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New innovative solar heating system (cooling/heating) production

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Abstract

This paper presents the development of a compact and cheap solar heating system based on photovoltaic panels, heat pump and heating storage through a smart regulation from a technical and economical point of view. The heat pump can be standard and have its own regulation. The building's owner may interact with the regulation through a web service to visualize the monitoring of the installation, update the calendar of the presence and change the operation mode. One of the goals of the regulation is to optimize the consumption of his own electricity production and therefore minimize the electricity taken from the grid. Several means are developed to reach the main objective. On one hand, the regulation takes into account the weather forecast to anticipate the future heating's needs and the photovoltaic production. Weather forecast data allows also to optimize the storage in hot water tanks and in the building structure. On the other hand, the project includes the development of an electronic module which collects the monitoring data and gives the commands to the heat pump and the pumps. This is accomplished without any intrusion in the heat pump's own regulation and therefore the user keeps the constructor's warranty. The new regulation was validated numerically. The expected energy gain due to the weather forecast is about 10%, while the one due to the self-consumption and the heat storage management will bring another 10-15%.

Peer-review by the scientific conference committee of SHC 2014 under responsibility of PSE AG

Keywords: heat pump; photovoltaic panel; storage; solar heating system; solar cooling system; artificial intelligence; regulation; energy production; solar energy; simulation; economics

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1. Introduction

The centre of gravity in energy research and development is shifting from centralized production to the level of building neighbourhood, district and urban systems that bring together a variety of classical research topics such as the production of heat/cold and of electricity via renewable and non-renewable technologies, electricity distribution networks, thermal networks, energy demand in buildings into one integrated system.

The reduction of the energy consumption is one the main actual challenges. Energy management of building heating regulation systems – especially in buildings with a high proportion of active as well as passive solar energy – requires new approaches. These buildings are equipped with latest technologies such as solar panels, geothermal heat poles, heat pump etc. To take full advantage of these systems, an extensive optimization of the energy building production/consumption/regulation techniques is required. The current project uses concepts based on artificial intelligence to optimize energy production, minimize electrical grid use, minimize energy consumption and optimize solar heating system and storage. Thus, it allows a decentralized energy production both on building, district and neighbourhood level, a better solar integration and solar use and a significant reduction of CO_2.

Nomenclature

Q_{need}	heating needs	[J]
GHI(t)	global horizontal irradiation at time t	[W/m^2]
$T_{ext}(t)$	exterior temperature at time t	[K]
$Q_{IG}(t)$	internal gain at time t	[J]
α(h)	coefficients vector of the exterior temperature depending on the hour of the day	[J/K]
β(h)	coefficients vector of the global horizontal irradiation depending on the hour of the day	[J·m^2/W]
γ(h)	coefficients vector of the internal gain variable depending on the hour of the day	[-]
Q_{stored}	stored energy in the hot water tank	[J]
$Q_{capacity}$	remaining storage capacity of the hot water tank	[J]
Q_{loss}	thermal losses of the hot water tank	[J]
Q_{out}	thermal energy taken from the hot water tank	[J]
T_1	hot water temperature at upper level of the tank	[K]
T_{max}	maximum allowed temperature of the hot water tank	[K]
T_{set}	setpoint temperature of the hot water tank	[K]
T_{mean}	mean temperature of the hot water tank	[K]
h_{max}	height of the hot water tank	[m]
h_{set}	height where the setpoint of the hot water tank is reached	[m]
R_{tan}	radius of the hot water tank	[m]
$c_{p,water}$	specific heat of water	[J/(kg·K)]
ρ_{water}	water density	[kg/m^3]

2. Technical installation

2.1. General concept

The current article presents the development of a compact and cheap solar heating system based on photovoltaic panels, heat pump and heating storage through a smart regulation from a technical and economical point of view (Fig. 1). The heat pump is standard, available on the market, and has its own native regulation. The building's owner may interact with the regulation through a web service to visualize and monitor his installation, update the building occupation's calendar, choose the operation mode. The goal of the regulation is to optimize the consumption of the own electricity production based on photovoltaic panels and therefore minimize the electricity taken from the grid, as well as to optimize the thermal storage. As the imported electricity has a higher price than the exported electricity, this is economically more advantageous and encouraging for the user to self-consume his own electricity production.

