KNX-based Energy Efficient Heating and Lighting in Educational Buildings*

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Abstract

In educational buildings user fluctuation and the lack of personal responsibility for the rooms often result in exceedingly high consumption of heating energy as well as electricity. Large energy savings can be realized in these cases by intelligent control systems on the basis of building networks. Heating and lighting control concepts are discussed and experimental results, derived from a KNX system in a university seminar room, are given.

Introduction

Up to now, there are only few measurement based investigations to quantify the gain in energy efficiency by network based single room control. A study of the Fraunhofer Institute of Building Physics states about 10-15% savings gained by PI - heating control versus standard thermostats [2]. Other results come from companies engaged in building automation. Here savings of 20-30% were achieved in residential [3] and large apartment buildings [4]. There seem to be no published measurements for commercial or educational buildings.

The present project was set up to yield reliable results on energy savings achieved by single room control via a building network in an educational building. Here, the energy savings potential of modern control schemes for room heating and lighting can be studied by comparison of two similar adjacent classrooms at Bremen University of Applied Sciences (Hochschule Bremen), one with and the other without KNX-based single room control. With a relatively simple KNX system – consisting of a room temperature controller and magnetic window contacts shutting the radiator valves – about 50 % savings in heating energy consumption were observed in a measurement period of three years [1].

The KNX-System has been enhanced to investigate and optimize solutions for heating and lighting control with respect to energy savings and cost effectiveness. To this end, a measurement system for both rooms was set up based on the ELVIS software. The aims of this investigation are

- Validation und detailed analysis of the "50% savings" result,
- Estimate the effect of heating control concepts using presence detection and time table information on room occupation,
- Analysis and implementation of daylight dependent lighting control concepts,
- Evaluation of electrical energy savings by daylight responsive lighting.

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Heating control

Objective

Heating energy consumption has been measured in the two rooms mentioned above since 2002. Figure 1 shows a plot of these measurements. From this, significant energy savings can be stated for the controlled room. It remains to be verified to what extent these savings can be attributed to the KNX system. Other possible influences and the main reasons for the energy savings have to be considered in detail. In addition, more sophistic control schemes shall be developed and evaluated taking into account room occupation and the availability of a priori occupancy information from student time-tables.

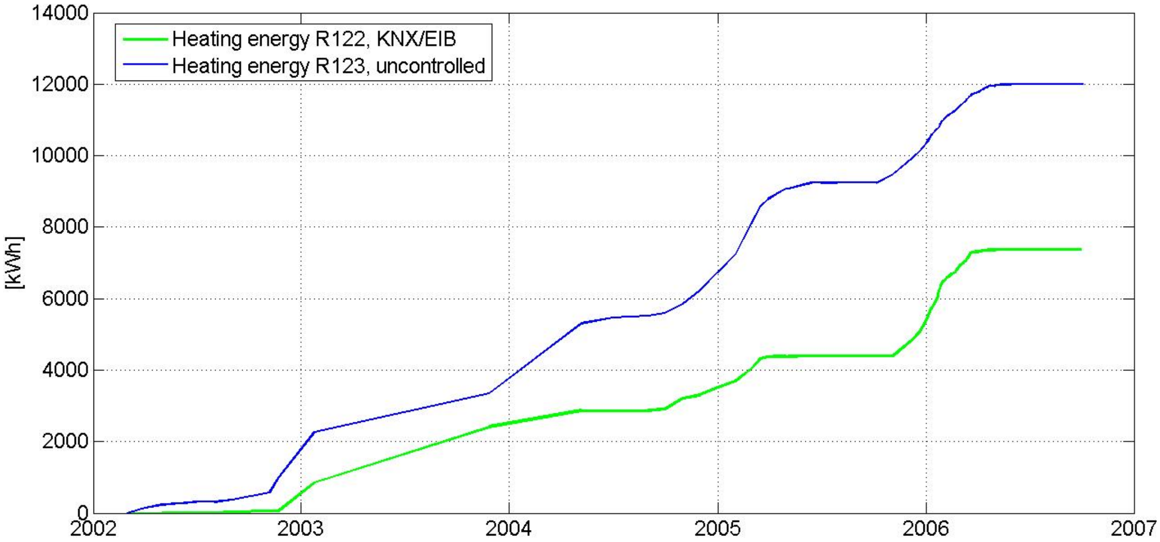


Figure 1: Heating energy consumption of two rooms with and without KNX-based control

