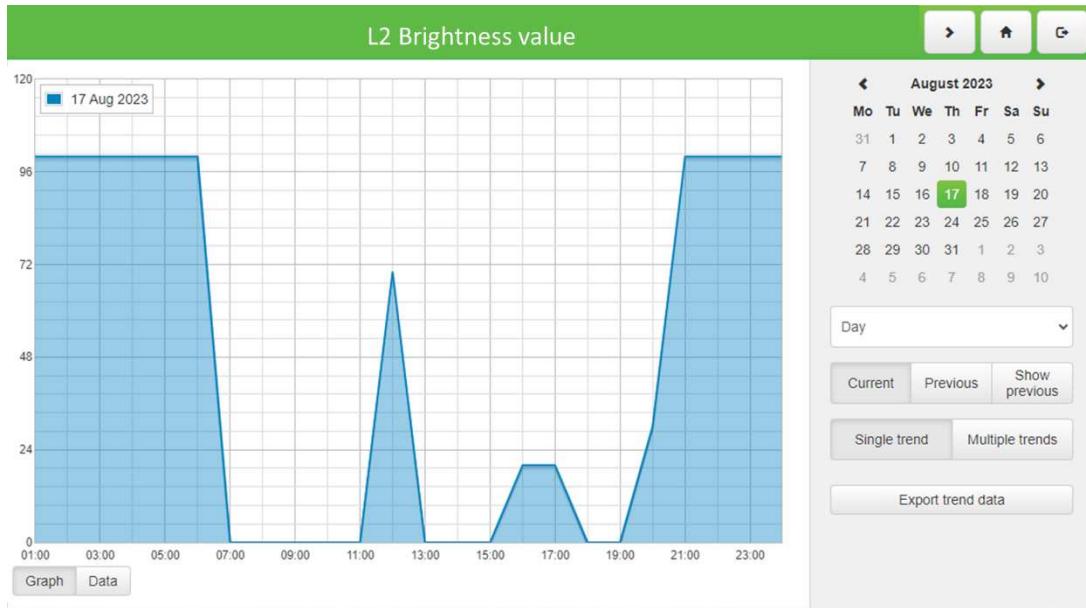


Figure 10. L2 brightness value.

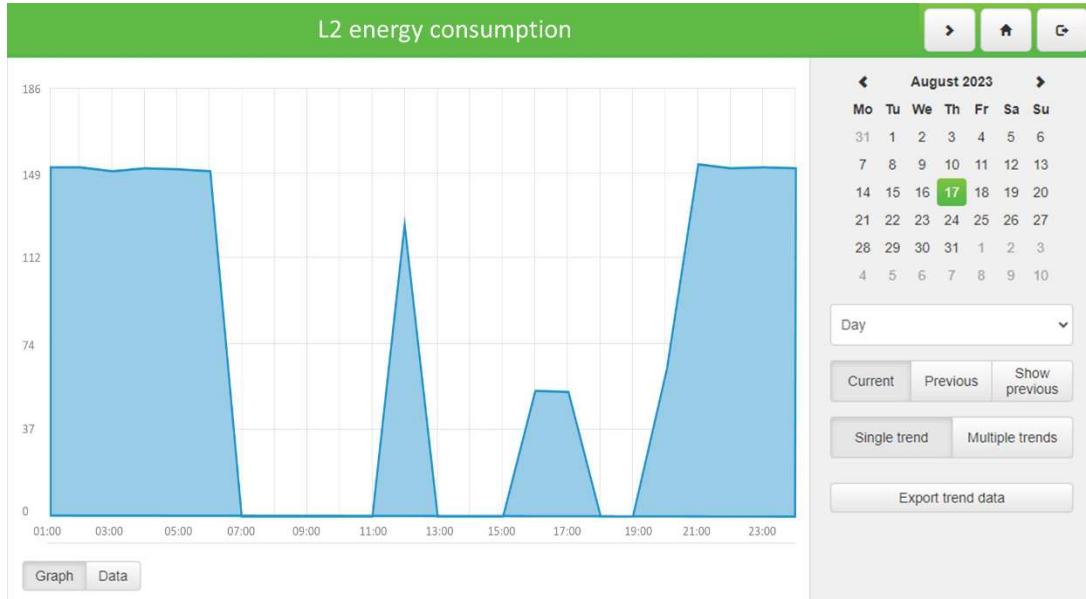


Figure 11. L2 energy consumption.