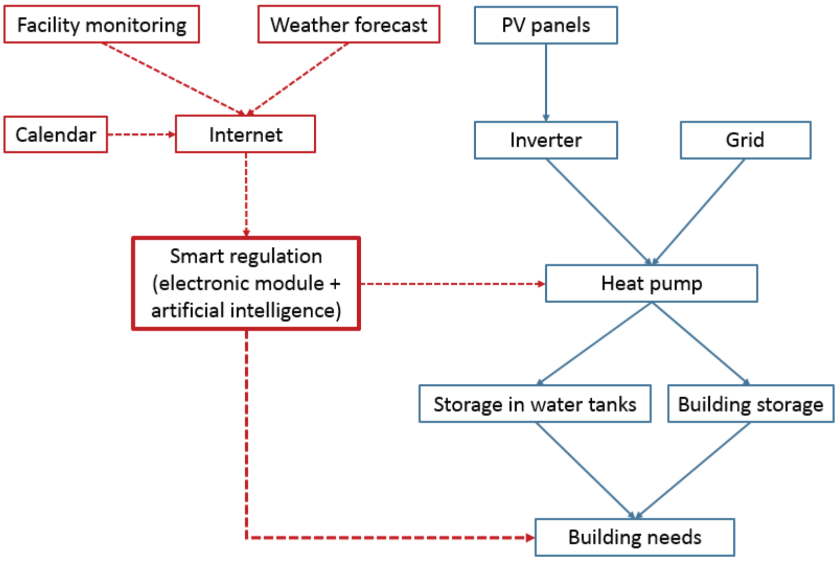

Fig. 1. Scheme of the smart regulation concept

2.2. Monitoring

The new regulation of a heating system requires certain measurements to calibrate it and for solving the energy balance and storage management. The monitoring system uses temperature sensors - for the domestic hot water tank and the buffer tank, interior temperature and exterior temperature - and a flowmeter to measure the domestic hot water consumption (Fig. 2.).

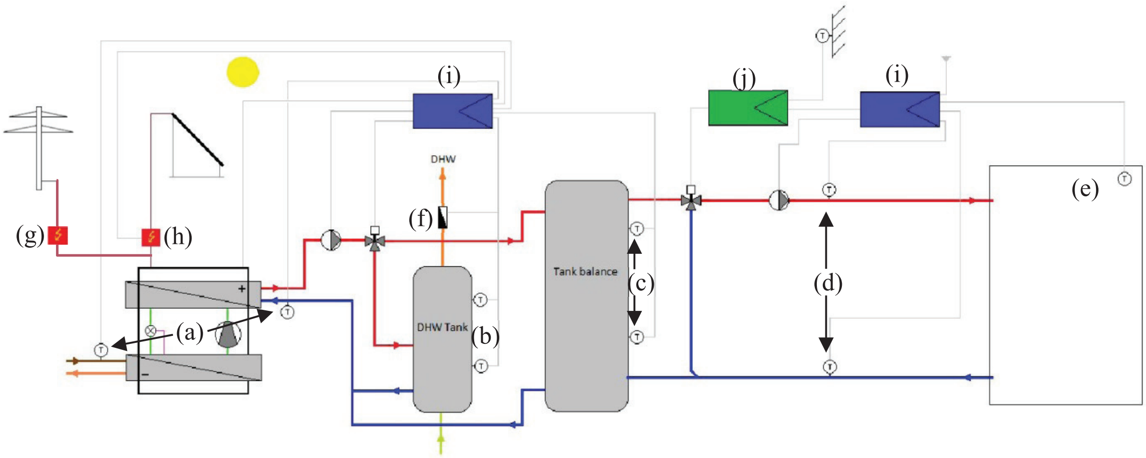

Fig. 2. Monitoring of the technical installation: (a) temperatures of the cold and hot source of the heat pump; (b) temperatures of the upper and lower parts of the domestic hot water (DHW) tank (c) temperatures of the upper and lower parts of the buffer tank; (d) temperatures of the inlet and outlet of the heating system; (e) temperature of the building; (f) DHW discharge; (g) electric counter from the grid; (h) electric counter from PV production; (i) new regulation; (j) existing regulation

The measures are collected in a new electronic module. The old one is kept in case of dysfunction of the new regulation. The regulation includes the scenario where one of the water storage tanks is absent.