Method

a) Validation of the "50% savings" result

To evaluate the energy savings effect of the KNX system long term measurements with an EIB-based measurement system are carried out. It consists of a PC-based system for continuous measurement data acquisition based on the ELVIS software[1], two 4-Channel-Pt1000 interfaces (Siemens N128) for temperature measurement at 3 points in each room as well as M-bus heat meters (**figure 2**) connected via an M-bus-EIB gateway. In addition, the state of the window contacts and the blinds is captured [1].

Based on these measurements the room temperature levels were compared to check if the energy savings compromised user comfort or were due to heat transfer from adjacent rooms. Room temperature decay with open windows and the overall trend of heating energy consumption in both rooms were analysed in detail.

Figure 2: Heat-meters with M-Bus-Interface

[1] Elvis Version 2.2, IT Gesellschaft für Informationstechnik, www.it-gmbh.de

b) Occupancy based heating

The possible effect of taking into account room occupation in a heating control scheme strongly depends on the type and thermal protection standard of a building. The heating and cooling time constants of a room are crucial for an adequate choice of the control scheme. Experiments to study the temperature of the rooms with open windows and heating turned off (cooling characteristic) as well as with heating at rated power – all radiator valves turned on 100 % - (heating characteristic) were carried out.

Based on these measurements a building simulation model was developed and adapted to the present case. By simulation studies the feasibility of occupancy-based control concepts was proven and the additional energy savings effects were estimated.

A presence detector was installed in the room and a user interface for time-table input was added to the ELVIS project (see **figure 3**) to implement the new control concept [5].