The Figure 12 below shows the motor energy consumption individually and the figure presents the motor energy consumption, the room setpoint temperature, the room temperature according to the low price.

In the Table 3 the results of the first experiment are presented

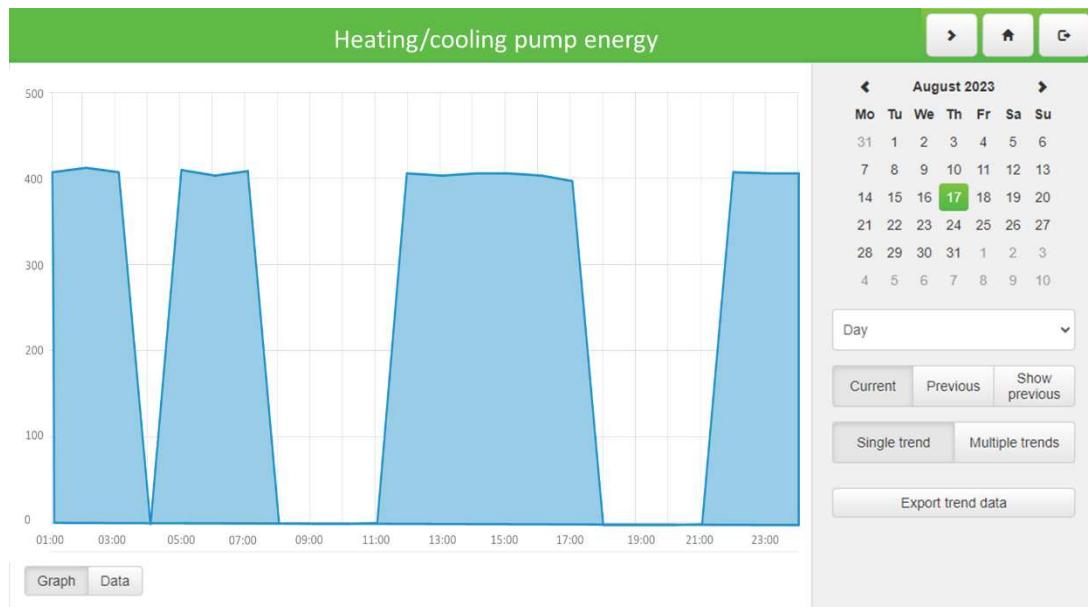


Figure 12. Heating/cooling pump energy consumption.



Figure 13. Low price, room temperature, setpoint temperature and heating/cooling pump energy consumption.

Table 3. Results during the day.

Hours	Temperature °C	Energy consumption Wh
01:00	25	403
02:00	25	406
03:00	25	403
04:00	25	405
05:00	25	403
06:00	25	403
07:00	25.7	404
08:00	27	0

09:00	27	0
10:00	27	0
11:00	27	0
12:00	27	403
13:00	27	406
14:00	27	403
15:00	27	405
16:00	26.5	403
17:00	25.3	405
18:00	25.7	0
19:00	26.2	0
20:00	26	0
21:00	25.1	0
22:00	25	405
23:00	25	403
24:00	25	405
Average	25.89	217.88

After these results a second experiment is following without the low-price signal and the HomeLynk algorithm. According to this, the energy consumption is presented when the setpoint temperature is always to 26 °C during the day. In the Table 4 the results of the second experiment are presented.

