Challenges of heat pumps coupled with building to make them a flexibility tool for the electricity network

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Abstract

The EU is setting increasingly ambitious energy and climate targets and is aiming at carbon neutrality for buildings by 2050. In the building sector, this objective implies restrictions on the use of fossil fuels in favour of, among others, electricity. Buildings will then become an interesting tool for grid flexibility, particularly to absorb and store electricity from renewable sources. Furthermore, heat pumps, whose market is booming, constitute a very efficient electrical heating technology and will become a pillar of the electrification of buildings in the coming years. Heat pumps will be a key component of buildings, used as a tool for balancing the grid.

This study presents a comprehensive literature review on flexibility potential. It constitutes the first step of research works aiming to develop a tool dedicated to the flexibility of heat pumps in buildings that will optimize and control the entire heat pump and storage system according to the characteristics of a building to meet a demand for flexibility from the grid.

This literature review shows that heat pumps can offer basic flexibility functionalities such as self-consumption of locally produced renewable electricity and adaptation to electricity tariffs, and can receive single orders from the grid. This study also highlights that, due to the wide variety of configurations and expectations, performance indicators are numerous but not always comparable and not suitable for an objective of optimizing response to various grid orders. In addition, we propose an overview of the different categories of controller addressing flexibility. This study concludes on the future works to be carried out to make the heat pump an efficient flexibility tool for balancing the grid.

Introduction

The growing interest in energy transition in Europe has led the EU to propose a pathway to carbon neutrality for buildings by 2050. Today, buildings account for about 36% of total EU CO2 emissions (European Commission, 2021) and 40 % of the total final energy consumption. Reaching this objective of carbon neutrality will not be possible without restriction on the use of fossil fuels and development of electricity in the building sector. Buildings, being widely electrified, will become an interesting tool of the grid flexibility, specifically to absorb the electricity produced by intermittent renewable sources that is expected to grow in the future years. As of today, the optimisation of building heating as a means to balance the electricity grid has become a real research subject as well as a major challenge. Indeed, new low carbon powerplants such as wind turbines and Photovoltaic (PV)panels rely on energy sources that are mainly intermittent, which can be a challenge for grid robustness.

Solutions to adapt the electricity production to the consumption and to avoid weakening the grid have been discussed for a long time. Historically, these solutions were focused on the production side. But nowadays, to address this multilevel and complex problem, Demand Side Management (DSM) techniques (Arteconi et al., 2016; Nolting and Praktiknjo, 2019) are seen to be a suitable tool to mitigate the issues explained above. In this case, the goal is to manage the demand curve to make it more suitable with the growing non-fully controllable supply curve. DSM can be categorized as summarized in Figure 1.