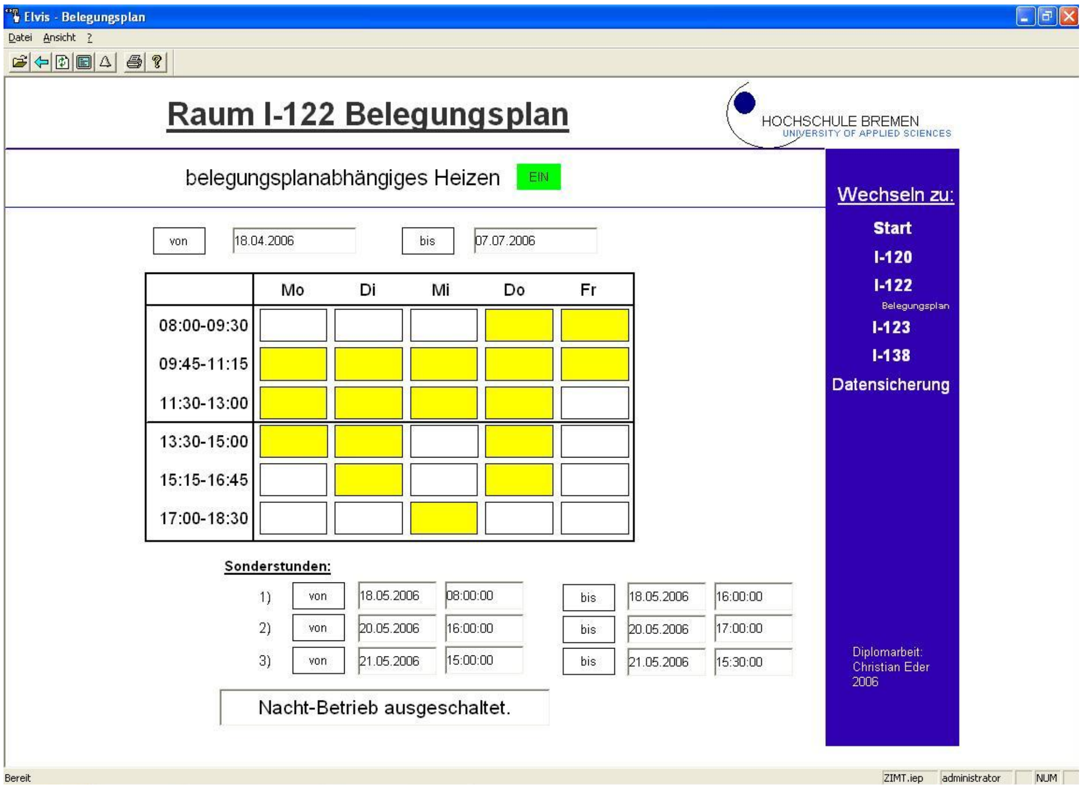


Figure 3: User interface for scheduled room occupation

Results

There is no significant difference in overall temperature levels between the rooms with standard thermostats and KNX-based control. The improvement in energy efficiency is realized without compromising user comfort. This can clearly be seen from figure 4. The mean temperature of the controlled room even tends to be slighty higher than in the other room. Room 123 with standard thermostats has a mean temperature of 21 °C and the controlled room 122 maintains a mean level of 21,3 °C. The wall temperature (dotted curve) lies between the two room temperatures as would be expected.

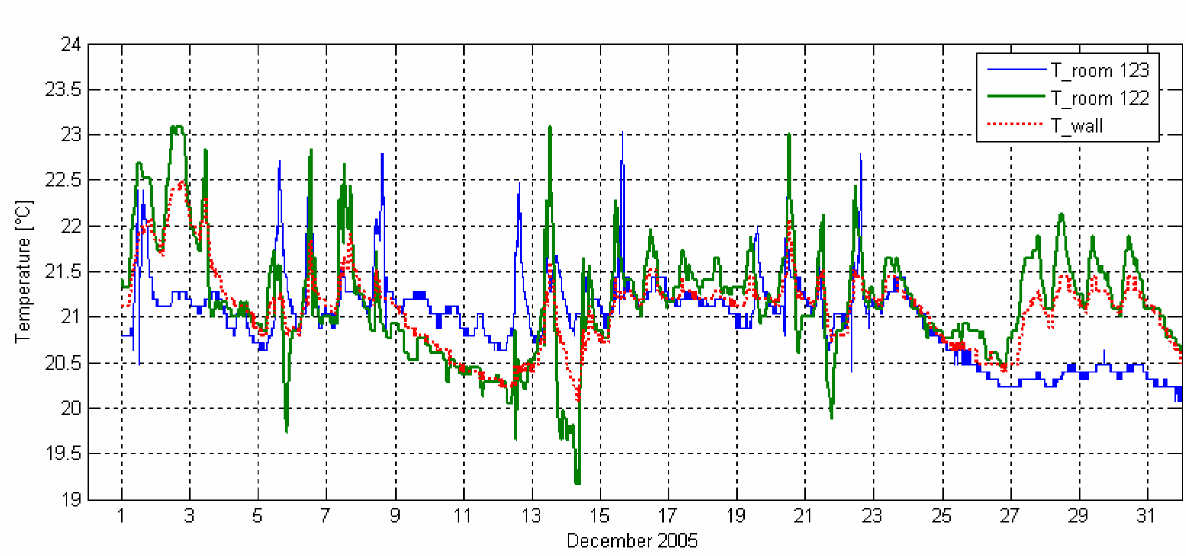


Figure 4: Temperatures of the two adjacent classrooms and temperature of the partition wall

The detailed measurement data analysis discovered two flaws in the installation. The temperature controller was parameterized such that the temperature nominal value was lowered to "absence" level when windows were opened. So the valves were shut only as long as the temperature remained above 18°C. Heating was turned on, when the windows kept open long enough to bring the room temperature down below that level, which resulted in a waste of energy. The parameters of the controller were changed to set the temperature nominal value for open windows to anti-icing level (7°C). This way, energy efficiency could be further increased.