2.3. Electronic interface

The development of a low-cost electronic module which collects the monitoring data and communicates with the server (or the application in the cloud) is foreseen and presented. The module transmits the data to the server and commands the heat pump and the water circulation pumps. This is achieved without any intrusion in the heat pump's own regulation and therefore the manufacturer's warranty is preserved. To command the heat pump and the heating system without intrusion into the original regulation and the heat pump own regulation, the module simulates the input values of the two systems, such as exterior temperature to control the heating system and temperatures of the hot water tanks to control the heat pump, and therefore it can at any moment switch to the previous regulation and by-pass the simulated sensors. It also manages the interaction between the heat pump, the grid and the PV production.

3. Regulation's strategy

The regulation's strategy is built and developed on 4 main principles (Fig. 3.):

- Forecast of energy production,
- Forecast of energy building needs,
- Storage management,
- The utilization of the past monitored data to improve the future regulation,

improving thus the heating system, optimizing the solar energy use and storage and decreasing the dependency on the grid. This approach is possible thanks to the monitoring of the facility and the weather forecast.

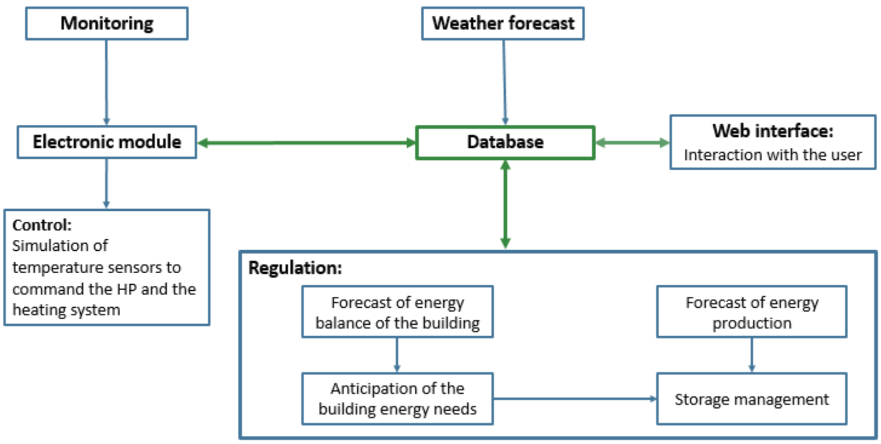

Fig. 3. General methods to develop a smart regulation based on building heating needs balance

3.1. Weather forecast data

Weather forecast includes global horizontal irradiation (GHI) and exterior temperature. They are provided by the Swiss company Meteotest. GHI is used to forecast photovoltaic production and heat provided through the building windows while exterior temperature allows to forecast building heating needs. From GHI, direct horizontal irradiation and diffuse horizontal irradiation are deduced using the model of Orgill and Holland [2].

Forecast weather is provided for the next 48 hours using a time step of one hour. The aim of weather forecast data is to optimize heating storage, utilization of the photovoltaic production and electricity consumption from the grid.

3.2. Building heating needs

New regulation is based on the building heating needs forecast. Calculated based on the weather forecast, the building heating needs for the next 48 hours are anticipated.

In a standard regulation of a heating system based on heat pump, the heat provided depends on the actual and previous exterior temperatures. Future exterior temperature aren't considered and, therefore, an increase of exterior temperature induces an increase of ambient temperature in the building leading to useless consumption of energy, see Fig. 4.

Thus, anticipation of building heating needs is a method to take into account the building inertia and to ensure a stable ambient temperature in the building. This method will allow to spare energy and avoid thus the wasted energy. The potential of economy, using this method has been evaluated at about 10% [1].

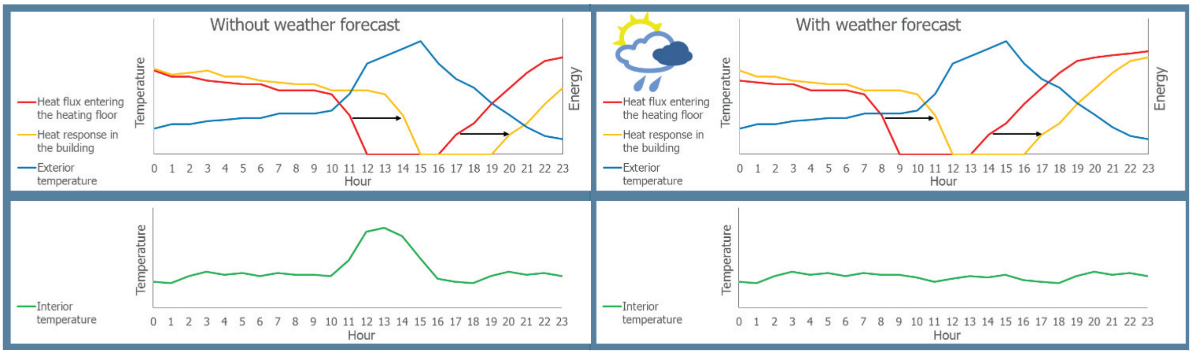

Fig. 4. Weather forecast concept applied to heating needs

Building heating needs are estimated using 3 variables:

- Internal gain (energy sources),
- Exterior temperature forecast,
- GHI forecast.

