Development of Automation Models for the Intelligent Use of PV Energy and Energy Storage in Regarding to Air Quality and Comfort in Buildings

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Abstract

The so-called "Plus-Energy-House" can make an important contribution to the future through a more efficient use of energy. In cooperation with numerous partners from the industry as well as the Fulda University of Applied Sciences (Fulda UAS), a multifunctional school building which meets the requirements of a Plus-Energy-House was built. Intelligent energy management achieves a high level of self-consumption and an energy excess. This paper explains the energy concept of the building, which consists of numerous components. These include for example, prediction algorithms for generating as well as using PV energy and a computer vision (CV) system, which integrates the human as a thermo-technical component in the energy concept of the building.

Keywords: Plus Energy House, Control, Prediction Algorithm

1. Introduction

The recent years have shown that the current method of energy production and energy consumption is not sustainable. As a result, energy transition in the Federal Republic of Germany is currently a very relevant issue of today's world. Energy transition defines the transition from unsustainable fossil fuels and nuclear energy to a sustainable and environmental friendly energy supply through renewable energies (Verbruggen, 2014). An important goal is to reduce the social, health and ecological problems caused by the conventional energy industry. A decarburization of the energy industry plays a significant role in stopping global warming. (Lüdeke-Freund, 2014) (Poizot and Dolhem, 2011) (Armaroli and Balzani, 2007) Therefore, a basic change in thinking of energy production and the use of energy has to follow in the future. (Mertens, 2011) The construction and housing sector provides a great energy saving potential. Currently, about 40 percent of the total primary energy consumption is spent on it (Ministry of Environment, Energy and Climate Protection, 2013). As shown by Köhler, Fischer and Lambeck (2014) the technology of the so-called "Plus-Energy-House" can make a major contribution to that. A plus energy house produces more energy than it needs for heating and the entire household electricity by using modern energy technologies in conjunction with energy storage (Lüdeke-Freud and Opel, 2014). Combining the technology of plus energy houses with additional energy optimization systems, further improvements are possible regarding energy consumption.

2. Application

A new multifunctional school building (see Figure 1) was built on the campus of the Johannes-Keppler-School in Neuhof (Germany) in cooperation with the manufacturer "Bien Zenker" as well as numerous other partners from industry and the handicrafts (Figure 1). It is in conformity with the requirements of a plus-energy-house. Fulda UAS is using the building for research purposes.

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Fig. 1: Front view of the school building

The modern, energy-saving and efficient house contains numerous systems that produce, store and distribute the required energy for the operation of the building in an intelligent way. For example, there is a photovoltaic system on the roof of the building. The generated energy can be used for operation, stored in a battery or fed into the grid. To ensure the lowest possible energy consumption, only highly efficient and energy-saving systems are used inside the building. A ventilation system with heat recovery ensures ideal air quality. An infrared heating system is used to heat the building. The control of actuators such as lighting, blinds as well as some sensors e.g. temperature, CO2, brightness or presence is done by a radio bus system.

The use of special prediction algorithms enables the prediction of energy generation and energy consumption in the building and helps to optimize the energy usage. In addition, the use of special camera systems to predict the CO2 concentration and room temperature help to improve the energy balance. The camera system makes it possible to determine the number of persons in the building. With the help of a Computer Vision (CV) system (see 4.1) the influence of the room temperature and the CO2 concentration can be calculated by the persons inside the building and their change can be predicted.

3. Efficient energy management

3.1. Three pillars concept

The energy of the building is used sensibly. As a result, only a little energy is taken from the public grid and the own consumption is increased. To achieve this, the energy concept is based on *three* fundamental pillars.

First, efforts are necessary to save as much energy as possible. The built-in highly efficient technologies contribute significantly to energy saving. It is important to reduce the energy consumption of the building as much as possible. Energy should only be used when necessary. For example, make contacts and presence detectors are installed inside the building, which allow some consumers to be switched off if there is no one inside.

Secondly, the storing of the energy has to be made possible. The photovoltaic system generates energy only during the day. As there is no solar energy available at night, it must be saved during the day time. This increases the self-consumption of the generated energy and thus has a decisive influence on the autonomy of the building. A battery system can be used for this purpose. In addition, the building has a special cement flooring, which has a high heat capacity.

