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A physically-based model for simulating inverter type air conditioners/heat pumps

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A R T I C L E I N F O

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A B S T R A C T

The engagement in demand response activities is increasingly becoming more attractive for several entities in the power systems sector. In general terms, the main goal of such activities is to change the demand level and patterns by implementing management actions over groups of loads to minimize peak demand or electricity bill, maximize profits or increase the systems reliability, among other objectives. However, in order to avoid potential undesirable impacts it is necessary to anticipate and adequately assess the changes in demand originated by such actions. This assessment requires adequate simulation tools and models with the ability to simulate demand management actions. This work presents a physically-based model that allows reproducing the behavior of an inverter type heat pump. This model can be used to simulate the demand of an individual device or several devices. Besides, it allows simulating and assessing the impacts of implementing demand management actions over this type of end-use loads. The results show that the model can effectively reproduce the demand of this type of equipment, becoming a useful tool for the prior assessment and even the design and selection of demand response actions to be applied over these loads.

1. Introduction

Demand response activities are increasingly attracting the attention of several entities, not only as a useful tool to improve the reliability [1,2] and the efficiency of power systems operation [3,4] or to postpone the investment in new capacity but also as an alternative resource that can be used in electricity markets [5e7]. Therefore, those activities become interesting for grid operators and regulators, being also an attractive way of potentially increasing the retailers' profits and at the same time eventually decreasing the costs of their customers [8,9] or even as a tool enabling a higher penetration of renewable sources [10e12]. The evolution of the smart-grid concept, also encompassing end-user loads and the development of enabling technologies both at electricity grids level and end-users level, will make possible to establish bi-directional communication channels between supply and consumption, thus allowing the development of new scenarios in which demand can respond to multiple signals or stimuli, such as dynamic electricity prices, emergency requests, available onsite generation. The use of demand responsive measures as a potential way to maximize the integration of renewable energy sources, namely small size generation units, dealing with their variability and/or voltage profile changes is of utmost interest since it can be seen as an alternative to expensive backup systems (mainly naturalgas combined cycle or hydro power plants). This leads to a para- digm change, since wires acquire a more active role and demand isno longer an uncontrollable load that must be served. No matter theobjective of using demand as an available resource that can be partially controlled, the integrated management of resources in power systems requires an adequate prior assessment of its impacts. The availability and the controllability of demand have been studied and the conditions to be fulfilled for demand to be considered a controllable resource have been analyzed [13e15]. Several studies and tools have been developed attempting to foresee the impacts of such demand management. There are two key issues to be dealt with during the implementation of load management programs. The first one is the design and selection of adequate management strategies [16e18] according to the objec- tives to be pursuit. Refs. [19,20] report demand-side management activities implemented by utilities. The second issue is the devel- opment of suitable models able to simulate the functioning of controllable demand without and with the application of load

[29].

management actions [21,22] thus allowing the prior assessment of

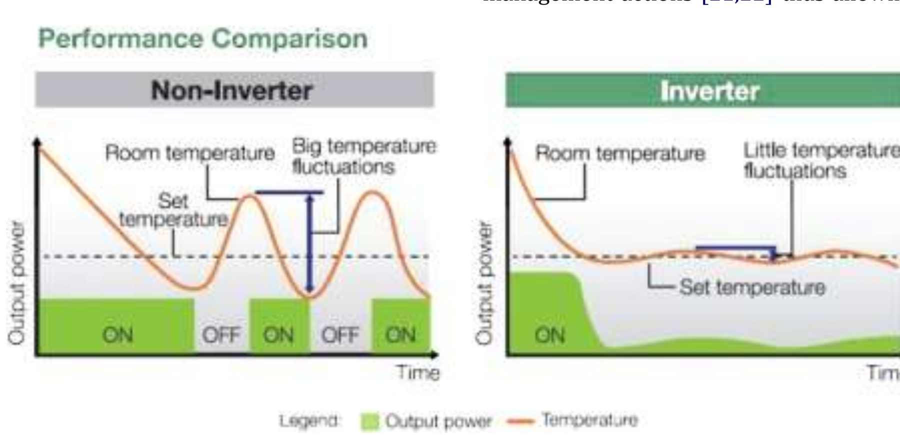


Fig. 1. Temperature and functioning of AC systems

their impacts.

With respect to modeling tools, it is recognized that physically-based load models (PBLM) are adequate to assess the impacts of management strategies [17,21,23]. These models reproduce the physical phenomena associated with storage-type loads - loads controlled by thermostats, which are usually the most appropriate loads for demand management actions. The demand of thermostatic loads is determined by the temperature of the fluid being cooled/heated. Once PBLM track the temperature of the fluid they enable the identification of the end-use load profile, both without and with the implementation of management actions. The analysis and the impact assessment of implementing control actions on the quality of energy service provided are also possible. An important characteristic that modeling tools should present is the ability to simulate the demand of groups of end-use loads. Typically, load management actions are implemented over groups of loads. Entities that may be interested in these activities are the system/grid operators, retailers and aggregators; therefore, simulation tools should be able to simulate demand with different aggregation levels. That is, they should enable to mimic the demand at, for instance, distribution power transformers level or at sub-stations level (feeding several distribution transformers) or simulating the demand of a group of customers of a given retailer. Due to the way PBLM are built up they fulfill this scalability requirement.