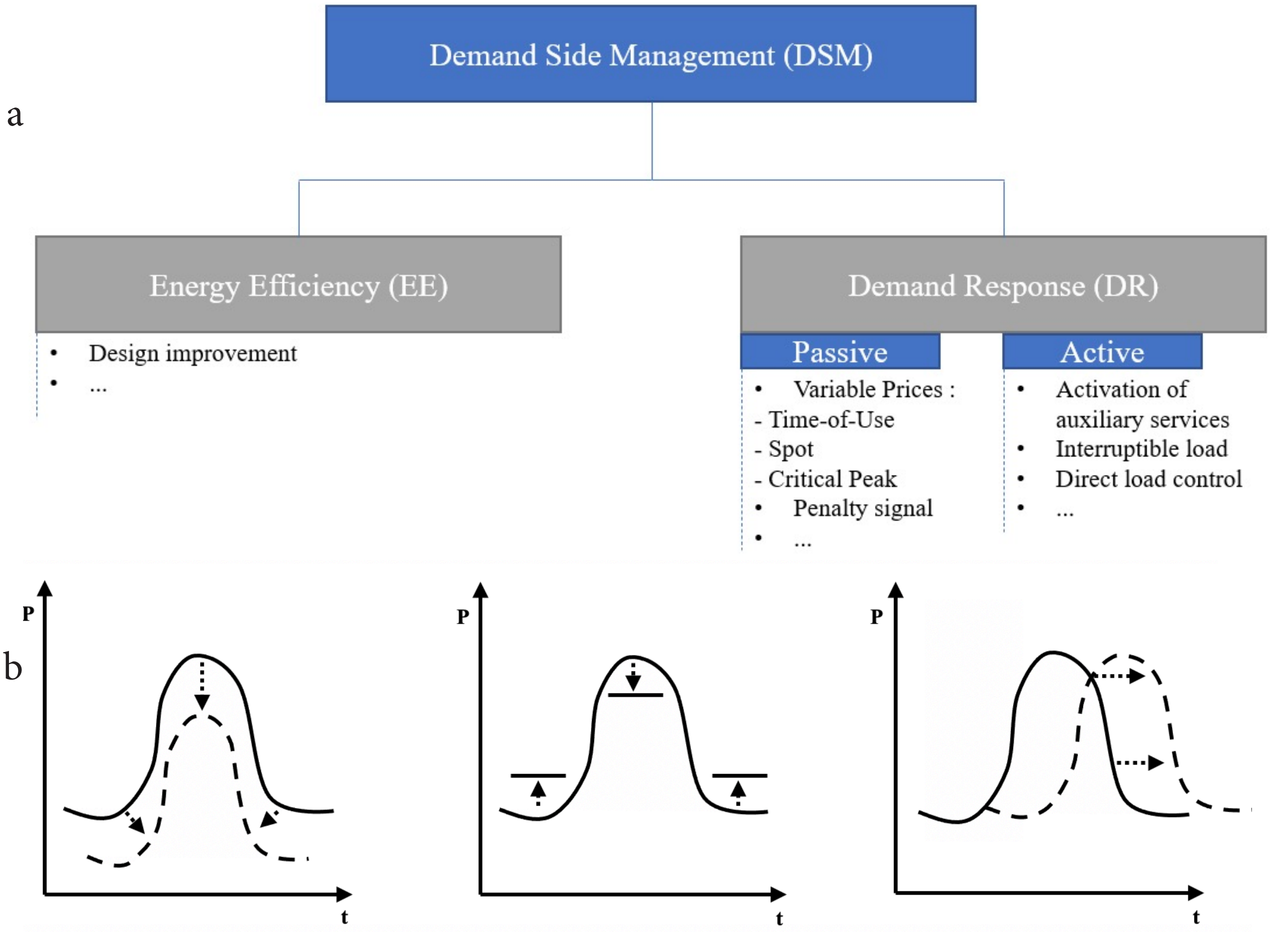

Figure 1. (a) (Qi Zhang, 2016) Demand Side Management methods categorization and (b) illustrations of their impact on the grid: from left to the right, energy efficiency, valley filling combined with peak shaving, load shifting.

On one side, Energy Efficiency aims to reduce the average load of the demand curve by improving the efficiency of consumer's equipment and thus to reduce the electrical consumption for the same end-use. On the other side, Demand Response consists in controlling existing equipment to fulfil the "flexibility" need by changing the shape of the demand curve. Concerning the second DSM action, it can be done by actively controlling the equipment by sending a signal that can for example shut down the system when needed or force the functioning of an auxiliary service. This is called active or explicit demand response. At the same time, the control can be done in an implicit way thanks to specific pricing schedules that will encourage the controlled equipment to operate during low price hours when a surplus of renewable energy is expected for instance.

To assess this problematic, there is a need of proper definition of flexibility as it can be defined differently according to authors across the literature as reviewed by (Airò Farulla et al., 2021). In this paper we will consider the IEA Annex 67 (Jensen et al., 2017) definition:

> The Energy Flexibility of a building is the ability to manage its demand and generation according to local climate conditions, user needs, and energy network requirements. Energy Flexibility of buildings will thus allow for demand side management/load control and thereby demand response based on the requirements of the surrounding energy networks.