Secondly it was detected and experimentally verified that the heating system installation differed from the original building plans. The heating circuit of the controlled room was laid out in a way that it also includes the radiators of a neighbouring laboratory, which has almost the same area and is KNX-controlled, too.

So, contrary to the room with standard thermostats, the heating energy of the controlled room 122 can not be measured separately. The measurements include the heating energy consumption of the laboratory **additionally**. Thus, a completely new assessment of the measurements obtained so far is necessary.

Heating energy demand of the lab was relatively low until 2005 because it was not in regular use and the temperature nominal value was set to "absence" level most of the time. So despite the fact that the controlled rooms together have almost double the area, their joint energy consumption was significantly lower, about 50% of the consumption of the uncontrolled room by summer 2005 (see figure 1). Since winter 2005/2006 the lab is regularly used for classes. Therefore it's heating demand is about the same as that of the seminar rooms. As a result, in this winter the energy consumption of both controlled rooms together equalled that of the seminar room with standard thermostats. This means that energy consumption in relation to floor area (kWh/m²) is halved in the controlled rooms, which further substantiates the claim that in educational buildings about 50% energy savings can be realized by network based heating control.

Lighting control

Objective

The effect of energy saving lamps in residential buildings has often been overestimated because electrical energy for lighting has only a small share in the overall primary energy consumption of households. However, in commercial and educational buildings this share can be significantly larger. Automatic lighting control taking into account human presence, daylight level and necessary illuminance on the student's desks can be expected to yield significant electrical energy savings in comparison with standard manual switching of lights.

In the present case the lamps of the two seminar rooms are dimmable fluorescent lamps switchable in three groups, the first along the front (blackboard), the second along the window side and the third along the wall opposite the windows. Obviously the highest lighting demand is in the area of this third group, whereas often no extra artificial light is needed near the windows. Nevertheless in the standard installation of the seminar rooms both groups are connected to the same switch.

Different control schemes have been recommended (see e.g. [7]). The present KNX system is an ideal basis for a comparative study of daylight dependent lighting control concepts and their evaluation with respect to energy efficiency and suitability in educational buildings (seminar rooms).

Method

KNX dimming actuators were installed for each group of lamps in room 122 (KNX controlled) and electricity meters with KNX interface were integrated into the electric circuits of the lamps of both rooms. Both were included in the measurement program so that a comparison of electrical energy consumption in both rooms can be done.

Feedforward and feedback lighting control strategies were investigated. Feedforward strategies measure daylight (radiation or illuminance level outside the building) and derive appropriate dimming levels for all lamps from this. Feedback concepts use lux sensors to provide information of the illuminance inside and control the dimming actuators to yield prescribed illuminance levels in the room.

Figure 5: Presence detector with light sensor

Two types of light sensors were used in the experiments on these concepts, a KNX illuminance sensor (Siemens, GE 252) and a light sensor integrated into a presence detector (Busch-Jäger). Both devices come with application programs to control dimming actuators. The achieved performance of the sensors and the control applications was verified by illuminance measurements on the student's desks using a lux meter.