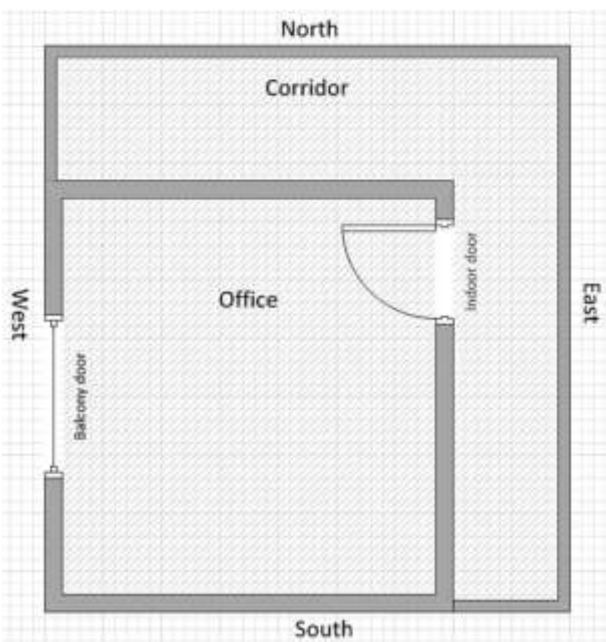


Fig. 2. One of the rooms used in the experiments.

The need for adequate load models has long been realized and can be witnessed by the number of publications dealing with demand modeling and simulation [24e26]. Despite some diversity, which is related not only with the individual load models but also with the aggregation process, all of those works have in common the same objective: reproduction of physical phenomena that occur in thermostatic loads. At the individual level, the main differences lie on the simplifications that are usually necessary to make the detailed and complex individual models suitable for practical use, even if a specific usage is envisaged. Some of this complexity arises from the stochastic behavior of demand generally taken into account in demand management programs. Such behavior results from the energy service usage, which is random in nature, and from weather factors, which largely influence the demand of some loads, namely air conditioners and space heaters.

The remaining of the paper is as follows. In Section 2 the different contributions for heat loads in space heating/cooling are characterized. In Section 3 the model developed for simulating individual inverter type air conditioners is presented and some results are analyzed. In Section 4 the simulation of groups of loads is described. In Section 5 a simulation based case-study is presented, followed by some conclusions in Section 6.

2. Load simulation

When the regular working cycle of thermostatic loads is changed by an external action the demand pattern over the subsequent periods of time may also be changed. What makes PBLM attractive is their ability to capture these changes and thus to predict the consequences of load control actions on the load diagram - both from the point of view of maximum demand reductions and the payback effect. This effect consists in an increase in the peak demand during the restoration of loads after a period of

Table 1
Characteristics of the room.

External walls (m^2)	19.8
Internal walls (m^2)	19.8
External door (m^2)	2.8
Internal door (m^2)	1.5
Thermal conductivity (W/m^2 °C):	
External walls (W/m^2 °C)	0.86
Internal walls (W/m^2 °C)	2.42
Glazing (W/m^2 °C)	4

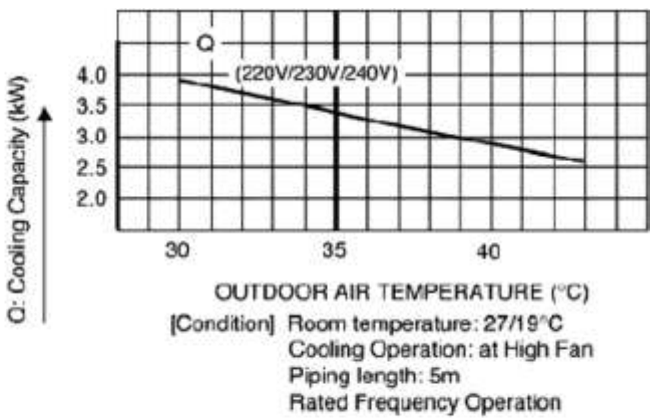


Fig. 3. Cooling capacity as a function of the outdoor temperature [29].

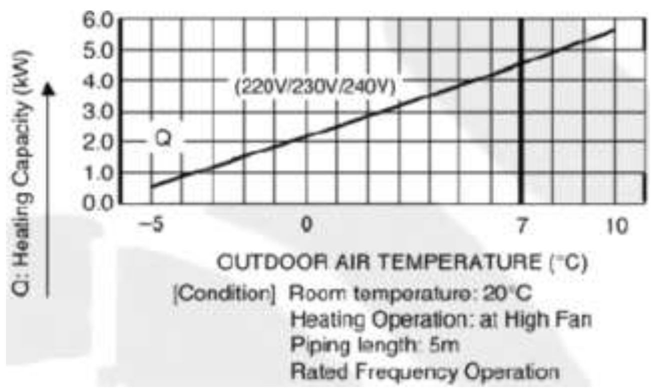


Fig. 4. Heating capacity as a function of the outdoor temperature [29].

forced interruption when compared with the demand that would exist if no load management (LM) actions have been applied. Therefore, tools such as PBLM allowing the simulation of load diagrams (LD) and with the capability of capturing the effects of LM actions are needed.

The heat load imposed to the heat pump (HP) systems, $Q(t)$, has four main contributions [21,27]: heat transmission through the envelope (walls), heat transfer through the windows e insolation, internal heat sources, and renewal of the indoor air-ventilation. The heat transfer through the envelope is due to the difference of indoor and outdoor temperatures. Insolation load is the thermal load due to the solar energy going through windows or stored and released by an opaque element of the envelope. It presents a diverse behavior according to the element of the envelope and its orientation. Thus, the heat gain through the opaque elements of the envelope presents a delay and a reduction factor that should be taken into account in the calculation of its contribution to the heat load. Insolation load through glazing depends on the physical characteristics of the windows such as transmission, absorption and reflection. It also depends on the time of year and solar hour. The internal heat load from persons, lighting and equipment should also be taken into account. So, with respect to temperature there are two main reasons why an HP is required to be functioning:

- To increase/decrease the amount of thermal energy stored in the fluid that is being conditioned;
- To counterbalance the losses.

The thermal load imposed to HPs can be changed by:

- Changes in sensible heat: transfer through the envelope due to the difference of indoor and outdoor temperatures, internal sources, solar radiation through the envelope, renewal of the indoor air;
- Changes in latent heat: people, renewal of the indoor air by outdoor air with a different moisture level.