According to this definition, there is a need for energy devices that can store energy over a certain period of time and give it back when needed in order to provide flexibility. One serious candidate for residential buildings is heat pump (HP) coupled with heat storage in building, whose market is booming with more than one million and a half units sold in Europe in 2020[1]. Thanks to its very high efficiency, it will become a pillar of the low carbon electrification of buildings in the years to come, with a very significant rollout on a European scale. Heat pumps will be a key component of buildings and could be used as a main tool for balancing the grid. One thing that needs to be considered is that this type of heating system, in particular air source HP, is thermically sensible meaning that low temperature tends to induce performance drops. This will therefore conduct to even more demand variability particularly during winter periods when the demand is already at maximum levels. Hence, it shows the deep need of flexibility in the coming years.

As said above, flexibility on the demand side need storage capacity. In the case of HP, the storage capacity is provided by a water heat distribution system, and/or directly by the thermal mass of the building. It has been already shown (Johra et al., 2019) that the flexibility potential of buildings depends

1. European Heat Pump Association statistics, www.stats.ehpa.org

extensively on their insulation level and thermal inertia. Having a good insulation and/or a high inertia increases the flexibility capacity of the system as the heating storage capacity is increased. Furthermore, some investigations (Arteconi et al., 2013; Fischer et al., 2017; Frison et al., 2019; Kuboth et al., 2020) have been made on the use of an additional thermal storage to enhance flexibility. These studies, at the system level, investigated storage with water tanks dedicated to domestic hot water (DHW) production as well as buffer tank inserted in the heat distribution system. Previous study (Arteconi et al., 2013) showed with a single heat pump and building system that switching off peak hour consumption can be achieved without harming the comfort for the consumer for a 3-hour period by adding to the system a 500L water tank as thermal energy storage (TES).

In the literature, flexibility has also been treated in an aggregated way with a pool of buildings heated with heat pumps for instance. (Fischer et al., 2018) used the already existing Smart Grid-ready interface to control a pool of 284 HP in a simulation environment, from an aggregator point of view. Smart-Grid ready heat pumps can be controlled using 4 different modes: ON, OFF, Forced On – Overheat, Forced On – Overheat with back-up. This allows the heat pump to address actively DR scheme. The outcome of this work showed that with this existing tool it is possible to address peak shaving by shifting the electrical consumption from peak hours to low priced hours. In a larger scale simulation, (Baeten et al., 2017) emphasised the potential of flexibility applications by aggregating 500 000 HPs, showing a substantial saving in installed power capacities thanks to the peak shaving method applied to the whole pool. Those saving counted for several hundreds of MW. This approach gives an idea on the feedback on the grid implied by the behaviour evolutions of a large pool of heat pump when addressing flexibility and highlights the great potential of this technological area.

These studies highlight the interest and potential of heat pumps for flexibility regarding the grid. In this paper we propose an analysis, through a literature review, of the main actual challenges in terms of evaluation approaches and specific issues when addressing flexibility towards the grid. We also analyse different control strategies concerning flexibility specifically applied to heat pump in the context of residential building.

Stakes of Heat Pumps flexibility

Flexibility with heat pumps is subject to different issues that need to be solved in order to make them a reliable and helpful energy device for the grid.

HOW TO QUANTIFY FLEXIBILITY

In a lot of European country landscapes, we find a tremendous variety of building configurations. Indeed, physical building characteristics change according to the type of building considered from individual houses to multifamily buildings. This wide variety is even more accentuated by the different configurations of TES implied, by the type of heating system used, by the heating control strategy applied or even by the presence of on-site renewable energy facilities such as PV panels. Those physical building characteristics bring a lot of complexity when addressing flexibility. At the same time, flexibility can be influenced by independent factors such as the weather (outside temperature, solar irradiation...) and even the user's habits. Hence, to address flexibility in a global point of view, the need for a proper way to evaluate building performances in term of flexibility is required as expressed by (Jensen et al., 2017). Across the literature, some authors considered energy or economy savings as their major indicators when evaluating flexibility. However, these indicators are not deeply well designed to check whether or not a strategy is beneficial for the electrical grid. For example, an energy system addressing flexibility can consume more energy compared to a reference across a year but can store energy when needed and consequently being completely profitable for the stability of the grid. Therefore, a classic evaluation methodology does not suit well the problem; there is a need for standardization in order to extend flexibility potential in a more beneficial way and at a larger scale as expressed by (Wang et al., 2022) or to define some new indicators dedicated to flexibility for the grid (and not for the consumer).