These variables are time dependant. Each hour there are different building heating needs as well as exterior temperature, GHI and internal gain. Moreover, the contribution of GHI to the building energy balance is also dependant on the hour of the day. Therefore, parameters depending on the hour of the day are added to the 3 main variables. To evaluate these parameters and resolve the linear system of equations, a minimum number of initial measurements of the heating needs are required.

The method allows to adapt the heating needs to the general orientation of the building and to the windows surfaces for each orientation.

The monitoring of the heating and DHW needs are used to adjust the future needs. The objective of this method is to have a specific parameterization which fits the energy balance of the building. Each time step, the previous measurements of the exterior temperature, GHI and heating needs, Q_{IG}, for the same hour of the current time are retrieved from the database. These 3 variables are used to recalculate each hour the three parameters (α, β, γ) with the method of the least square applied to the equation 1. The monitoring of the DHW consumption allows also to adjust the prediction of future consumption.

$$\begin{pmatrix} Q_{needs}(t-i) \\ \vdots \\ Q_{needs}(t) \end{pmatrix} = \begin{pmatrix} T_{ext}(t-i) & GHI(t-i) & Q_{IG}(t-i) \\ \vdots & \vdots & \vdots \\ T_{ext}(t) & GHI(t) & Q_{IG}(t) \end{pmatrix} \begin{pmatrix} \alpha(h) \\ \beta(h) \\ \gamma(h) \end{pmatrix} \quad (1)$$

3.3. Storage management

There are 3 heating storage systems: the domestic hot water tank, the tank for the space heating system and the building mass itself. Some energy can be stored in the building mass through a small variation of the building temperature. Each storage unit is used to minimize the leaks and to optimize comfort and self-consumption.

Optimization of full potential of the hot water tanks storage needs a smart management. The smart regulation calculates each time step the available energy and the remaining storage capacity in order to maximize self-consumption and minimize electricity consumption from the grid. In order to calculate these 2 values for the water tank, it is necessary to know the temperature variation in the tanks with the height. As only two temperature sensors per tank are available, for simplification, a linear variation is assumed. The following equations allow to determine the available energy (Equ. 2.) and the remaining storage capacity (Equ. 3.):

$$Q_{stored} = (h_{\max} - h_{set}) R_{\tan}^2 \pi \times c_{p,water} \rho_{water} \times \frac{(T_1 - T_{set})}{2} - Q_{loss} \quad (2)$$

$$Q_{capacity} = (T_{\max} - T_{mean}) R_{\tan}^2 \pi \times C_{p,water} \rho_{water} - Q_{loss} + Q_{out} \quad (3)$$

The potential of building storage is defined by the storage capacity of the building structure and by heating power, meaning the capacity to restore this energy to the building. To quantify these heating power capacities of the building structure for the building used as pilot tests, dynamic simulations have been performed with the software IDA-ICE (Fig. 5 (a)). The building used for the pilot tests, using PV-heat pump system, is a single family house of 250 m^2. Therefore, the only source of energy is electricity. The model has been validated by the measured electricity consumption of the last 3 years. In the simulations, the heating power of each zone has been sum up (Fig. 5 (b)). The total mean heating power of the structure building is of 2.1 kW. This value is considered for the calculation of the utilization of the stored energy into the building structure.