When moving thermal energy from a low temperature fluid to a high temperature fluid, heat pumps use electricity in order to provide the adequate amount of work. The relationship between electric power needed to drive an HP and the heat power is given by the Coefficient of Performance (COP) when the HP is in heating mode and by the Energy Efficiency Ratio (EER) when it is in cooling mode. COP and EER can be seen as the ratio between heat power and electric power and are a function of the ambient temperature. When HP devices are running the amount of energy available for cooling (heating) the room is given by $[P(t) - Q_T(t)]\Delta t$, where $P(t)$ is the value obtained multiplying the electric power of the HP by the EER (COP). When in cooling mode, the indoor temperature is given by $T(t + \Delta t) = T(t) - [P(t) - Q_T(t)]\Delta t / mc_p$, when the HP is on, while when it is off the temperature is given by

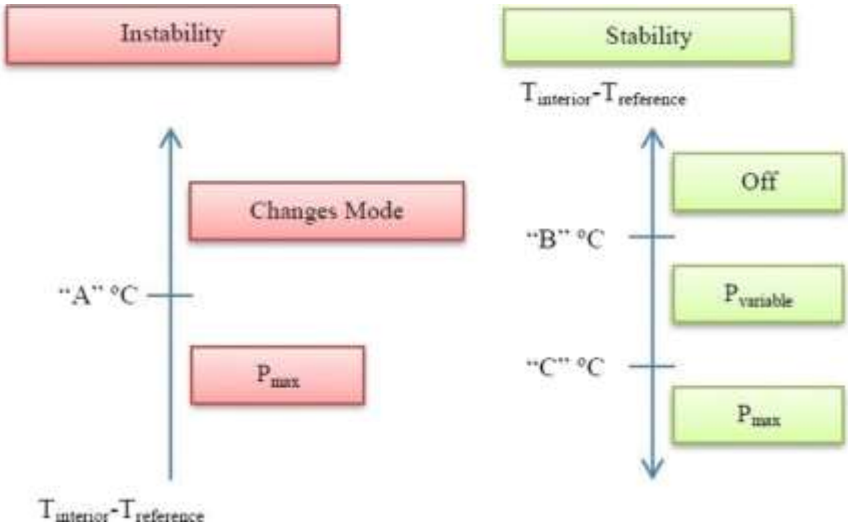


Fig. 5. Inverter unit e heating mode [28].

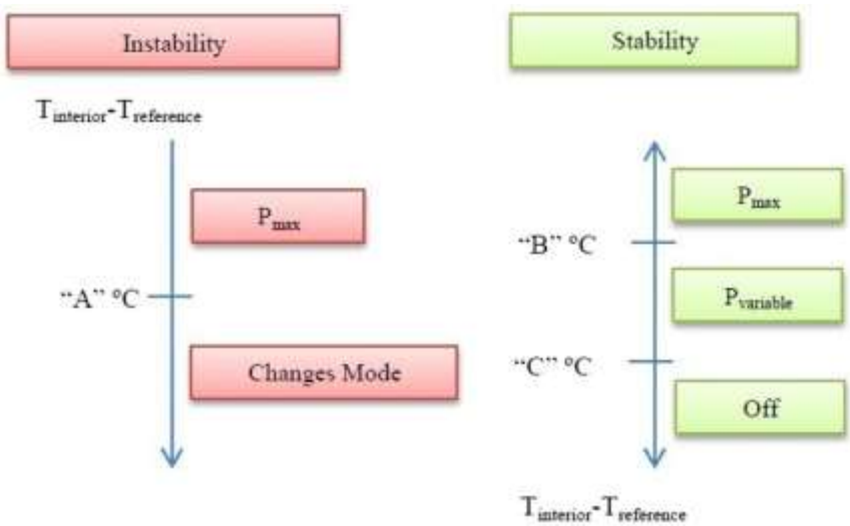


Fig. 6. Inverter unit e cooling mode [28].

$T(t+\Delta t) = T(t) + [Q_T(t)]\Delta t / mc_p$. $T(t)$ is the indoor temperature, m is the amount of air and c_p is the specific heat of the air. This is the model that has been implemented in this work to reproduce the functioning and the electrical demand of HP/AC devices. The hardest task is associated with the computation of the heat load in the rooms being cooled/heated, due to the number of parameters needed for an adequate heat load calculation and also due to the stochastic behavior of some of them. Other issue raised by LM programs and related with the parameters is their representation in time. While for studies related with the buildings thermal behavior and the identification of the suitable capacity of heating, ventilation and air conditioner devices the extreme values for parameters are usually enough, LM studies ask for some time detail (resolution) for each parameter. This is an extra effort that must be undertaken in order to be able to implement suitable load models [21].

3. Inverter type heat pump

The demand for heating, ventilation and air conditioner loads has substantially increased in recent years, and in some situations this has greatly contributed for changing daily load diagrams. Heat pumps and air conditioners move thermal energy from one space (fluid) to another space (fluid) at higher temperature. The amount of heat to be "moved", the desired temperature and the efficiency of the engine determine the electricity to be used in order to develop the necessary work to transfer the heat. As the amount of work to be done varies over time (due to the variation of temperature and heat load) recent equipments use variable speed drives to more efficiently control the way the work is done. These devices, known as inverter type devices (henceforth called inverter AC or inverter HP), instead of the traditional on/off operating cycles, are kept running at an adequate rate to maintain the indoor reference temperature.

The cyclic functioning of "traditional" systems is determined by the thermostat that, when the AC runs in cooling (heating) mode,

Table 2
"A" values according to the outdoor temperature [28].