The *third* priority is the preventive use of excessive energy. The excessive energy is used where it is required in the near future, e.g. for heating or ventilating the building. The battery has only a limited capacity. In spring, summer and autumn the capacity is enough to supply the building at night without any power from the grid. In the winter, the infrared heating requires a lot of energy that the battery cannot cover. That is when the usage - optimization is put to use. There is a sufficient number of sunny days in the winter time, when the photovoltaic system produces enough energy. On these days surplus energy which is normally fed into the grid, is to be effectively used in the building in order to prevent energy consumption at a later time.

3.2. Use of prediction algorithms

Renewable energy has many advantages like low environmental impact and endless resources. However, there are also some disadvantages. For example, the energies are highly weather-bound and therefore not always available. This makes it necessary to store and use such time-dependent energy. It would be ideal to adjust the power consumption to the power generation. Thus, the produced energy could be consumed concurrently, peak loads would be reduced and stored energy would be available longer. To realize this, it is advantageous to forecast the produced energy by suitable methods to plan their use in advance. Thus, the energy consumption of the produced energy can be tracked by PV forecasts and suitable activation of electric loads. On the one hand this prevents unwanted load peaks and on the other hand economic losses of the system. The basis for a forecast-based operating method are suitable methods to predict the PV production in order to plan the usage of the generated energy better.

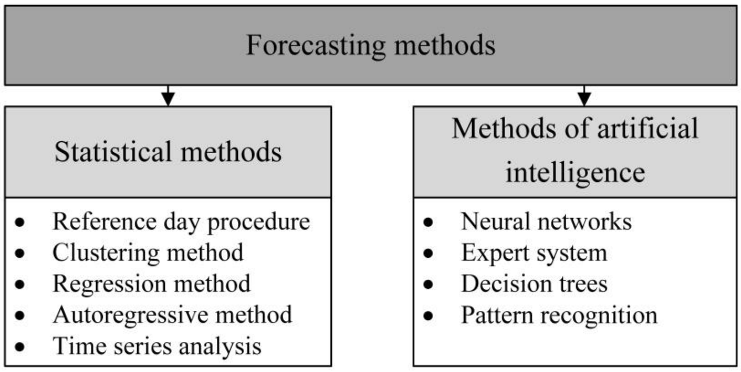

Fig. 2: Overview of typical forecasting methods (Köhler, Fischer and Lambeck, 2014)

There are two typical types of forecasting methods, as Figure 2 shows. Statistical methods use mathematical combinations of historical data combined with information on the influencing variables to predict the future behavior of consumers. However, if no expedient prediction can be made because of unavailable influence factors, it could be helpful to use methods of artificial intelligence. Methods of artificial intelligence learn patterns of behavior with the help of historical data and project these as a function of the expected operating conditions into the future. To select the optimal forecasting method for a particular application, it is also important determine the required time horizon of the forecast. Short-term forecasts (forecast horizon for one day) can be created on the basis of measurements and current data. In contrast to long-term forecasts (forecast horizon for several months) where mostly methods of artificial intelligence are used. These learn the different patterns of behavior based on historical data and project them into the future. Sometime various forecasting methods can work differently for certain sectors of the influencing factors. Because of this, combined or cascaded models are increasingly used. These include a number of methods. Each of them operates only for certain input variables and complement each other. A combination of different methods for a forecast can improve the forecasting accuracy. (Prokhorova and Heimel, 2013) (Theil, 1966) (Schlittgen, 2001)

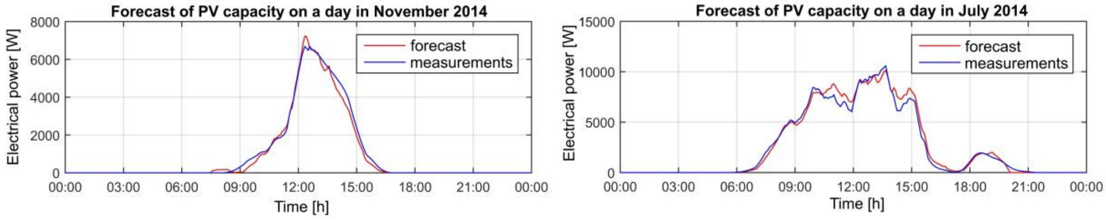

Fig. 3: Comparison between simulation and measurements on two days (Köhler, Fischer and Lambeck, 2016)

