Strategies in buildings' operation to maximise the on-site use of PV electricity generation

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Abstract
By the significant market uptake of solar PV systems, the on-site electricity consumption and storage is becoming more and more important. For the past years there was constant research which aimed at maximising the consumption of the electricity produced by grid connected PV systems thus reducing the impact on the electric grid. In case of buildings the key is to firstly identify the usage patterns, thus the behaviour of the occupants can be formed through demand side management. Secondly the HVAC system of the building can also be utilized to increase the on-site consumption of the produced electricity. In this paper the direct electric heating, the heat pumps and the thermal component activation are introduced.

1. INTRODUCTION

There is an ever-growing need to reduce energy consumption and thus improve energy efficiency and extend the use of renewable energy sources. It is necessary to reduce greenhouse gas emission, which is one of the causes of global warming. The building sector accounts for 40% of the CO_2 emissions, thus it has arguably the biggest potential to reduce CO_2 emission [1]. The European Union has implemented several legislative instruments, which are drivers for improving the energy efficiency in buildings within the EU [2–5]. According to the legislative framework from 2021 all new buildings must be nearly zero energy buildings. Since the latest directive (844/2018) on the energy performance of buildings the key point has been on smart buildings and smart technologies. This includes already defined smart homes and smart grids, however it also introduces new terms, such as the smart-ready buildings and the smart readiness indicator.

To reach the targets, set by the European Union in the past years the installation of grid-connected PV systems has skyrocketed to supply the buildings' electricity demand and thus increasing the renewable energy consumption of buildings. This phenomenon, however, has put an additional stress on the electric grid, thus the need for utilizing the produced electricity on-site is getting more and more significant [6]. In this paper the key strategies are summarized to maximise the on-site use of the produced electricity in buildings.

2. ENERGY STORAGE POSSIBILITIES

Storing electricity is a challenge since there are limited technological solutions. In case of buildings the main opportunity for electricity storage is in batteries. While the battery technology has developed over the past decades it is still not financially feasible to install bigger capacities. To reduce the required battery capacity there has been extensive research on the demand side management (DSM) over the past years. The aim of the demand side management is to shift the peak loads to the valley periods as an example show below:

