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Operation and Automation in Smart Energy-Efficient Buildings
A State-of-the-Art

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RESULT (summary)

This report marks the start of subtask 3.3 "Operation and Automation" within the project "Smart Energy Efficient buildings" ("SmartBuild"). The aim of the SmartBuild project is to develop new knowledge, integrated solutions, and technologies that will make it possible to cover our buildings-related energy needs with substantially less harmful environmental emissions, while still satisfying the whole range of end-user needs such as comfort, aesthetics, costs, operability, reliability, and functionality.

The main purpose with automatic control is to keep the particular indoor environment variable inside the desired level without involving any human effort and with a minimum use of energy.

The central concept of Building Energy Management System (BEMS) is to optimize the operation of all technical installations. In the beginning of computerized control of buildings installations the computerized system covered heating, ventilation and cooling systems at a central level. Today the computerized system can cover all the technical installations on all levels from a single room control for temperature to the central plants.

The challenge is to exploit the opportunities that is embedded in the BEMS and at the same time keep the systems robust easy to understand and operate. It must be possible to show specific savings and benefits that can be reached trough the BEMS.

Operation and automation have important relations with almost all the other subtasks in the "Smart Energy Efficient buildings" ("SmartBuild") project.

KEYWORDS

SELECTED BY AUTHOR(S)		
	Automation	Energy
	Control	Operation

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1 INTRODUCTION

This report marks the start of subtask 3.3 “Operation and Automation” within the project “Smart Energy Efficient buildings” (“SmartBuild”). The aim of the SmartBuild project is to develop new knowledge, integrated solutions, and technologies that will make it possible to cover our buildings-related energy needs with substantially less harmful environmental emissions, while still satisfying the whole range of end-user needs such as comfort, aesthetics, costs, operability, reliability, and functionality. To accomplish this, a 5-year multi-disciplinary project has been initiated in 2002, combining the knowledge of a wide range of experts in the field of energy use in buildings at NTNU and SINTEF, as well as the expertise of related Norwegian industry.
The aim of this report is to form the basis for further work within the SmartBuild project, and to provide information that may be used by the other project participants in order to see the possibilities for effective integration of our different fields of expertise.

2 CENTRAL CONCEPTS

The main purpose with automatic control is to keep the particular indoor environment variable inside the desired level without involving any human effort and with a minimum use of energy.

The indoor climate is continually influenced by a number of disturbances (wind, changes in outdoor temperature, etc.), which can easily shift it from desired values. In order to be able to maintain a preferred indoor climate at all times, climate-control installations must also comprise equipment for automatic control of their own operation. The purpose of automatic control systems is to maintain one or more climatic conditions within desired limits without human involvement, in a way that can be justified in resources and economic terms.

Suitable building automation is a prerequisite for good energy efficiency. The quality of automatic control of climatic conditions is determined on the basis of the interaction between the building itself, its climate-control installations and the automatic control system. An understanding of the characteristics of each individual component and of their interaction in the total climate system is an important prerequisite for the proper functioning of the system.

In the broadest sense of the term, automatic control of climate-control systems comprises three distinct functions, each of which is of major and decisive importance for the correct functioning of the climate-control system:

Monitoring
Monitoring is the transfer of information about conditions within a climate-control system. Monitoring comprises both information regarding actual indoor climate parameters and operational settings for individual components and for the system as a whole. Information may be provided via printouts, light signals, displays, etc.

- Monitoring could consist of:
- Monitoring – Indication
- Alarms
- Operational status for motors On or off
- Position for valves
- Operational status for the plant
- Day, night, weekend, holyday
- Desired set points
- Values at different measuring points
- Values of different controlling inputs
- Power to the boiler, burning level of the furnace

Open-loop control (Steering)
Open-loop control (Steering) is the deliberate exertion of influence on a climate-control system. Such influence need not necessarily be the direct result of measurements of indoor climate conditions. The provision of electrical interlocks for a ventilation system is an example of automatic steering. The purpose of these is to ensure that dampers and fans in the system are started and stopped in the correct order. Another example is timer control, which causes technical systems to be switched on and off according to set values. This is one of the most important types of control in an energy conservation context.