To overcome this challenge, some authors have established Key Performance Indicators (KPI) to propose standard evaluation tools that try to provide a complete way of assessment when investigating new flexibility strategies. (Airò Farulla et al., 2021) and (Johra et al. 2019) reviewed those KPI across the literature. Johra et al. (2019) proposed to divide them into 4 categories named the load shifting ability, the power adjustment, the energy efficiency, and the cost efficiency. This repartition is motivated by the similarities founded in the literature between the existing KPI. On the other hand, (Airò Farulla et al., 2021) proposed a categorization based on 3 groups focusing on the load match, the grid interaction, and the energy flexibility. The authors also decided to propose a succinct evaluation of each indicator by underlining their asset and downside. The first two groups in their work are generally used to characterise system that uses on site PV production even if some of their KPI are not exclusive to other configurations. The last group is dedicated to KPI specifically designed to evaluate flexibility potential of buildings.

To illustrate this, (Finck et al., 2019) used 3 indicators to evaluate flexibility for their system composed by heat pump integrated with PV on site generation. They tested two different control strategies. The first one was aiming to improve flexibility to consume electricity from the grid at low price period. The second strategy was aiming to enhance PV on site self-absorption while guarantying low price period consumption from the grid. The two strategies differ from each other by aiming to improve some KPI over others. The most used one in this study is the flexibility factor *FF* quantifying the ratio of system running during low-price period and high-price period thanks to:

$$FF = \frac{\int_{t_{low-price\ start}}^{t_{low-price\ end}} Qdt - \int_{t_{high-price\ start}}^{t_{high-price\ end}} Qdt}{\int_{t_{low-price\ start}}^{t_{low-price\ end}} Qdt + \int_{t_{high-price\ start}}^{t_{high-price\ end}} Qdt}$$

where *Q* is the heat capacity (in kW) of the HP. Flexibility factor of 1 informs of maximum shifting load ability whereas the value -1 indicates the inflexible characteristic of the system.

In the same idea, (Frison et al., 2019) chose to work with the absolute Grid Support Coefficient (GSC) in a hardware in the loop environment composed of a simulated residential building with a real heat pump installed in lab facilities. In this work, the authors focused on having a control strategy that could provide support to the grid. The support was once again characterized by improving consumption during low price hour. The GSC indicator is expressed thanks to:

$$GSC_{abs} = \frac{\sum_{i=1}^{n} W_{el}^{i} G_{s}^{i}}{W_{el}\overline{G_s}}$$

with $W_{el} = \sum_{i=1}^{n} W_{el}^{i}$ and $\overline{G_s} = \frac{1}{n}\sum_{i=1}^{n} G_{s}^{i}$,
where W_{el}^{i} represents the electrical consumption of the system at a time step i, G_s^i is the value of the grid signal – generally the price – at the time step i and where n represents the total number of time steps. This indicator therefore informs whether the consumption is done at high, medium or low-price periods thanks to GSC taking value superior, equals or inferior to 1 respectively.