Mode	Outdoor temperature, T_{out} °C	Value of A

switches the AC on when indoor temperature is above (below) the maximum (minimum) allowed temperature, and turns the AC off when indoor temperature goes below (above) the minimum (maximum) desired temperature. Unlike “traditional” on/off air conditioners that either run at full power or do not run, inverter systems draw an amount of power from the grid that is propor- tional to the heat gains/losses of the room. Inverter AC systems are driven by variable speed drives which impose a continuous func- tioning but at variable speed according to the heat load. In this way the indoor temperature does not vary as much as it varies whena traditional AC is used (Fig. 1).

Several experiments have been carried out to experimentally validate the model. The characteristics of one of the rooms cooled/ heated by the inverter heat pump being analyzed are shown in Fig. 2 and Table 1. Some characteristics of the heat pump are dis- played in Figs. 3 and 4. For a given equipment, the efficiency with which the heat is moved from indoor (outdoor) to outdoors (indoors) depends on the air temperature, i.e. the COP/EER is a function of the temperature. This characteristic of each equip- ment was taken into consideration in the model. Figs. 3 and 4 show, respectively, the cooling capacity and the heating capacity of the HPdevice under study [28].

A distinctive characteristic of inverter devices is that when an inverter system is switched on and the indoor temperature is far from the desired one, the inverter system runs at high speed, therefore allowing to bring quickly the indoor temperature back to the desired value (Figs. 1 and 8). The same behavior occurs when there are high fluctuations of indoor temperature. This high speed operation mode is sometimes called “instability mode”. In this operating mode devices typically run at rated power, or even at higher power values. When the difference between the indoor temperature and the reference temperature is small, the inverter system runs at lower speed also called “stability mode”. In this operating mode the device runs at variable speed drawing a vari- able power from the grid (lower than the rated power). The range of the temperature differences that makes the inverter system to

Table 3
A values according to the outdoor temperature [28].

Mode	Outdoor temperature, T_{out} °C	Value of A
Cooling	$30 \leq T_{out}$	þ0.5 °C
	$T_{out} < 30$	þ1.0 °C
Heating	$9 \leq T_{out}$	—1.0 °C
	$5 \leq T_{out} < 9$	—0.5 °C
	$1 \leq T_{out} < 5$	0.0 °C
	$T_{out} \leq 1$	þ1.0 °C

Table 4
Inverter HP e characteristics [28].

	Cooling capacity (kW)	Heating capacity (kW)	EER COP	Electrical data	
				Voltage (V)	Current (A)
Heating		4.8 (0.8e6.5)	3.81	230	5.8
Cooling	3.5 (0.8e4)		3.63	230	4.5

Table 5
Inverter HP - power and EER as a function of the outdoor temperature (heating mode).

Power (kW)	0.8	1.11	1.42	1.73	2.04	2.35
T outdoor (°C)	—5	—4	—3	—2	—1	0
EER	0.63	0.88	1.13	1.37	1.62	1.86
Power (kW)	2.66	2.97	3.28	3.59	3.9	4.21
T outdoor (°C)	1	2	3	4	5	6
EER	2.11	2.35	2.60	2.85	3.09	3.34
Power (kW)	4.52	4.83	5.14	5.45	5.76	6.07
T outdoor (°C)	7	8	9	10	11	12
EER	3.59	3.83	4.08	4.32	4.57	4.82

Table 6
Inverter HP e power and COP as a function of the outdoor temperature (cooling mode).

Power (kW)	3.70	3.61	3.51	3.42	3.33	3.24	3.15
T outdoor (°C)	30	31	32	33	34	35	36
COP	3.85	3.76	3.66	3.56	3.47	3.37	3.28
Power (kW)	3.05	2.96	2.87	2.78	2.68	2.59	250
T outdoor (°C)	37	38	39	40	41	42	43
EER	3.18	3.08	2.99	2.89	2.80	2.70	2.60

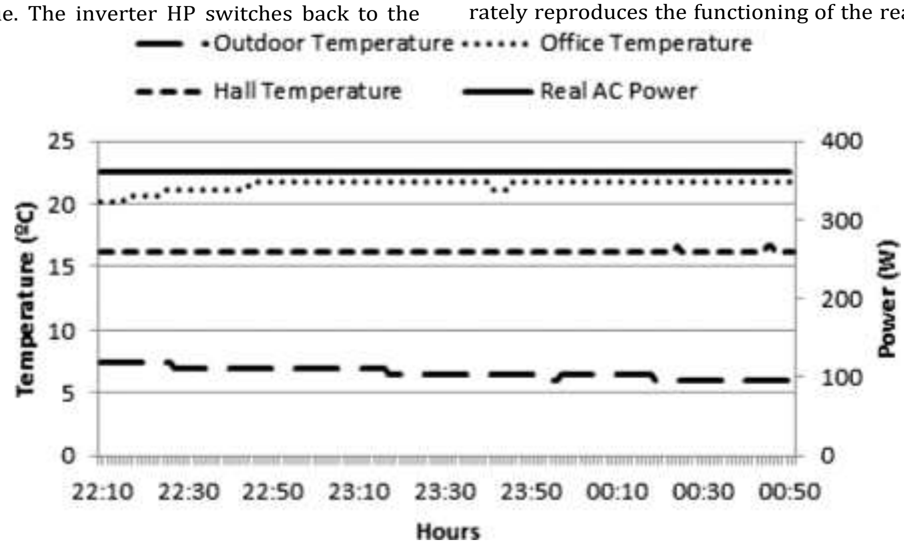
switch between a high speed operation and a low speed operation mode depends on whether the inverter is heating or cooling the room. Figs. 5 and 6 illustrate these functioning modes.

Tdif is the difference between the current indoor temperature and the desired one. The functioning in heating mode is as follows. When the inverter HP is switched on it operates in "instability" mode while the *Tdif* is below *A* (Fig. 5), then it switches to "stability" mode. The aim is to quickly approach the desired temperature and then keep the indoor environment as close as possible to the desired temperature. When operating in the "stability" mode the compressor runs at a variable speed keeping the indoor temperature around the desired value. The inverter HP switches back to the "instability" mode only if *Tdif* goes beyond *C* °C (the indoor temperature is far from the desired value). If the indoor temperature is much higher than the desired value, that is, the difference is above *B* °C, the inverter HP turns off (the indoor temperature is above the desired value). *B* and *C* may be set by users and typical values are 2 °C and —2.5 °C, respectively. The value of *A* depends on the outdoor temperature, as can be seen in Table 2.

