Short Summary

Improvement of energy efficiency and comfort in building operation with the use of Predictive Operational Procedures (PräBV)

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1 Objective

The field of Technical Building Operation Services shows that in the recent years, many new possibilities for both energy supply and distribution have been developed. These developments are increasingly common in new constructions and are even partially seen in the refurbishments of building structures. Typical examples are technologies from the usage of geothermal energy to generate heat and cold or new systems for energy distribution, such as air and water carrying systems in large mass structures, the so-called thermo active building elements. Also, new methods based on the existing technology have been developed. An example of this is the night ventilation system. The existing night air can be used to maintain ventilation systems and secure comfort according to the prescribed limits in the building without the use of air conditioning.

Long-term studies have shown that the conventional building automations with existing algorithms are not in a position to maximise energy saving potentials and also not to fully optimise the usage of sustainable energy sources anymore.

This is partly because nowadays buildings are becoming increasingly complex. Often there is more than one way to heat up or cool down a building. Generally there are more energy sources (renewable and fossil) and different distribution systems available. Additional components are mostly storages for heating and cooling systems in order to compensate the loss of weather-dependent renewable energy. The optimal interaction of all these different components cannot be achieved with the conventional methods of the existing building automation.

As soon as energy storages or very slow process like the thermo active building system are implemented, dynamic operational issues, such as the need of an optimal storage management will appear.

In practice, weather prognosis has been increasingly integrated into building automation systems. However, most of it only involves improving the conventional automation process, so that the control settings due to the weather forecast can be corrected. Thus, the possible potential of improving energy efficiency is not achieved. As an example, the control system of TABS (thermal activated structural elements) is consistently operated at variable supply temperatures, which is formed by means of heating and cooling curves based on the outside temperature.

If weather prognoses are included in the control system, mostly a correction of the supply temperature depending on the analyzed data for the predicted outside temperature and perhaps global radiation as well, is fulfilled. While the energy demand of the buildings is not known, an automatic control of this supply temperature is not possible, due to the big inertia of the TABS. The implementation of the control system is based on past experience and done by manual setting modifications during operation until a satisfactory performance has been reached.

In order to fully utilise the potential that exists in the usage of weather prognosis, the future energy demand of a building or each individual zones should be predicted. This predicted amount of energy can then be inserted into the storage components with the highest possible efficiency. To achieve this, the system must operate at a maximal or minimal possible supply temperature. As a result, the operation time of the system will be minimised, thus optimising the energy demand and also the environmental comfort.

The objective of this project PräBV is to develop a new predictive algorithm for the building automation system, which is capable to achieve a sustainable, energy efficient and comfortable building operation, despite the described problems and challenges.

Therefore it is necessary to provide a customized weather prognosis for every respective location of the building. For this purpose, a new method should be developed and tested. Weather forecasts can be transmitted over a long-wave radio transmitter and can be optimized on site by using weather data from the respective location in terms of precision and the degree of detail.

In addition providing services like “On-site Weather Prognosis” and receivers which can be used in building automation are developed as well. With the help of a new predictive algorithm, the customized weather prognosis can be integrated into the existing building automation to maximize the usage of renewable energy and minimize the fossil fuel consumption.

2 Development of predictive methods for building automation

2.1 Development environment

A standard test environment by coupling the programs TRNSYS and MATLAB is created for the development of the predictive automation process. The involvement of MATLAB in the building simulation from TRNSYS allows the development and the test of complex mathematical algorithms. The simulation of the building, together with its thermally active components will be carried out in TRNSYS. This is done in a reliable and well proven method. The reproduction of the internal load and the simple task of building automation such as lighting and blind control are also implemented in TRNSYS. The development and simulation of the predictive and self-learning procedures of the TABS-control are outsourced in MATLAB. This enables the implementation of complex mathematical methods with full integration into the dynamic simulation of the building. A single storey building with six zones, modeled in TRNSYS, has been chosen as the test building. The ceilings will run as thermally active components (TABS) and are used to heat and cool the building. These TABS of each zone can be controlled separately. This development environment has been used by all project partners for the design of a predictive and self-learning process in an outstanding proven way.