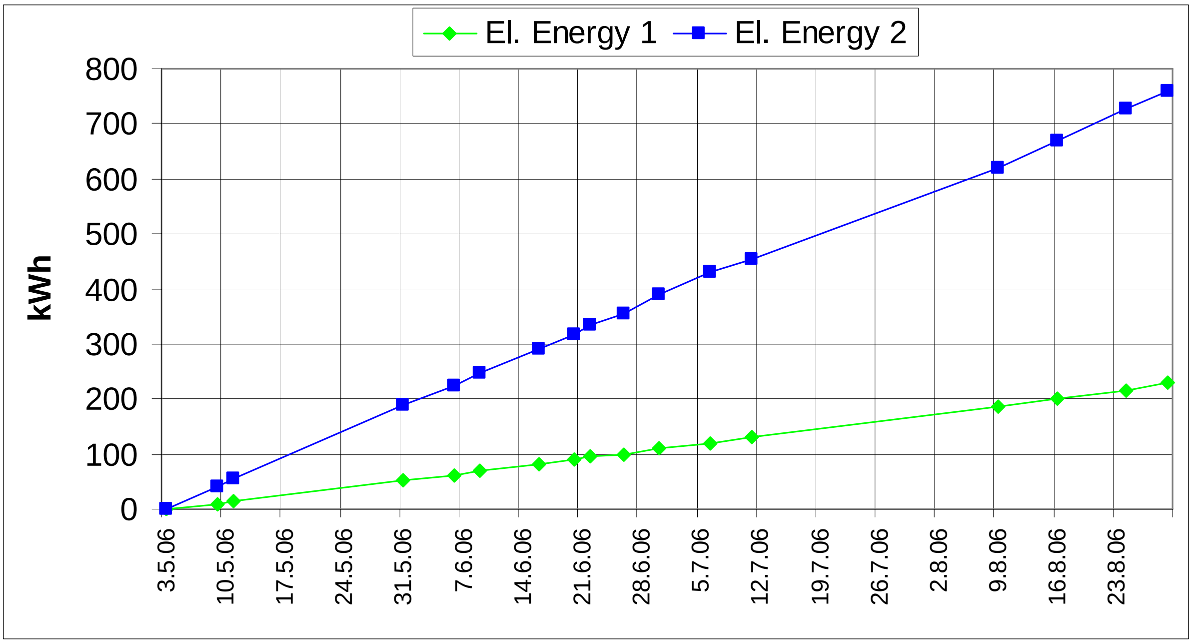
Results

A sensor embedded in a tube directed towards the window may be used to estimate the daylight level and control the dimming actuators accordingly (feedforward control strategy). This might be preferable to a sensor outside the building that can not detect when the blinds are shut. However, this daylight measurement could not be used in combination with the standard dimming application programs of the device because there was no proportionality between the measurement and the illuminance level on the desks.

To use presence detectors as a control device for dimming seems fairly obvious. Presence detection is an important part of automatic lighting control anyway (e. g. to prevent lighting of empty rooms) and it almost always includes a light sensor. However, experiments under varying daylight conditions showed that the light sensor of the presence detector was influenced by incoming sunlight and other light sources in a way that no constant or at least minimum illuminance level on the desks could be maintained.

A sensor with a tube directed towards the surface where a certain illuminance level is prescribed is influenced significantly less by varying daylight conditions. However, suitable placement of the sensor is crucial for a good performance. A configuration with two sensors, one near the windows and one near the opposite wall turned out to yield good results with respect to maintaining a minimum illuminance level of 500 lux on the desks.

Since the installation was done late in spring 2006 no results concerning energy efficiency are available yet for the seminar rooms. From other investigations and projects energy savings of up to 60 % have been reported. One example is a test setup in a large mail distribution center in Bremen. To prepare for a complete renewal of the lighting equipment and control two groups of lamps were equipped with electricity meters and one with feedback light control. Figure 6 shows the electrical energy consumption of these two groups of lamps since May 2006.



After 4 months the energy consumption of the controlled group of lamps was only about 30% of that of the uncontrolled one. From this, energy savings of about 230.000 kWh/a were estimated for the complete lighting system after renewal. The investment costs would be amortized by the savings after no more than one year.

Conclusion

The informatics building of the University of Applied Sciences is relatively new (2002) and was built according to modern thermal protection standards. The overall heating energy consumption of about 40 kWh/m² is relatively low, as compared to average values of school buildings. Nevertheless, the results of the current project show that further savings of about 50% are possible by network based heating control. Measurements in coming heating periods will show to what extent these savings can be even further increased by control schemes with presence detection and time-table information. This ongoing investigation will be backed by simulation studies with dynamic models of (parts of) the building including its heating control system.

There seems to be a lack of good standardized solutions for daylight responsive lighting control. Discontentment is reported more often than satisfactory installations. Feedforward strategies need sophisticated – and therefore rather costly – intelligent lighting control devices to provide satisfactory operation. The ongoing project will focus on the evaluation of feedback control schemes employing standard illuminance sensors and aims at giving setup guidelines for placement and control system configuration. Thus, energy saving lighting concepts will be promoted to other educational buildings.

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