When in cooling mode the inverter HP behaves in a similar way as in heating mode (Fig. 6). It is in "instability" mode while the difference between the indoor temperature and the desired one exceeds *A* °C, then it switches to "stability" mode. *A* depends on the outdoor temperature as can be seen in Table 3. If *Tdif* is below *C* °C the inverter HP switches off. If *Tdif* is between *B* and *C* it runs at variable speed trying to keep the indoor temperature as close as possible to the desired one. *B* and *C* may be set by the users and typical values are 2.5 °C and —1.5 °C, respectively. If *Tdif* is higher than *B* then the inverter system runs at full power. After the transient period that occurs when the indoor temperature is far from the desired value the inverter HP system enters in steady state operation. Table 4 shows the generic characteristics of the HP being tested, while Tables 5 and 6 and 66 show the EER and the COP of the HP [28] as a function of the temperature, computed as displayed in Figs. 3 and 4.

Several data acquisition campaigns have been carried out on both modes: cooling and heating. The values obtained in the experiments have been compared with the results obtained from the simulations resorting to the PBLM. The average results show that the differences between the results obtained with the model and the values monitored are less than 1% when in the heating mode, while the differences are less than 2% when in cooling mode. Fig. 7 displays the data collected during one heating mode period (22:00e01:00 h).

At 23 h the outdoor temperature was 7 °C, the room temperature 21.67 °C (office temperature) and the temperature in indoor adjacent rooms 16.19 °C (hall temperature). The power drawn from the grid was 360 W (real AC power). As the COP is 3.59 then the thermal power being introduced by the inverter AC into the room is 1292.4 W. The total computed losses are 1296.94 W, which is only 0.35% higher than the monitored results. In this period of time the real device consumes 747 Wh while the result of the simulation carried out with the model is 743.8 Wh, which corresponds to a difference of just 0.43%. When in stability mode the PBLM accurately reproduces the functioning of the real device.



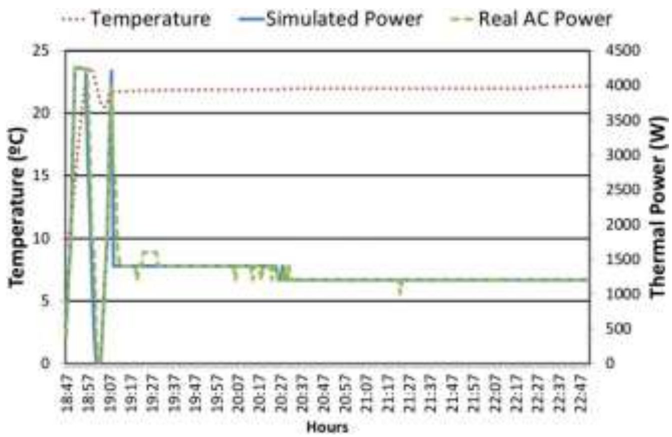


Fig. 8. Results from the model and monitored from physical device.

Fig. 8 shows the results obtained during an instability period in which the indoor temperature (9 °C) was far from the desired value (22 °C). The inverter air conditioner worked at higher speed thus quickly heating the room; then it entered a low speed functioning (stability mode) for maintaining the indoor temperature. Despite very small differences in the transient period, the behavior of the simulated model and the real device is very similar. The instability period duration is very similar and the differences regarding energy consumption are only about 1.84%. In Table 7 the results of three different heating periods are shown.

Similarly, the validation of the model in cooling operation required several experiments to be carried out. Fig. 9 shows the indoor temperature, the real AC power and the power of the simulated device. The difference in energy consumption is about 0.95%. Table 8 shows the results obtained in three cooling periods.

From the results obtained, regarding the energy consumption, indoor temperature and power drawn from the grid over time, we can conclude that the PBLM developed is able to reproduce with adequate accuracy the functioning of the real device both in heating and cooling mode.

4. Simulating the demand of groups of loads

The ability to simulate the demand of groups of heat pumps/air conditioners is essential to characterize the demand of this type of loads at an aggregate level and assessing the impacts of load management activities in the load demand diagram of a group of a retailer's customers or a sub-station, for example. In order to simulate the demand of a set of loads resorting to the individual PBLM the aggregation of average demands of individual loads is done, being the average individual demand obtained through Monte Carlo simulations, in which some parameters characterizing the individual loads and the spaces being cooled/heated may change according to a probability distribution previously identified. Some of the parameters that can change are, for instance, the weather parameters, the usage of the energy service or the internal

Fig. 9. Results from one cooling period.

thermal loads. Some other parameters, like the power demand, the physical characteristics of the envelope, and the COP/EER do not change during the Monte Carlo simulations carried out to identify the average load demand of an individual end-use load, but may change when obtaining the average load diagram of a group of loads. These changes also follow distribution probabilities previously identified in field works. Obtaining the average demand of a big number of loads requires performing the Monte Carlo simulations for every single load. The software tool developed allows to feeding each individual load and every individual room with different parameters. It is also able to compute different values for different parameters starting from a given seed resorting to a given distribution probability.

The external walls of the room being cooled have a thermal transmission coefficient of 0.86 W/°C m^2 with a total area of 17 m^2. Glazing area is 5 m^2 with 2.66 W/°C m^2 for transmission coefficient and a 0.5 shading coefficient. Maximum value of outdoor temperature is 35 °C. The regular functioning of the "traditional" on/off HP between 2pm and 3pm and the evolution over time of indoor temperature is shown in Fig. 10, while Fig. 11 shows the regular working cycle of the inverter HP in the same period of time.