2.2 Principle of energy demand prognosis

As a typical application for predictive methods, various approaches have been developed for the operation of thermal activated structural systems (TABS). They are all based on the principle of energy demand prognosis combined with the operation of TABS at a maximum or minimum possible supply temperature to achieve the maximum energy efficiency of the overall system. The management of the energy consumption works exclusively time controlled and not by varying the supply temperature or the mass flow.

To determine the energy demand of a building with meteorological predictions, the development of simple models of energy demand is necessary to introduce them into the building automation.

In the first approach, the TRNSYS building model will be operated with ideal heating and ideal cooling. Thus the total amount of energy that must be theoretically supplied to the building can be obtained in order to gain the comfort conditions. The type of heating and cooling is irrelevant. The dynamic properties of the corresponding system cannot be considered in the simulation. One will obtain a result in form of a prognosis model, which is suitable even for the usage in real buildings. However, an adjustment of the parameters during normal operations is required, so that the model is adaptable to the reality.

In another method, the TABS are simulated in the building model. For each day of the year an iterative process determines the minimum operating time of the system, which is required to stay in the limits of comfort. The result is the optimum which shows what is achievable whilst using predictive methods, with regards to both the comfort and energy demand. The output of this complex simulation can be used by a multiple linear regression method for creating energy demand models and reproduce the real behavior of the building very well. If enough historical measuring data of the qualified operation with TABS are available, models can also be created very easily from these historical data.

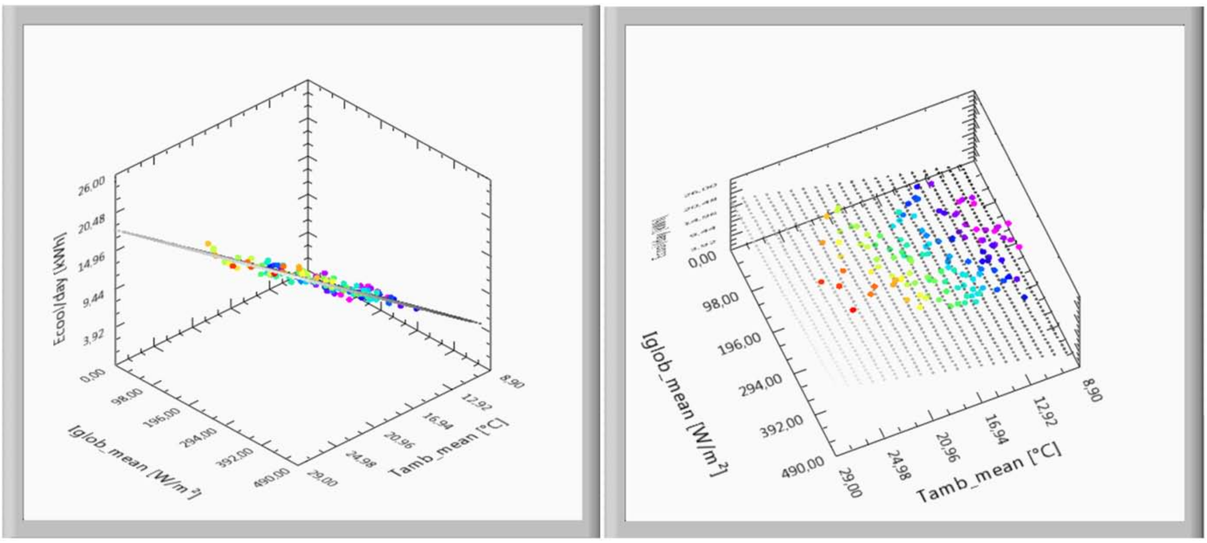

Figure 1: View of a two multiple linear fits for the cooling energy demand of working days in the SE Zone

Such a model is shown in Figure 1. It shows the daily cooling energy demand of a zone of a test building as a function of daily mean outdoor temperature and global radiation. Due to the linear relationship, the energy demand model can be represented by a plane equation. The equation is generated by using a multiple linear regression method which requires historical measurement data or simulation results. When the daily mean values for the outside temperature and global radiation are available, the prognosis can predict the energy demand for the cooling system of the following days. The amount of needed energy can be timely and with high efficiency inserted or dissipated in the zone.