In another example, (Vigna et al., 2019) wanted to evaluate the absorption capacity of renewable energy from a cluster of buildings. Therefore, they used the Flexibility Index (FI) defined as follow:

$$FI = \frac{\int\left(q_{match}^{Ref} - q_{match}^{Control}\right)dt}{q_{cons}^{Ref}}$$

with $q_{match}^{Ref} = \int max\left(0, q_{consumed}^{Ref} - q_{produced}^{Ref}\right)dt$ and

$$q_{match}^{Control} = \int max\left(0, q_{consumed}^{Control} - q_{produced}^{Control}\right)dt,$$

where q_{match}^{Ref} is the reference non-renewable demand, q_{match}^{Smart} is the non-renewable demand after applying the tested control strategy and q_{cons}^{Ref} is the reference demand. Having a higher value informs that the studied system is absorbing a higher amount of renewable energy compared to a reference.

These three examples here give an idea of the diversity of those KPI. The outcome of these various studies showed that according to the goal and the definition of flexibility KPI must be chosen carefully to precisely address the objective. They should be further used in the evaluation of flexibility strategies.

ISSUES FOR HP REGARDING FLEXIBILITY

We have seen that flexible activation of residential buildings is undoubtedly a major point of interest in the coming years to actively participate in solving the decarbonation issue of the heating sector in Europe. However, this kind of technology may have different types of impact on existing and future energy systems. Indeed, a flexible way of functioning implies a change in the classic behaviour of the building and its embedded heating system. Focusing on the heat pump system itself, flexibility can impose some strong constraints and may jeopardize the actual equipment. As modelized by (Nolting and Praktiknjo, 2019), the heat pump coefficient of performance (COP) drops when addressing flexibility, indicating that the system is running in a non-optimal way. Moreover, this kind of control strategy implies additional start and stop situations for the heat pump thereby jeopardizing it on a long horizon of time by reducing its lifetime. Finally, the uncertainties on production and demand prediction turn out to be a prominent point of interest. Indeed, the variability of renewable energy production in the future, the unexpected variations in occupancy habits or the wrong weather predictions at regional scales can induce important losses when not well considered because the system did not predict those phenomena.

Both at a system level and at a clustered level, another major point of discussion coming from the literature is the risk of a global overconsumption (Baeten et al., 2017; Frison et al., 2019; Klaassen et al., 2015; Liu et al., 2019) when addressing flexibility especially when the goal of the control strategy was to improve the cost of operation. This overconsumption is of course sensible to the current characteristics of the investigated buildings. One major illustration of this overconsumption is the rebound effect that occur when applying interruptible strategy (Weiß et al., 2019). If we want to keep the temperature into a comfort zone while interrupting the space heating demand of a building, we generally face a preheating period and a recover period after the interruption that leads to a peak of load. This overconsumption can also occur when we want to massively absorb a production of renewable energy for example. To mitigate optimally these effects, the technical challenge lies in an optimal control strategy to find a good compromise between grid needs (release the stress applied to the grid) and user expectations (reduce the electricity bill). To that extent, many authors, e.g., (Nolting and Praktiknjo, 2019; Fischer and Madani, 2017) across the literature would recommend establishing a financial incentive that would help to convince people to switch to a flexible way of functioning. All the efficiency losses and their consequences should be clearly evaluated and contrasted with the actual gains obtained in favour of the grid.

In addition, actual flexible control strategies are not free from comfort issue for the end-user. This problem is even more complex, as comfort is very subjective, and variously evaluated from one individual to another. People may also find that they lack control on their own heating system. As expressed by (Sweetnam et al., 2019), end users participating in a DR program based on aggregated controlled heat pumps were not confident in their heating system. In fact, they were not supposed to modify their set point comfort temperature as they wish. Nonetheless, some of them actively changed the configurations of heat pump over the testing period which led to non-conclusive results. Furthermore, an advanced controlled system is not suitable in some cases as people want things to be simple and controllable. This example shows the growing need of sensibilisation and good communication between end-users and flexibility providers. The good and healthy communication towards the end consumer should be also present between the different stakeholders such as aggregators, energy producers and public institutions. The need of policy and common regulations between of all these actors is a major prerequisite to a national and international scale deployment of this technology in the future.