4. Comfort and air quality for people

A major problem in well-insulated buildings is the air quality. The high insulation makes the air exchange with the environment more difficult. This has advantages and disadvantages. One advantage is that the energy, like heat from humans, remains inside the room. A disadvantage is that old depleted air remains inside the building. For these reasons, various systems have been integrated into the building, which also significantly increase the energy efficiency.

4.1. Use of prediction algorithms

Figure 4 shows that an average person with a light activity produces a heat current of 120 W. This results in a daily heat output of about 2.9 kWh per day 8 (24 hours). This factor is multiplied many times due to the many students inside the public building. Accordingly, this would be a heat flux of 3000 W at an average of 25 students. (Specht, 2005) Thus, the human is a part of heating system which is an important factor in the control of heating and ventilation.

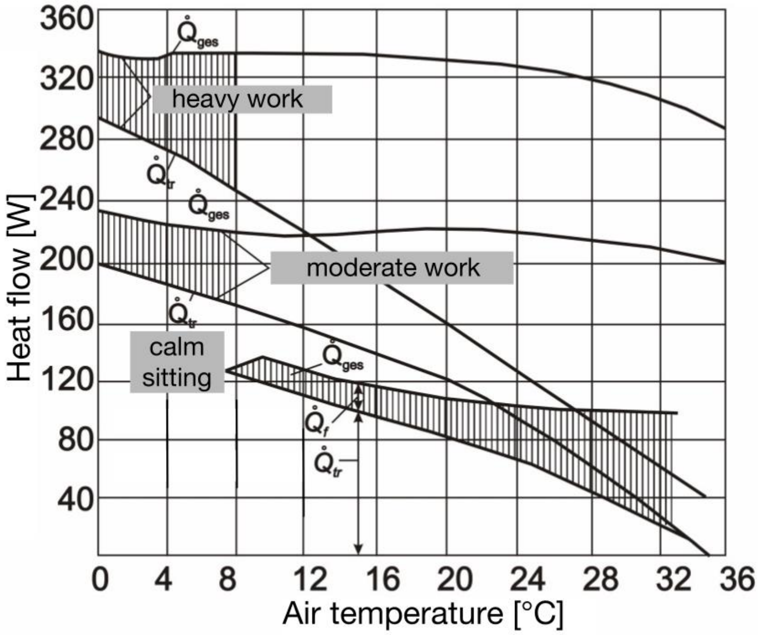

Fig. 4: Heat emission of humans (Specht, 2005)

A Computer Vision (CV) system (ADBF-Vision) was developed to recognize the number of people in the room. Depending on the number of detected persons in the room, the heating is throttled and unnecessary energy is saved. The Viola-Jones algorithm, which was originally presented in 2001 by Paul Viola and Michael Jones as a possible solution for the problem of facial recognition, is used to realize the recognition of persons. (Behera and Mohapatra, 2015) information on this development, refer to (Böttcher and Köhler, 2017). This can also be applied to detect other objects.

The algorithm gains high acceptance because of the comparatively high computational efficiency that allows real-time image processing. In one iteration, a migrating window moves over the input image pixel by pixel. After completion of a run, the image can be scaled into a smaller format or the mask can be enlarged. The image area inside the movable window is analysed step by step. The Haar wavelets developed by Alfred Haar are processed (see figure 5). These are folding masks. The black and white areas represent the sign for the summation of the brightness values of the covered pixels.