The comparison of the presented predictive operational method with the current conventional method using variable supply temperatures, which depend often on the outdoor temperature, shows a possible potential in energy savings from a scale of 20 to 30 %.

An extensive sensitivity analysis was able to demonstrate a relationship between the supplied amount of energy and the change in the ambient temperature. This relationship can be used for a self-learning method based on a fuzzy expert system. This makes the initial operation and continuous adaptations to changes in system behavior much easier. Changes in system behavior can be for example, internal load changes by user occupancy. The ongoing correction of the energy demand model of a building would be possible in this way due to the experience from the operation itself.

2.3 Self Learning Algorithms

Starting from a simple predictive algorithm based on the principle of energy demand prognosis, two self-learning optimization methods have been investigated at the University of Cologne. The task was to adapt the process of the predictive energy demand to the different thermal properties of the six zones in the building model. In the initial version, all 6 zones are equally controlled, which, due to the different thermal properties caused by different window surfaces and their orientations, lead to partially bad results. This corresponds to the situation, which usually exists at the initial operation of building systems. The control functions for each individual zone can be corrected using the measured data of the current operation. It was done with a multiple regression model and with an artificial neural network (KNN).

After an operating time of about four weeks, the methods are in a position to provide the required comfort conditions, although not perfect but overall still with satisfying results. In problematic zones with large window surface and high solar gain there is a superiority of the regression methods compared to artificial neuronal networks (KNN). A second problem could also be solved with a satisfying result. By using a set of weather data (Bologna instead of Stuttgart), the algorithms should be able to demonstrate their capability to adapt to a changing climate. Both methods showed a successful adaptation of the energy demand model to the changing climatic conditions. However, the results display a relatively common over-temperature problem so there is still potential for improvements.

As the last and most difficult task, the internal loads since mid July were changed. A reduction of 25 % of the load was corrected without a problem, but less satisfactory results arose when the load was reduced to 50 %, which could be compensated only after many weeks. A complete removal of the internal loads, which is also the assumption of a sudden vacancy, cannot be compensated by the two learning process until end of the simulated year.

The studies on self-learning method based on regression models and artificial neural networks were able to demonstrate the basic functions of the approach. However the methods must be further developed to obtain a technical maturity in the practical operation.

A fundamentally new concept for a new predictive method has also been developed using the development environment TRNSYS/MATLAB at the University of Offenburg. The determination of the optimal switch-on time of a heater was chosen as an example.

The procedure is first to analytically describe the time characteristic of the ambient temperature by a differential equation. Subsequently, an algorithm has been developed. The algorithm allows the adaptive determination of the occurring building parameter, which appear in the solution of the differential equation. This adaptive determination is done during operation on the basis of measurement data. The solution from the differential equation describes a relatively simple building model.

Afterwards while operation it is possible to determine by means of cyclic tests or trial calculations based on weather prognosis the starting time of the heating system. The starting time specifies when the heater must be turned on at last in order to achieve the required ambient temperature at the beginning of the employees working time.

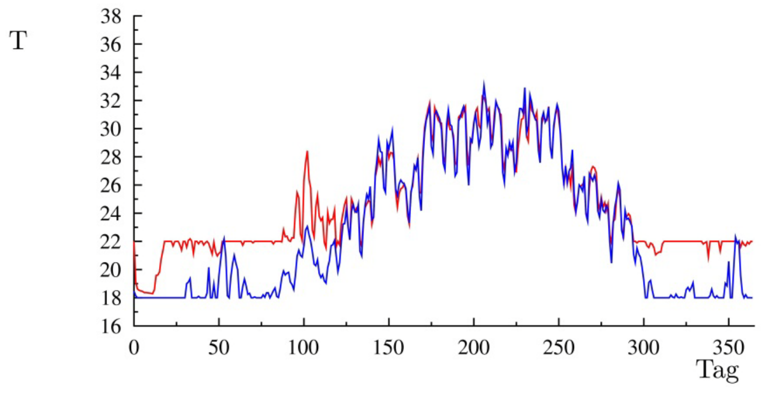

Figure 2 Simulated temperature profile of a building in Stuttgart at 8 am with conventional heating system (blue) and self-learning heating control (red)