Control Strategy

We have seen that fulfilling the expectations of consumers, manufacturers, and grid operators is not an easy task. The major challenge therefore lies on having an efficient and reliable control strategy adjusting in real time the system functioning according to the flexibility objectives. The goal is to manage the heat generator, here the heat pump, and the thermal storage, being here the thermal mass of the building or the water tank, to complete the flexibility objectives that are fixed for this system without harming the user comfort. In past studies on heat pump control, the flexibility goal was not addressed, and the main objective was to improve the energy efficiency of the system. Two main families of heat pump control strategy are generally applied by the manufacturers as discussed by (Madani et al., 2013): Hysteresis approach and the PI controller. They are both based on using a heat curve that determines the sink temperature calculated linearly from the outside temperature. This temperature is then pursued by the whole system. The slope of the curve can be adjusted and is determined generally after a trial-and-error period following the installation of the equipment. This methodology has shown to be successful and propose some minors comfort issues when the system is well tuned even if oscillations tend to occur. However, those strategies do not consider any flexibility dimension. To that extent, some propositions have appeared over the years to address this specific goal with new types of control strategy. As mentioned in the literature (Fischer and Madani, 2017; Jensen et al., 2017; T. Q. Péan et al., 2019), they can be divided into two mains groups: Rule-Based Control (RBC) and Model Predictive Control (MPC).

RULE-BASED CONTROL (RBC)

An RBC controller is a simple way of controlling a heat pump when considering flexibility. Basically, this technique relies on an "if condition" such as: if (Triggering variable > Threshold value) then (do an action). The triggering variables are generally temperatures obtained through sensors or time whereas the actioner is generally the power of the heat pump. This tool offers a great variety of possibilities and allows addressing flexibility issue with a simple formulation. For instance, (Klaassen et al., 2015) analysed the performance of a RBC control strategy applied to a pool of 38 heat pumps aiming at shifting the consumer load regarding the price variations across a day. With their strategy they succeeded an 8 % reduction in energy costs during winter periods. (Fischer et al., 2017) compared the performances of 4 different RBC each one based on different control variables to address flexibility with a unique heat pump system. They aimed to improve PV on-site consumption and reduce electricity bill for the end user. The less successful strategy obtained a result of 2–4 % cost reduction across the year. In the same idea, (Alimohammadisagvand et al., 2018) also compared 4 different RBC in a system composed by a heat pump, a building and two storage water tanks dedicated to DHW and space heating (SH). Each strategy was aiming at the same goal, reducing operation cost and energy consumption, but differs from each other due to the formulation. The outcomes of this work illustrate that every control strategy reduces operation cost from 6.5 % to 14.5 % and energy consumption and from 5.7 % to 7.7 %.

While those strategies show a few percent of reduction in energy consumption, they are especially simple to design as they do not rely on a complete modelling of the studied system. Moreover, they do not require tremendous computational effort which is a major asset when addressing flexibility at a large and industrial scale. Nevertheless, this type of controller also carries some difficulties. As they are made of expert rules, they are thus non optimal. In fact, they depend a lot on the knowledge of the system as they must be designed thanks to a prior experience. Knowing that each system is different, it is complicated to replicate the same strategy to different buildings and their embedded heat pumps.

Besides, those controllers do not have in the general case any predictive aspect which means that they lack integrated vision. To that extent, RBC generally do not allow to take into account future values that could impact the current strategy applied. Therefore, some misguiding could appear subsequently driving the system above threshold values. Furthermore, the values of threshold that are imposed at the designing phase cannot be changed and adapted to the current situation. This point strongly limits the flexibility objective that can be reached by such control strategy. For example, anticipation will be needed to address the intermittent renewable energies integration as a flexibility objective.