Comparing Figs. 10 and 11 it is possible to conclude that the indoor temperature variations with the invert HP are lower than those occurring with traditional on/off HP. The load diagram of traditional HP is the typical one with "off" periods in which the indoor temperature rises followed by "on" periods in which indoor temperature falls. The energy consumptions are 346.67 Wh and 363.33 Wh for the traditional HP and for the inverter HP, respectively. It was expected that the amount of electricity used by the on/off device and by the inverter type HP was similar since the room is the same and the technical characteristics of the HP (power and COP/EER) are also the same. However, there is a significant difference regarding the power drawn from the grid. Unlike traditional on/off devices, when inverter systems are cooling/heating they are always using some power to move indoor heat to outdoors, the amoun of used power depending on the heat load in every

Table 7
Values obtained in three different heating periods.

Data analyzed	Heating intervals		
	1st	2nd	3rd
Reference temperature (°C)	22	22	22
Length of interval (min)	245	94	103
Real AC energy (Wh)	1695	747	822
Simulated AC energy (Wh)	1664	738	808
Difference %	1.84	1.23	1.73

Table 8
Results from three different cooling periods.

Data analyzed	Cooling intervals		
	1st	2nd	3rd
Reference temperature (°C)	23	23	24
Length of interval (min)	157	155	138
Real AC energy (Wh)	1159	1162	1092
Simulated AC energy (Wh)	1148	1155	1100
Difference %	0.95	0.6	—0.73

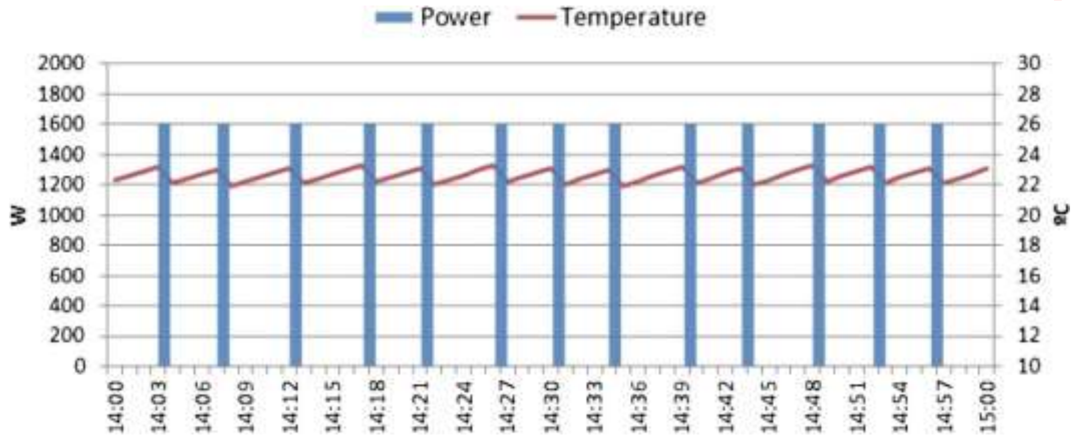


Fig. 10. Regular working cycle of a traditional HP.

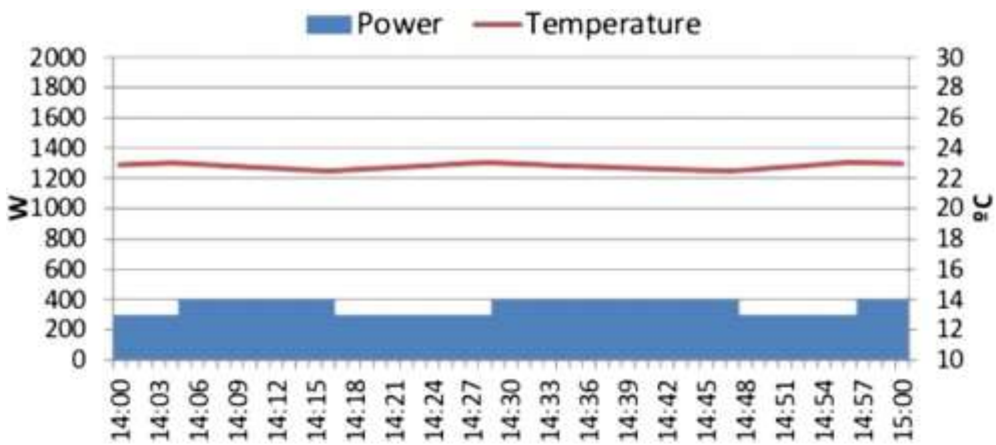


Fig. 11. Regular working cycle of an inverter HP.

moment. These differences should be taken into consideration when designing load management actions to be implemented over this type of loads. In Fig. 12 it can be seen that when the power demand of inverter type HP increases the traditional on/off HP is running during more time ("on" time periods last longer and "off" periods are smaller).

5. Assessing the impacts of direct load control

One interesting characteristic of PBLM is the ability to simulate control actions, i.e. it is possible to simulate the demand of loads when control actions are implemented and assess the impacts of such actions. A simulation based comparative analysis of the traditional HP and the inverter HP responses to a direct control action is presented below. A cycling control strategy "20 min on þ 5 min off" has been applied to the heat pumps in cooling mode. When applying these control strategies to the traditional on/off HP the indoor temperature increases, and the maximum value reached depends on the indoor temperature value when the HP is turned off.

From Fig. 13 we can see that the indoor temperature reaches values between 21.4 °C and 24.9 °C. For inverter systems, Fig. 14, the indoor temperature also increases but the maximum value does not change as it does for the on/off systems, since inverter systems keep the indoor temperature around the desired value. In this case, the indoor temperature reaches values between 22.17 °C and 24.7 °C. For this room/HP set, the control strategy allows both equipments to restore the desired temperature during the on period in the room being cooled.