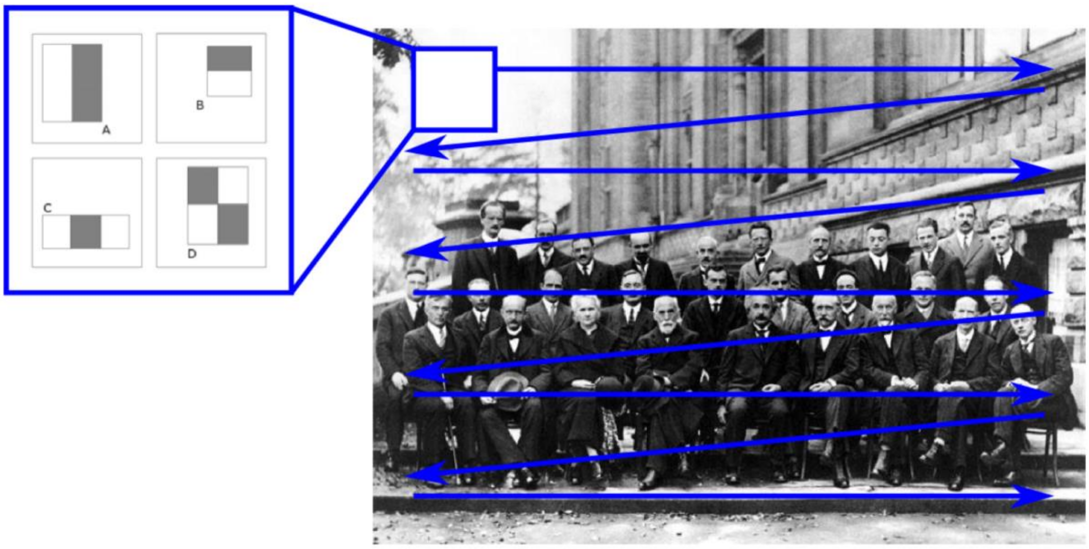

Fig. 5: Bewegliches Fenster und Haar Kaskadenmuster (Zhenyu, 2012)

The object detection is based on the cascade filter. Within a position of the moving window, different Haar-cascade elements are applied according to the state of the filter on this area. The individual results of the masks are summed. If a specific threshold is exceeded, the area is passed on to the following level. If the threshold for matching with the masks falls to a certain level, the content of the window is not checked anymore for correspondence and the window moves. If the content of the windows can exceed the required threshold in all levels of the filter, it is included in the result set of the detected objects. Therefore, it is possible for the algorithm to search for possible facial shapes inside the movable window (figure 6). For further information on this development, please refer to (Böttcher and Köhler, 2017).