MODEL PREDICTIVE CONTROL (MPC)

To address more complex flexibility objectives, the development of MPC has been a great breakthrough and a major research subject for the last years. MPC basically relies on an optimization problem and a set of constraints. Precisely, MPC formulation needs a model of the controlled system. It is then used to calculate the satisfying trajectory of the system thanks to an objective function minimized using an optimization algorithm. The trajectory is calculated over a certain horizon of time and generally only the first step is applied leading the whole system to a new state. The optimization problem is then recalculated starting from the new state of the system. The first calculated state is yet again reached by the system and so on and so forth. Globally, this control strategy offers a large spectrum of possibilities especially as anticipation can be addressed. For instance, by providing hourly weather data and electricity prices with a 24h projection, it is possible to find the optimal pathway to reach an objective of electricity bill reduction.

Depending on the aim of the control strategy, the objective function must be designed accordingly. Table 1 presents a review of the main characteristics of MPC controllers applied to heat pumps found in the literature. In those examples, the objective function is generally focusing on economic or energy savings when addressing flexibility. The MPC controller can also include constraining rules. These rules called constraints are divided in two main categories. The first one represents hard constraints. They are useful to prevent the system to reach certain values which exclude them completely of the reachability area. It can be especially useful when knowing technical limits of the equipment to avoid unnecessary harming such as grid stability due to PV feed in (Kuboth et al., 2020). However, those constraints can turn the system into a suboptimal one, therefore a wise focus on this specific part must be done. The other category represents the soft constraints. Those take the form of penalty terms directly integrated in the objective function which does not exclude any state from the reachability. Each state is then associated with an additional cost which make some of them harder to reach and prevent the system to be driven towards unwanted configurations. This is especially the case with temperature (Kuboth et al., 2020; Péan et al., 2019)

As illustrated in Table 1, the authors claim interesting results in terms of flexibility and efficiency of the controlled system by providing substantial cost and energy consumption reduction. However, they do not in general case use KPI to evaluate flexibility and keep using energy and economy savings as their main evaluation

tools. Concerning the TES facilities, the Table 1 also highlight the fact that the thermal mass of the building is always considered when addressing flexibility. The DHW tank is considered as a flexible tool in a lot of cases, with a varying tem-

Table 1. Main characteristics in MPC control applications for heat pumps addressing flexibility.

Author	Objective			Storage type			Time Step	Time Horizon	Test environment	Results	Comments
	Eco.	Ener.	CO2	Thermal mass	Water tank SH	Water tank DHW					
(Fischer et al., 2017)	X			X	X	X	?	?	Simulation	- 6-16 % cost savings - Some minor comfort violations	PV coupling 1 Year simulation
(Frison et al., 2019)	X			X	X		900s	24h	Hardware in the loop	- Increase of energy usage by 2% per day - 3,1% cost saving per day - GSC = 0,84	Non-linear formulation
(Kuboth et al., 2020)	X			X	X		Cal.: 1 hour Control: 15 minutes	24h	Real building integration	- 9% cost saving - Electric consumption reduced by 4,1% - Improvement PV self-consumption	PV coupling 125-day experiment Non-linear formulation
(Péan et al., 2019)	X		X	X		X	12 minutes	24h	Hardware in the loop	Depending on the configuration: - Up to 7 % costs savings - Up to 17% CO2 reduction with increase of energy use	Cooling + Heating mode 3 days experiment
(Pichler et al., 2017)		X		X		X	?	24h	Simulation	Increase PV consumption from 20% to more than 50%	PV Coupling
(Rastegarpour et al., 2021)	X			X		X	30s	20min	Simulation	Up to 8% energy saving	Adaptive COP model
(Xia et al., 2017)		X		X		X	?	?	Real building integration	- Up to 8% energy saving in heating mode - Up to 9% energy saving in cooling mode	

perature setpoint. Concerning the SH water tank, authors agree that it offers greater flexibility potential as the heat storage is increased, but the efficiency of the whole system decreases due to the heat loss of the tank. The space congestion in buildings is also a point of interest which makes the SH water tank more difficult to integrate.

According to the various results shown in Table 1, the authors estimated that MPC strategies show significant results when looking at consumption or electricity bill reduction. However, these results should be analysed with regard to calculation and measurement uncertainties. Although, in all cases, MPC control is providing better results than RBC control when they are compared (Fischer et al., 2017; Péan et al., 2019), the economic flexibility goal addressed may not be optimal for helping the grid.