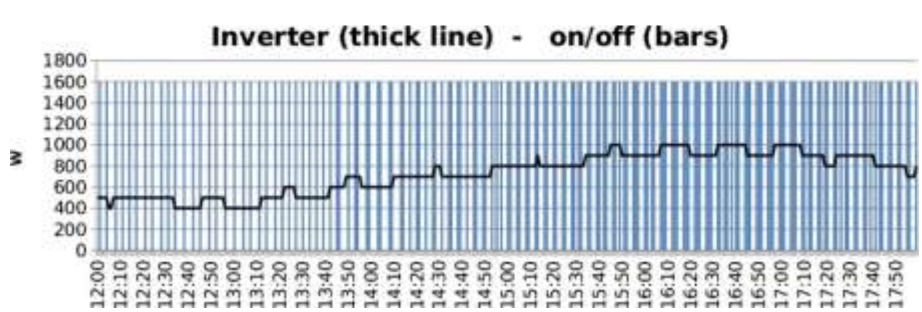


Fig. 12. Inverter type and on/off type functioning.

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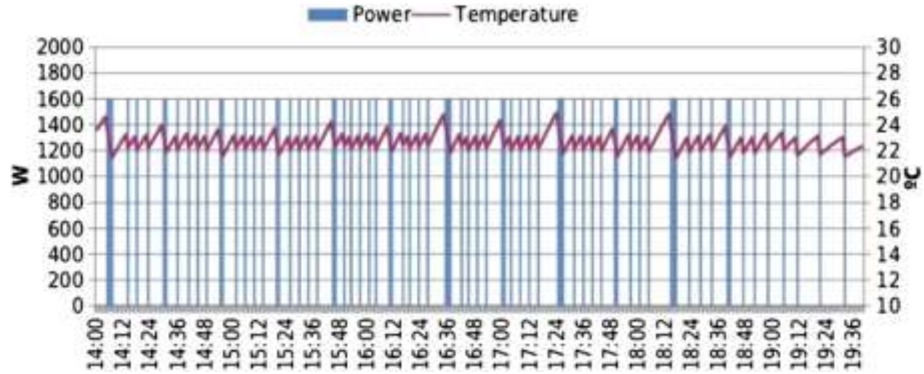

Fig. 13. Indoor temperature and load diagram after a load control (20on þ 5off) has been applied e traditional AC.

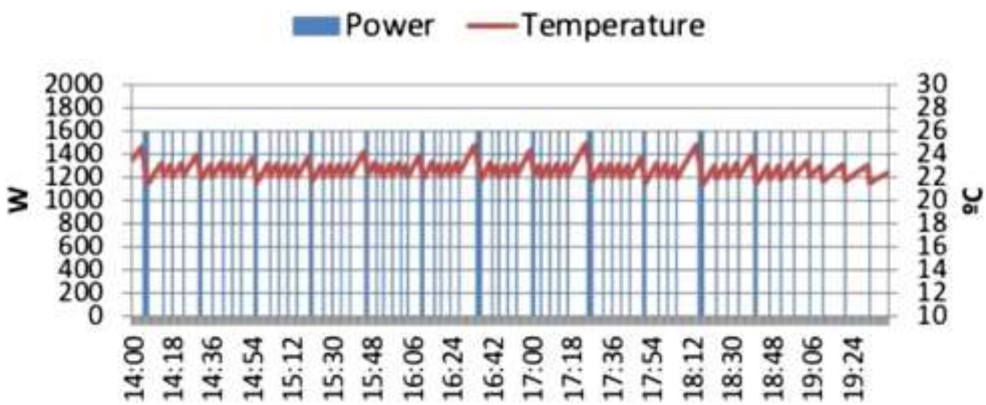

Fig. 14. Indoor temperature and load diagram after a load control (20on þ 5off) has been applied e inverter AC.

An interesting characteristic of the inverter type H is its ability of using higher power values than the nominal power, thus quickly restoring the desired indoor temperature in the room being cooled/heated. This behavior was simulated and the results are shown in Fig. 15. It can be seen that the HP runs at 1.9 kW, higher than the nominal power 1.6 kW, quickly bringing the indoor temperature closer to the desired value. Also, the maximum temperature reached was 24.7 °C, slightly higher than the maximum value when the HP runs at the rated power. It must be pointed out that when the inverter devices are running at higher speed (power) and the indoor temperature is close the desired value, inverter devices change their functioning to a mode in which the power drawn is lower than the rated value (Fig. 8). The major difference when comparing the functioning of inverter HP at 120% of the rated power and running at only 100% of the rated power is that the indoor temperature approaches more quickly the desired value and there are not major differences regarding the maximum indoor temperature provoked by load control actions.

A second cycling control strategy, “20 min onþ10 min off”, has also been applied to the air conditioners. The impacts on both the indoor temperature and the load diagram can be seen in Fig. 16 for the traditional HP and in Fig. 17 for the inverter HP. When the load control action is applied to the traditional and inverter HP the temperature increases up to 26.5 C.

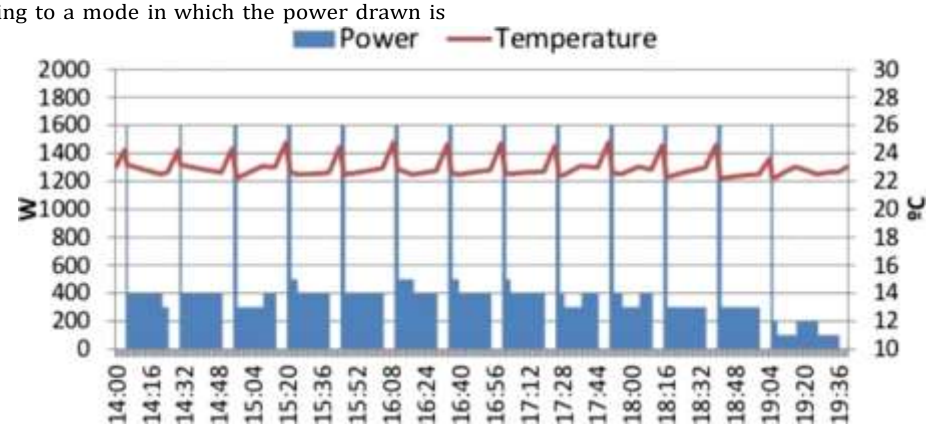

Fig. 15. Indoor temperature and load diagram after a load control (20on þ 5off) has been applied e inverter AC running at 120% of rated power.