A representation of the results is shown in figure 2. It shows the temperature at point t_0 (8 am) in the period of one year. The desired temperature was at 22 °C. A conventional heating system is shown in the blue curve, by which the heating phase begins at 8 am, if the targeted temperature has not been reached and ends at 6 pm. Outside of these hours, the heater will only run when the temperature falls under 18 °C. The temperature during the heater control based on the self-learning algorithm developed within this project is shown in red. One can see clearly that at the beginning of the simulation, the red curve is below the target temperature. However, after a short learning phase, the parameter α and β can be sufficiently determined and the temperature at 8 am is almost the targeted temperature. With the rise in temperature in spring and summer, this temperature is exceeded even without heating. In the subsequent autumn and winter, the self-learning heating controls will begin to maintain the internal temperature at 8 am at the desired 22 °C.

This promising new approach has proved successful in the development environment and will soon be tested and applied to other applications.

3 Weather Prognosis

The reception of weather prognosis is usually via FTP-Download from a server of the metrological service provider. In a few cases a web service may be used by having a direct access to the database using an internet connection. However there are cases in which the building is not accessible via internet connection, especially for security reasons. For this reason a new method for the transmission of the weather prognosis has been developed.

3.1 Weather prognosis with longwave radio technology

Our project partner, HKW Elektronik GmbH has developed a system called Meteotime I which enables the transmission of the weather forecast data using longwave radio signal and the longwave time signal transmitter DCF77. With this system, only small amounts of data for weather stations in the consumer sector will be transferred. For most professional applications in building automation and energy management is this data transfer not sufficient. As part of this project, the technology of the system Meteotime II is further developed to transfer larger amounts of data. This makes it possible to offer more and higher resolution in weather prognosis. The much higher bandwidth is mainly determined by the use of three longwave transmitter of the European GmbH, which are operated in energy management and data services. In addition, the potential service area of the new transmitter will be significantly expanded.

For the receiver in the building, a compact and inexpensive receiver module based on a radio clock receiver has been developed. For the interface to the building automation, the Modbus Standard, a simple and widely used protocol with minimal installation effort has been chosen.

Because of time lags in the procurement of prognosis data during the entire duration of the project, it was not possible to provide hourly resolution weather forecasts. Alternatively, the temperature expansion was determined by interpolating the maximum and minimum temperature of the day. However, the shift to higher resolution data is currently being prepared and with the help of the technology development of the transmitter and receiver possible.

3.2 Correction method of the weather prognosis using on-site measurements

Studies have shown that even a small change in location can cause a significant change in the local micro-climate of a site depending on environmental conditions. The grid for the forecast area cannot be scaled down indefinitely. Therefore a new method has been developed. This method allows obtaining a high precision while adjusting and optimizing the forecasts for extensive areas to a small area, the local site of a building. For this purpose, local weather measurements must be taken in the vicinity of the building and different algorithms have been tested through extensive simulations. The best results were obtained with the so-called long-term correction method, which then was implemented into the receiver. In this method, the system requires a training period in which the precision of the output prognosis can be further improved. After that the weather prognosis data that arrives at the receiver are compared with the locally measured data. From the difference between them correction values can be calculated, which leads to a significant improvement of the forecast. For the practical testing and evaluation, a long term field test is required. However it couldn't be implemented in this project. But the future results from the field test should help to perform adjustments on the algorithm of the correction process. Thus further improvements in the system can be achieved.

4 Implementation of predictive methods in the building automation

The building control management of the company Wonderware was expanded by our project partner FMSbase.com and prepared for the usage of advanced and modern predictive algorithms. It is programmed with a fuzzy logic system which allows realizing fuzzy rules or fuzzy expert systems. Furthermore, a multiple linear regression method has been implemented to allow a modeling of predictive methods. The weather prognosis from the longwave receiver is directly imported via a serial interface into the programmable logic controller (PLC) of the building automation.

Due to organizational reasons, the closing practical application of the developed predictive automation process with the long-wave reception of weather forecasts and on-site value correction could not be achieved. A long term study concerning the reception of weather predictions, is in preparation and the developed predictive algorithms can be found in several subsequent project applications.