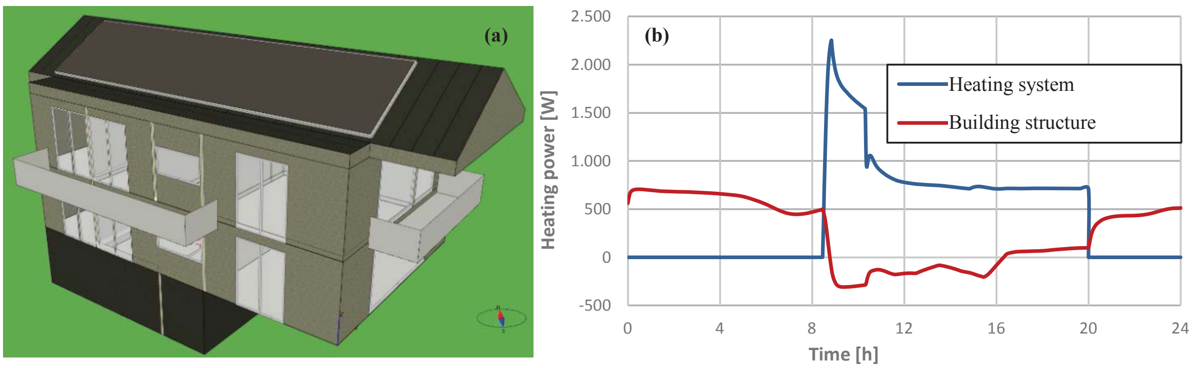

Fig. 5. (a) IDA-ICE model of the pilot building (b) Comparison of the heating power of the heating system and building structure of the zone 1 of the model

4. Validation

The validation of the regulation is achieved by a number simulations of the behavior of the algorithm driven the regulation and measures on a pilot facility in a single family house. The test installation is a villa in Switzerland and will begin in October 2014.

To test the algorithm, several reference values for the tank temperatures, interior and exterior temperatures and GHI have been tested. Afterward, the results have been compared to the regulation strategy.

The heat consumption of the building is assimilated to the electricity consumption, as the primary source of energy of the technical installation is electricity. The evaluation of the new regulation on the pilot facility requires a comparison between the previous and the actual electricity consumption. The actual electricity consumption is used for the new regulation. The virtual electricity consumption for the actual period of the previous regulation must be estimated. There is a strong correlation between the monthly sum of the heating degree-day and of the electricity consumption. Therefore, the potential electricity consumption is evaluated using the linear equation applied to the previous regulation of the Fig. 6.

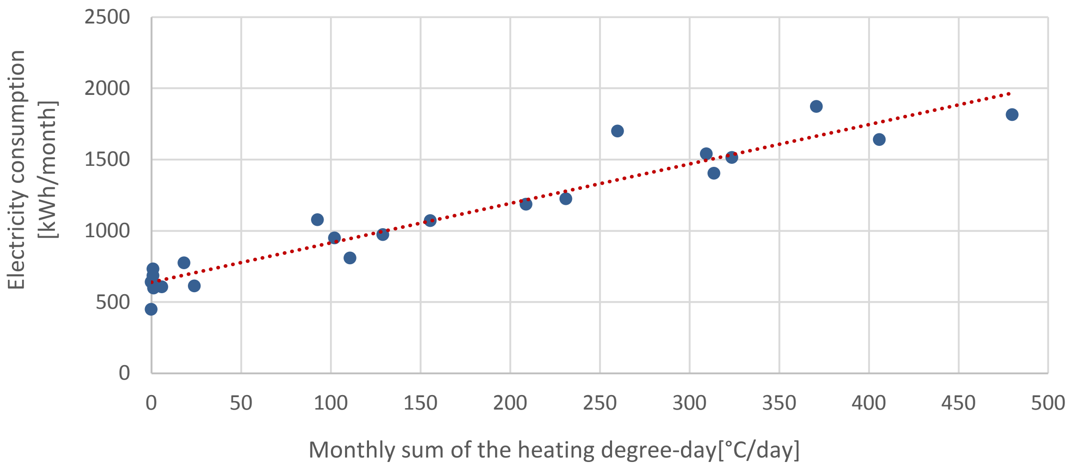

Fig. 6. Monthly sum of the heating degree-day variation with the monthly sum of electricity consumption

5. Conclusions

The presented concept gives a new, integrated and innovative approach to consider the weather forecast in the heating regulation for all types of heat-pump directly PV driven system, by developing a smart regulation. The methodology is based on the prediction of the energy building balance and PV production for the next 48 hours. The quantification of future energy needs and PV production allow to optimize the thermal storage management in the hot water tanks and in the building structure. This new, innovative approach will allow to increase the self-consumption, releasing the dependence on the storage capacity and energy production of the grid, and also to decrease the energy consumption through to the anticipation of the heating needs. The developed regulation was validated by numerical simulations and it will be monitored during the winter 2014-2015.

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