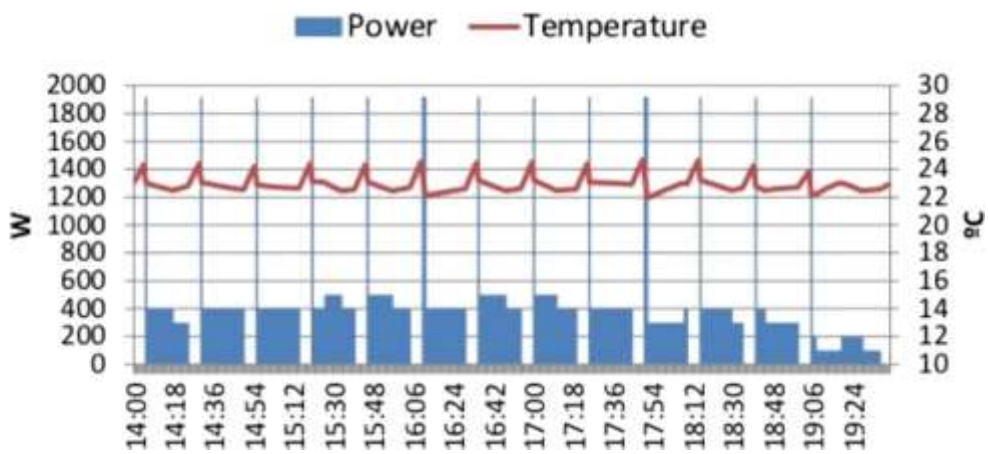

Fig. 16. Indoor temperature and load diagram after a load control (20on þ 10off) has been applied e traditional AC.

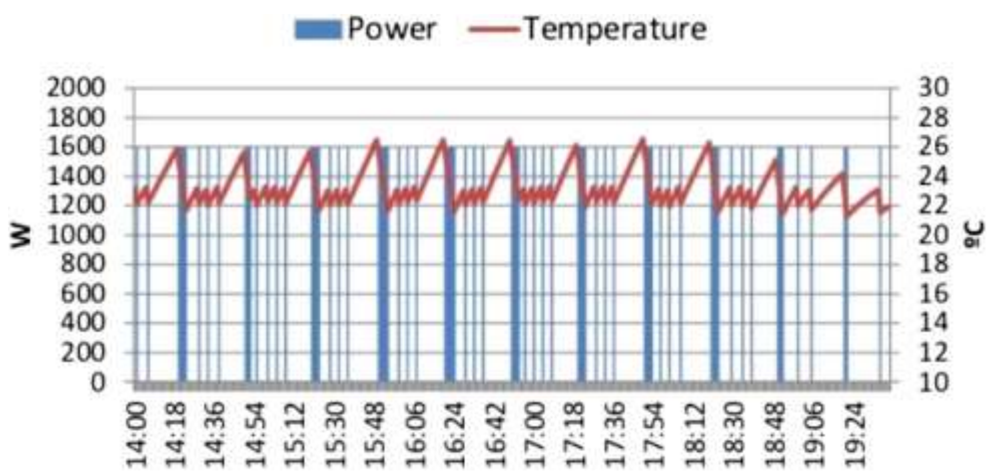

Fig. 17. Indoor temperature and load diagram after a load control (20on þ 10off) has been applied e inverter AC.

In this case, the impact of the cycling strategy in the indoor temperature seems to be more severe with the inverter HP. As can be seen in Fig. 17, when the inverter HP is turned off the temperature rises up to about 26.5 °C, far from the desired value (range 22.5 °Ce23 °C), which makes the inverter HP running at full power in order to quickly re-establish the desired temperature when the power off period ends. This is due to the way inverter HP works: when the indoor temperature is far from the desired value (the difference is higher than 2 °C) it runs at high speed (high power) and runs at lower speed when the difference is lower than 2 °C. In this scenario, with a cycling strategy “20 min on þ 10 min off”, the inverter device is no longer able to bring the indoor temperature near the desired value, and in every following cycle the situation worsens. It can be seen in Fig. 17 that the maximum indoor temperature increases in each cycle. This means that despite their ability to quickly respond to high indoor temperature fluctuations, the inverter type heat pumps need more time to restore the correct indoor temperature. This analysis highlights the need for adequate control strategies as well as a previous assessment of their impacts.

6. Conclusions

Air conditioning loads have been used for demand-side management activities over the years. Regarding power drawn from the grid, inverter systems present a different behavior when compared with traditional on/off systems and the response to load management actions of inverter type loads is also diverse from the response of “traditional” systems. Instead of cyclic functioning, inverter systems always draw a given amount of power from the grid, which means there is always some power available for control. However, the payback effect in this type of air conditioners can be worse than the payback effect of traditional air conditioners since they can impose high power demand. Therefore, care must be taken when designing control strategies in order to prevent undesirable effects regarding the comfort of end-users. The physically-based load models developed can accurately reproduce the functioning of inverter air conditioners and be used for simulating and assessing the impact of demand response actions implemented over these loads. Inverter type heat pumps/air conditioners quickly respond to high fluctuations in indoor temperature but as they work gently around the desired temperature they may need more time to bring the indoor temperature back to the desired value.

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