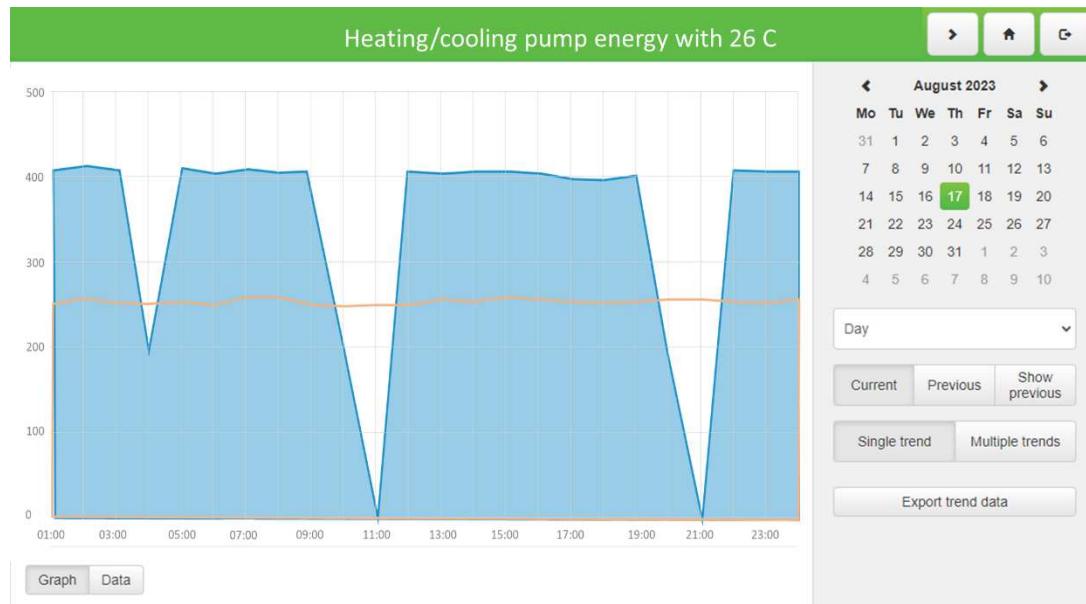


Figure 14. Heating/cooling pump energy consumption with temperature setpoint at 26 °C.

Table 4. Results during the day.

Hours	Temperature °C	Energy consumption Wh
01:00	26	403
02:00	26	406

03:00	26	403
04:00	26	205
05:00	26	405
06:00	26	403
07:00	26	407
08:00	26	403
09:00	26	405
10:00	26	203
11:00	26	0
12:00	26	403
13:00	26	406
14:00	26	403
15:00	26	405
16:00	26	403
17:00	26	405
18:00	26	403
19:00	26	406
20:00	26	196
21:00	26	403
22:00	26	405
23:00	26	403
24:00	26	405
Average	26	361.91

By comparing Tables 3 and 4, the suggested system transfers the selected load (heating/cooling pump) to a time with low electricity prices and the total energy consumption is 217.88Wh with an average room temperature 25.89 °C, instead of 361.91Wh with an average temperature 26 °C.

Taking account only the energy consumption of the heating/cooling pump and an average environmental temperature in the summer of 35 °C, the monthly energy cost savings are too high. The total monthly energy consumption is lowered to 6,536.4 Wh instead of 10,857 Wh, reducing by 40%.

The suggested BMS schedules the lab appliances based on the tariff category, which changes based on the total accumulated usage during the day. The proposed BMS take two major factors into account in order to provide a comfortable lifestyle for the users. Users can change the ambient temperature to their favorite region. Recent smart homes allow for a variety of room inhabitants. The best schedule of inhabitant rooms, i.e., the comfort zone, is determined and advised to home owners. The area covered by a heating/cooling pump (chiller) is simply adjusted to minimize energy consumption by designating comfort zones, i.e., room/rooms that vary depending on the available tariff category. Second, all appliances can be switched manually to satisfy the sudden wants of home residents.

4. Discussion

The next steps of the research of the authors include the integration of energy storage (14,4 kWh batteries and 2 hydrogen fuel cells of 1,1 kW each) into the microgrid, which will also be controlled by KNX decentralized algorithms, highlighting also the impact of energy storage in grid stability and

grid ancillary services indices, as well as comfort indices. Installing a battery will increase probably the economic benefits of the home PV system. Vehicle-to-home will be studied also as an alternative source for smart homes. Therefore, there will be economic benefit of using electric vehicle batteries as a home source with the studied slab tariff.

5. Conclusions

Many developing countries, including Greece, use IBR tariffs for residential structures or "homes." There have been no significant studies on this popular tariff in relation to smart homes.

The suggested BMSs rely primarily on a load-shifting technique, which moves controllable loads to low-cost periods to avoid high loading during peak hours. Many BMSs minimize some loads, such as heating/cooling pumps and lighting, to reduce total spent energy. All of these options were investigated for the IBR pricing structure.

This research looks at a developing country's household energy system that uses the Greek block-rate tariff.

Because of the block-rate tariff structure, shifting loads such as heating/cooling pumps and lighting has a small influence on total electrical cost. The total monthly cost could be reduced to 40% of the default value..

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