Moreover, (Péan et al., 2019) already reviewed results from MPC strategies applied to heat pump for flexibility and they emphasize the lack of real heat pumps testing in lab or even in real building situation. During the last years, we can see on table 1 that some attempts have been made proving that MPC offers also encouraging results in more realistic environments as semi-virtual lab facilities (hardware in the loop) or in real system integration. Nonetheless, the gains seem less optimistic compared to simulation. This difference can be explained by the real behaviour of the heat pump that is generally not considered during simulation such as defrosting cycles, on/off cycles or by the nonlinear dynamics of the heat pump.

Indeed, in most papers, the authors are using a linear HP model and a building RC network model in the MPC controller. Those models and their approximate parameters may not represent precisely enough the dynamics of the studied system, which causes misguiding directions to the whole system. However, this imprecise representation is most of the time needed. Indeed, as MPC controller relies on an optimization problem, the calculation burden is a major concern in these studies. Having detailed models could drive the system being sub-optimally controlled because the optimal direction could not be found during the calculation period. This is especially the case when considering online-based applications that have only limited calculation power. In addition, the control system must be robust to the uncertainties such as weather, occupancy, and price variations. One way of doing so would be to model those phenomena but this is very challenging especially because of the stochastic aspect of those occurrences. Wrong estimations could again harm the user comfort and reject expectations. Therefore, authors tend to focus on the robustness of the controller instead of the precision.

To conclude, this control strategy is relying a lot on the computational capacity. This is the main issue when using MPC controller. However, in the future years, we expect to have more and more of computation power to solve complex formulations especially in embedded systems. This technology is then expected to grow as we should be able to model various types of physical system more realistically. However, the current formulation may not be optimal if we think the heat pump as a tool for the grid because the prominent objective in literature is focusing on energy consumption improvement and lack of grid consideration.

Conclusion

Global warming stakes are a major point of interest for the EU. To assess the ambitious targets for 2050, a development of electricity use in the heating sector is expected. Heat pumps will therefore have a key role to play due to their native high efficiency. However, this evolution might deeply impact the electrical grid when considering the growing integration of renewable energy plants, all causing harmful stress on existing transportation and distribution facilities due to intermittency of production and non-constant demand. To avoid this situation, flexible buildings and their embedded heat pump appear as a great tool to mitigate the growing need of DSM. To that extent, we have seen that the feasibility and potential of flexibility for heat pumps are already demonstrated. Indeed, there are some practical cases enlightening the substantial gains of flexibility at a system level but also in an aggregated way both for the grid and for the individual system. These examples also shown the benefits of RBC and MPC controllers and exhibit the superiority and the best potential of MPC strategies. Moreover, common evaluation methods would be useful when addressing flexibility for residential buildings to compare the performances of those systems and their controller. The literature shows that financial incentives or energy tariffs are often considered as good drivers to address flexibility, which opens a path for new business models that should satisfy everyone, from the energy supplier to the end user. At the same time, the authors of this paper think that a major research work is still to be done on the development of advanced control strategies when addressing flexibility to balance the grid. This research work has to address several topics. Indeed, although the potential of flexibility for the grid has been demonstrated, actual MPC formulations still focus most of the time on economy or energy saving which may not be most significant indicators. Concerning the heat pump model, the non-linearity of the dynamics is still a great challenge to overcome without harming the computational time (Rastegarpour et al., 2020) (Noye et al., 2022) but may be necessary to consider when functioning with a large temperature range. Concerning the building model, due to their great variety of typology, the model parameters have to be adapted to each building. Therefore, the need of system identification and data driven models for building (Wolisz et al., 2020) will be a major point of interest. Finally, the uncertainties such as weather or occupancy as well as the typical behaviours of heat pumps such as defrost cycle should not be neglected and further considered inside the control strategy to avoid equipment harming and exploit all the flexibility potential of the building and its embedded heat pump system.

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