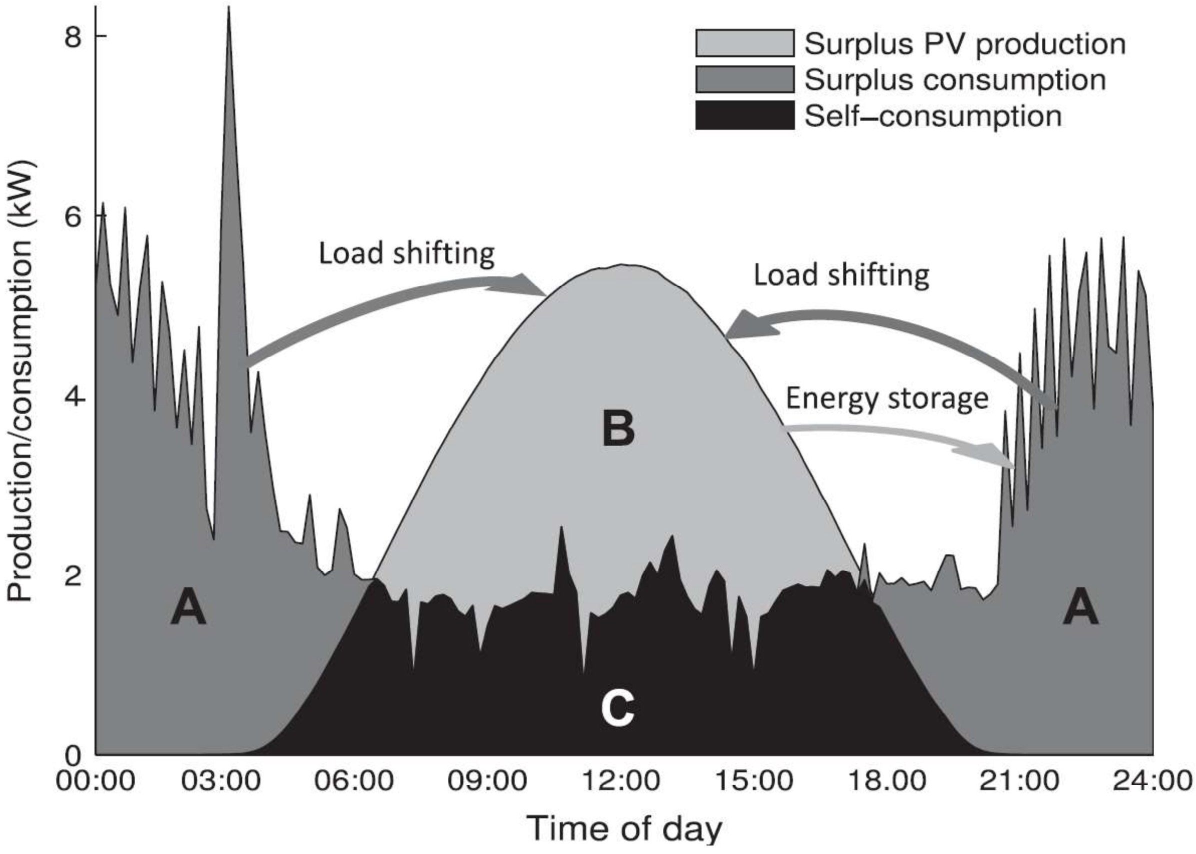

Figure 1. The effect of load shifting considering the demand (A) the surplus PV production (B) and the covered demand (C) [6]

To utilise the load shifting potential the key first step is to understand the consumption patterns and user behaviour [7]. There have been several papers aimed at identifying the usage patterns [8–10]. These studies mostly use smart meter data and utilise clustering and data mining methods to identify different consumption patterns. After the consumption patterns are specified the appropriate DSM measures can be applied.

In most cases the DSM measures aim at influencing the building users to change their habits to use electricity, when there is surplus production from the PV panels or the market price of electricity is lower. The other option is to use the buildings HVAC system to utilise the surplus production when necessary, thus the self-consumption of the building is higher. In the following the basic solutions are introduced.

2.1 Direct electric heating

In the recent years there has been a small uptake for installing direct electric heating supplied with PV systems due to their low investment cost and the improved thermal performance of buildings, while their application in old, uninsulated buildings is financially not feasible [11]. There are several electric heating solutions, such as electric radiators, heating coils, infrared panels, infrared heaters, electric convectors, etc., which all have a significant disadvantage: it is not possible, or just for a limited capacity to store heat with them which means that they are not suitable to mitigate the surplus PV production. Another drawback of such systems is that they can't provide cooling for the building.

The electric water heater is the only viable option to store electricity in the form of heat from the PV panels, which can this way supply the building's DHW demand and provide a constant demand throughout the year.

2.2 Heat pumps

In the buildings in the past years the heat pumps for heating and cooling are more widespread. The main advantage of heat pumps is that they can supply both heating and cooling systems. To maximise the on-site PV generation a smart controller must be added to the PV system, which monitors both the PV production and the building's electricity demand and when it is required it switches on the heat pump to use the surplus PV production for the building's heating, cooling and DHW systems, where the heat can be stored. A schematic of the concept is presented in the following figure:

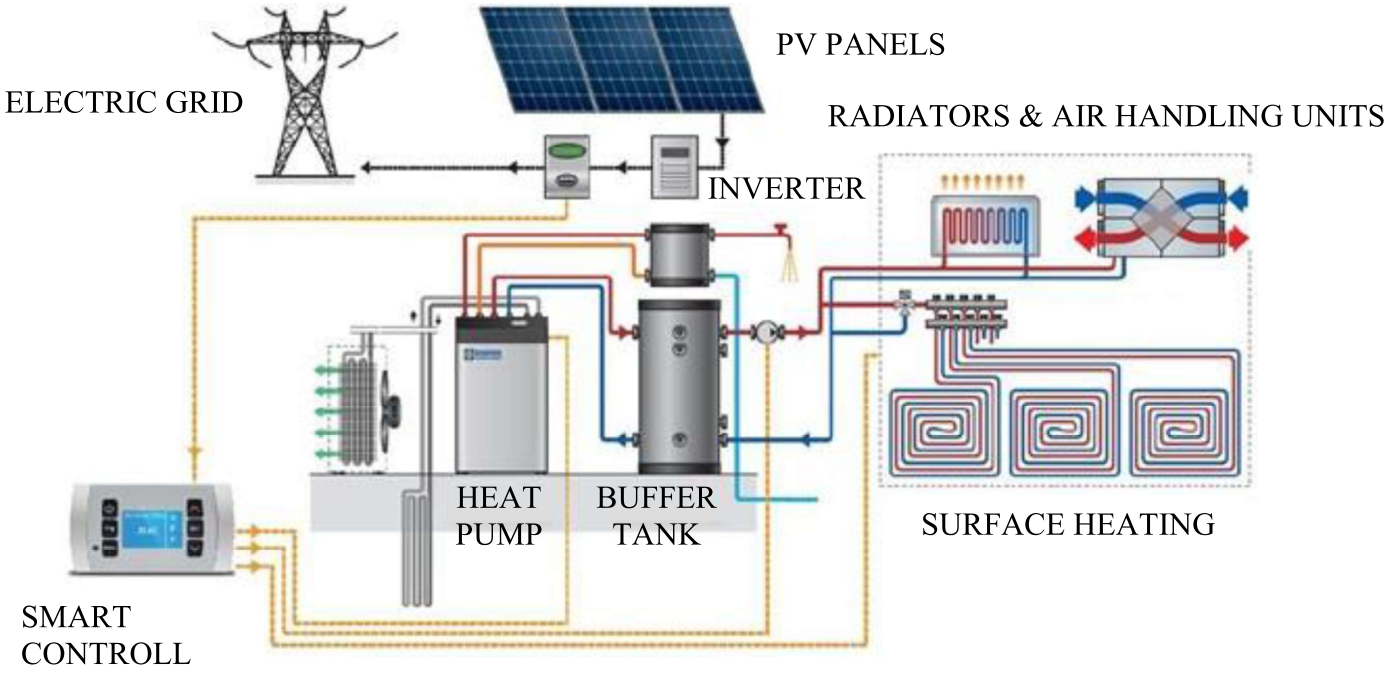

Figure 2. Solar PV and heat pump system operation example [12]

2.3 Heat storage in structural building elements

The third option is utilising the structural building components in the heat storage. Thermal Component Activation (TCA) is a special form of the surface heating/cooling systems, where the piping is installed closer to the core of the concrete slabs, thus utilising the high thermal storage capacity and the good heat conductivity of the reinforced concrete slab. By using this solution more heat can be stored in the building structure without significantly rising surface temperatures over the room temperature and causing comfort issues in the occupied zone or installing bigger storage tanks. The heat storage is nearly without losses since the heat flow is mostly towards the conditioned space since the outer building shell is well insulated. The application of TCA depends on the following slab parameters: heat conductivity, specific heat, density and the thickness. The drawback of the TCA is that it has a limited heating/cooling performance unlike radiators or fan-coil units. The maximal heat output of the TCA is approximately 25 W/m^2 in case of 4 °C temperature difference between the slab and the room. An example for the TCA system is presented in the figure below:

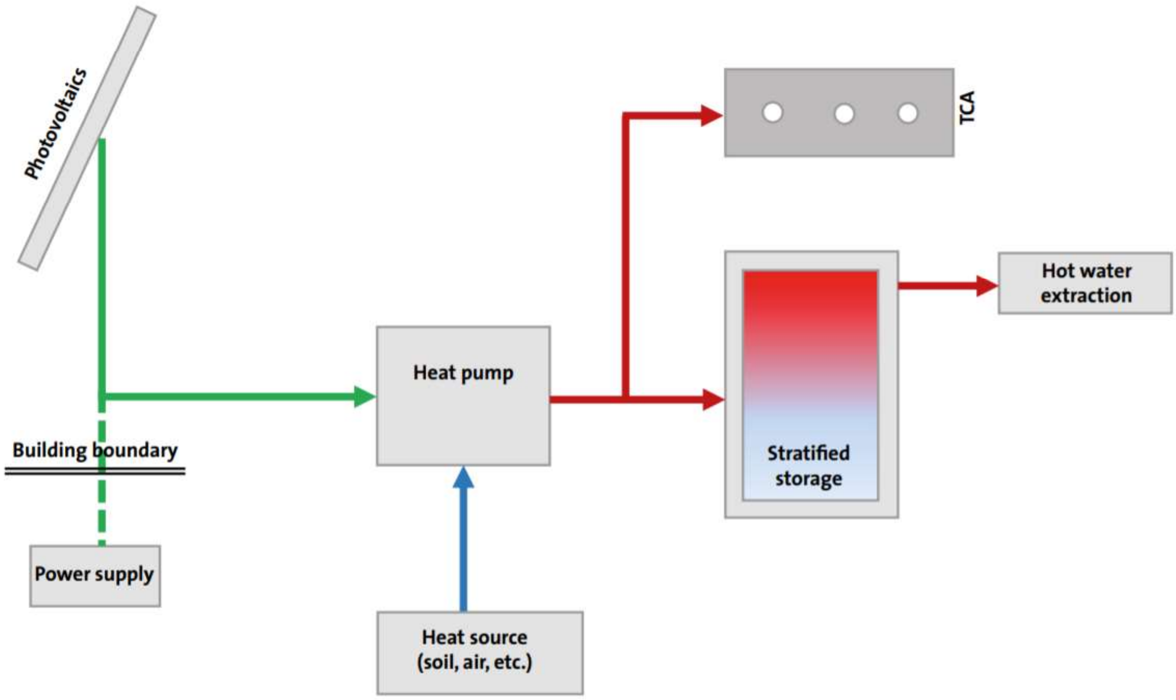

Figure 3. Solar PV and heat pump system operation example [13]

For the TCA the biggest challenge is the control, since it has a long response time and has limitations regarding the surface temperature for both heating and cooling. For heating the limit is the thermal comfort to avoid radiation asymmetry, while in cooling the condensation has to be avoided, thus the surface temperature has to be above the dew point temperature. [14–16]

3. CONCLUSIONS

By the significant market uptake of solar PV systems, the on-site electricity consumption and storage is becoming a more and more pressing matter. For the past years there was constant research which aimed at maximising the consumption of the produced electricity thus reducing the impact on the electric grid. In case of buildings the key is to firstly identify the usage patterns, thus the behaviour of the occupants can be formed through demand side management. Secondly the HVAC system of the building can also be utilized to increase the on-site consumption of the produced electricity. The traditional direct electric heating methods are not suitable for maximising the on-site consumption in the summer period, when the PV system has its peak production, only the electric water heater has an all-year-round demand supplying DHW for the building. The heat pumps supplemented with a smart controller can significantly increase the building's self-consumption rate, since they can supply heating, cooling and DHW demands, in this case only the storage tank capacity limits the applicability. An additional option is to utilise the building structure for heat storage as well, which can be achieved by Thermal Component Activation. In all HVAC related storage options, the knowledge of the building's consumption and PV system production is essential. It is important to evaluate the different options not only during the building operation, but also in the planning phase, thus the extensive knowledge on occupant behaviour, storage capacity and dynamic effects is required. Due to the complex effects the dynamic performance simulation tool is required to fully evaluate the different options.

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