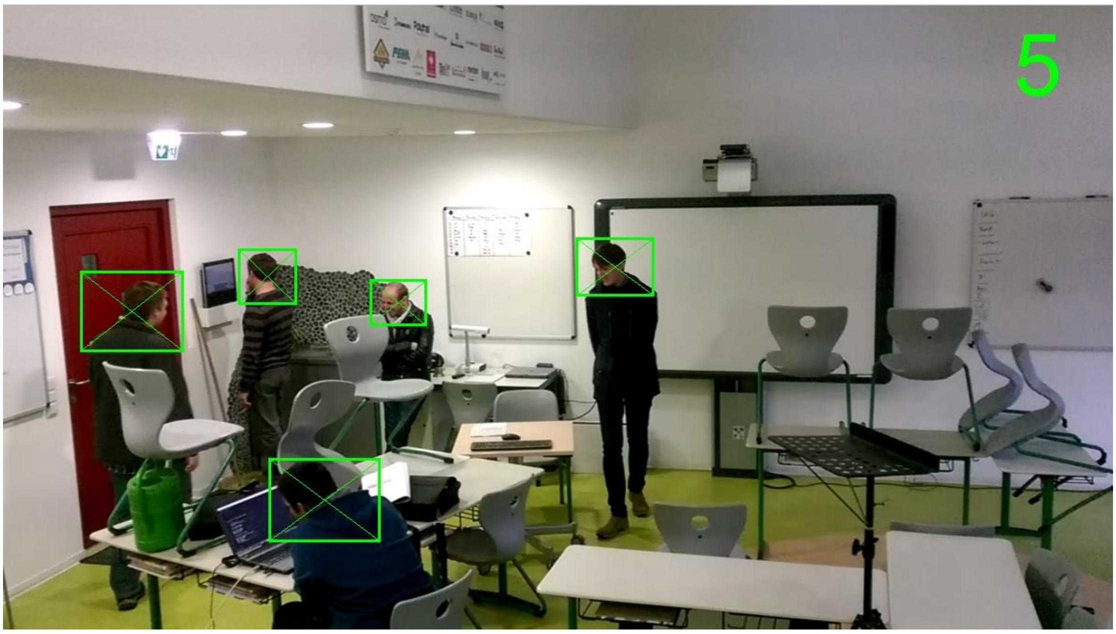

Fig. 6: Person detection inside the classroom

4.2. Carbon dioxide (CO2) and temperature

Various studies have shown that the air quality in classrooms is poor and that CO2 concentration is too high, especially during the winter months. This can lead to tiredness or lack of concentration for teachers and pupils. The amount of CO2 depends on the activity of the people inside the room. Breathing air contains about 4 percent by volume CO2. This corresponds to 18 to 20 l/h CO2 per person (Benedix, 2006). In contrast to water vapor, the exhaled CO2 is not absorbed by surfaces. It accumulates completely in the air. During a lesson, it leads to an increase of the CO2 concentration from 400 ppm up to 2000-2500 ppm. The maximum permitted

CO2 limit in public areas is 1500 ppm according to DIN 1946-2. The CO2 and temperature sensors as well as the computer vision (CV) system allow a predictive control of the ventilation. Thus, it is possible to maintain the air quality inside the room under efficient conditions.

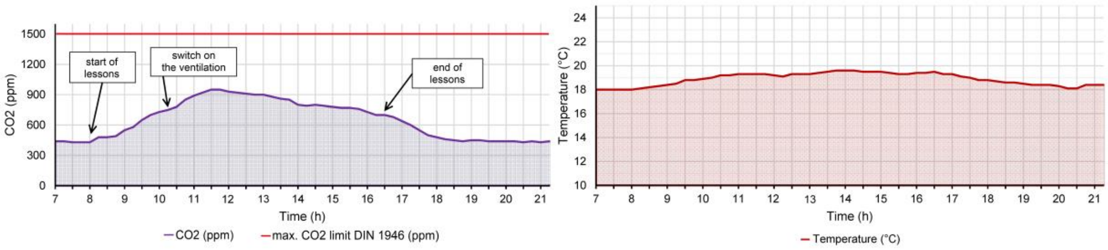

Fig. 7: measurements of carbon dioxide (CO2) and temperature for one day in school

5. Conclusion and prospects

The energy management of the multifunctional school building has already proved over the past few years that intelligent, predictive control strategies allow an environmental friendly operation of the building and an efficient use of renewable energies. In particular, the low energy consumption of the building as well as a high part of renewable energy in the total energy consumption should be highlighted. The strategies used to regulate temperature and CO2 concentration leads to an ideal air quality and comfort.

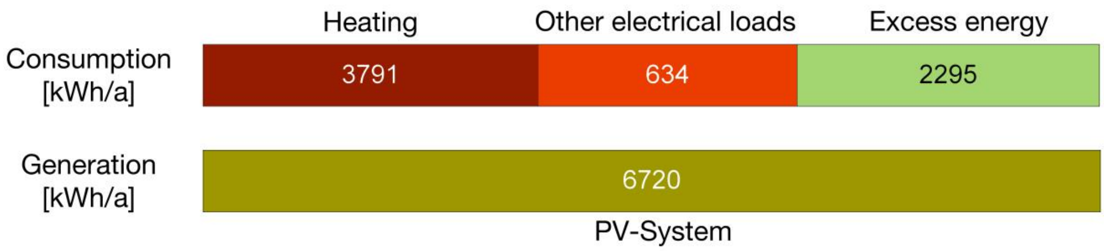

Fig. 6: energy balance

Through integrating the Computer Vision system into the existing automation unit, further energy saving potentials will be realized in the near future. A statement about the level of energy saving or an improvement in air quality can only be made when the system is operating in the building over a longer period of time. In the future, it is also important to coordinate the integrated systems and optimize their functions in order to increase the efficiency of the building.

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