Open-loop control (Steering)

- Time control (on/off) of heating and ventilation plants
- Time control of set points for temperatures
- Optimal on/off operation of heating and ventilation plants
- Control of electric power supply
  - maximum available power demand
  - duty cycling
  - delayed start after interrupted electricity supply

Closed-loop control
Closed-loop control is the deliberate control of a climate-control system, as a direct consequence of a comparison of measured and desired values for the climatic conditions involved. The purpose of control is to maintain climatic parameters within given specifications or wishes.
Control

- Air and water
  - Temperature
  - Pressure
  - Flow

The relationship between a cause and its effects on a climate-control system are virtually never simultaneous. A climate-control system consists of a series of components, each of which has its own quite distinct characteristics, which may be either static or dynamic. If we wish to design a proper control system we need to thoroughly understand all these characteristics. However, the components that make up a climate-control system are related to each other and affect each other. This means that individual parts of the system and the controlled system as a whole will acquire completely new static and dynamic properties, which will be a result of a complex set of interactions between individual components.

Building automation comprise of all systems for monitoring, steering and control of different building installations that are to be found in buildings. Building Energy Management System (BEMS) is the equipment used for a centralized building automation that is based on digital technique and components

The central concept of (BEMS) is to optimize the operation of all technical installations. In the beginning of computerized control of buildings installations the computerized system covered heating, ventilation and cooling systems at a central level. Today the computerized system can cover all the technical installations on all levels from a single room control for temperature to the central plants. There are some regulations in security systems such as burglar alarm and fire alarm installation that prevents a full integration of all the technical installations in one system.

Operation and Maintenance

- Maintenance alarms
- Job instructions
- Energy monitoring
- Energy signature
- Control by forecasts
- Simulation of different scenarios
- Two ways communication with the utility

The development in computer technology has lead to a development:

- From analogous to digital controllers
- From Master/slave hierarchy to distributed CPU capacity
- From Stand alone systems to Network
- From closed system with one supplier to open systems with many suppliers

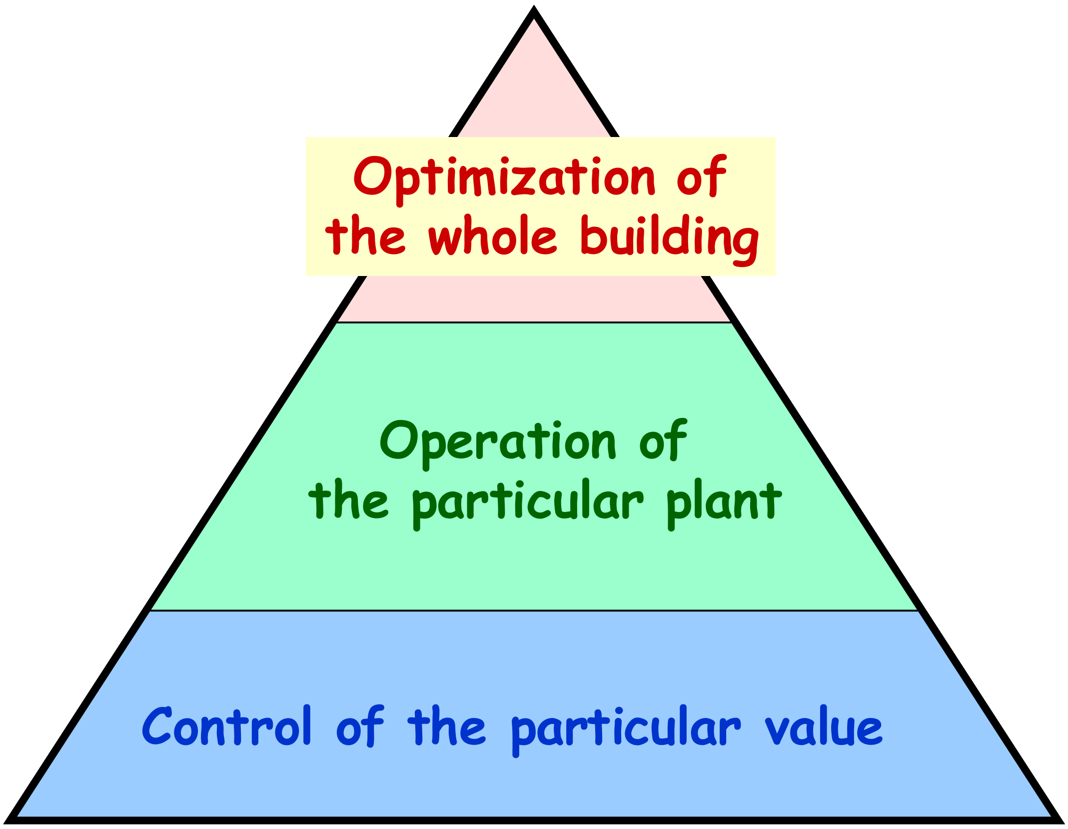

Figure 1 Building Energy Management System BEMS

Roughly, it is possible to divide BEMS into three levels in Figure 2:

- The field network
- The automation network
- The management network

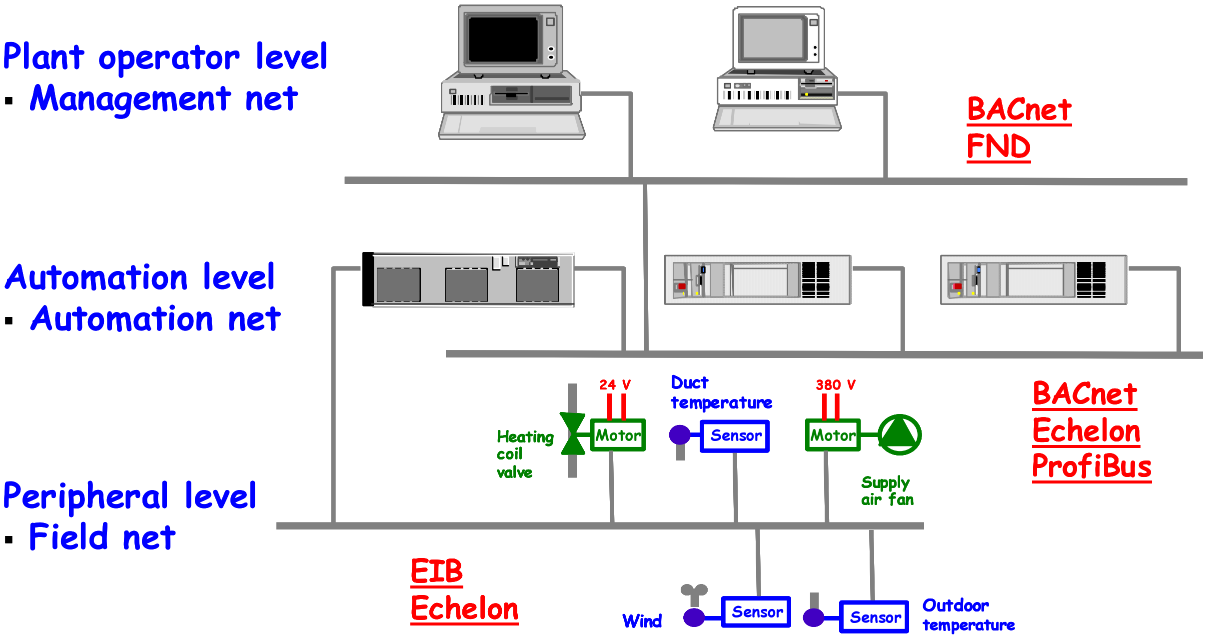

Figure 2 General BEMS

The field network is the connection between the BEMS and the process components (sensors, valves, motors etc. The routines are programmed in substations that also collect measured values. At BUSS level (room control) the control routines are programmed in each individual component.

The automation network is the connection between the substations and one or more computers. The computer collects measured data from the substations. The computer can also store data in a database if desired. The computer in the automation network is used as a tool for the operation staff. Examples on such use is:

- Historical curves
- Real time curves
- Alarms are displayed
- Set points can be changed

The management network is functionally connected to the system through the database of measured data. All measured data are collected in the database and the superior system may only collect historic data. These data can be treated statistically for presentation, reports and billing.

3 TECHNOLOGY AND MARKET

The products that are available for operation and automation are commercial BEMS from numerous suppliers. These systems can operate almost every available component on analog basis through standard industrial signals based on electrical resistance, current- or voltage. There is also a transition against systems that can communicate digitally.

The prices for these systems are 100-250 NOK/m^2 depending on complexity and extent. a zone control system costs approximately 3500 NOK

The players in this market are large multinational companies. Johnson Controls, Siemens, Honeywell etc. They have great financial strength and technical good solutions.

3.1 Challenges

There are several challenges in exploiting BEMS in a better way. The systems could be used more frequently and more effectively to the benefit of the building owners. BEMS are knowledge-based systems and this means also that there must be sufficient knowledge in the operating staff. The old caretaker profession and personnel is still used in advanced control systems. This is probably due to old-fashioned attitude and tradition.

Another problem is to exploit the opportunities that is embedded in the BEMS and at the same time keep the systems robust easy to understand and operate. It must be possible to show specific savings and benefits that can be reached trough the BEMS.

There have also been a development against more integrated systems and this development will continue until we reach a level where all the technical installations share all relevant information in a common system with a common goal: To achieve a process that provides an optimal utilization of the building, the areas, the installations and the organization with the main goal to provide support for an efficient business.

Today we are at level where the information is transferred over the same cables or other media.

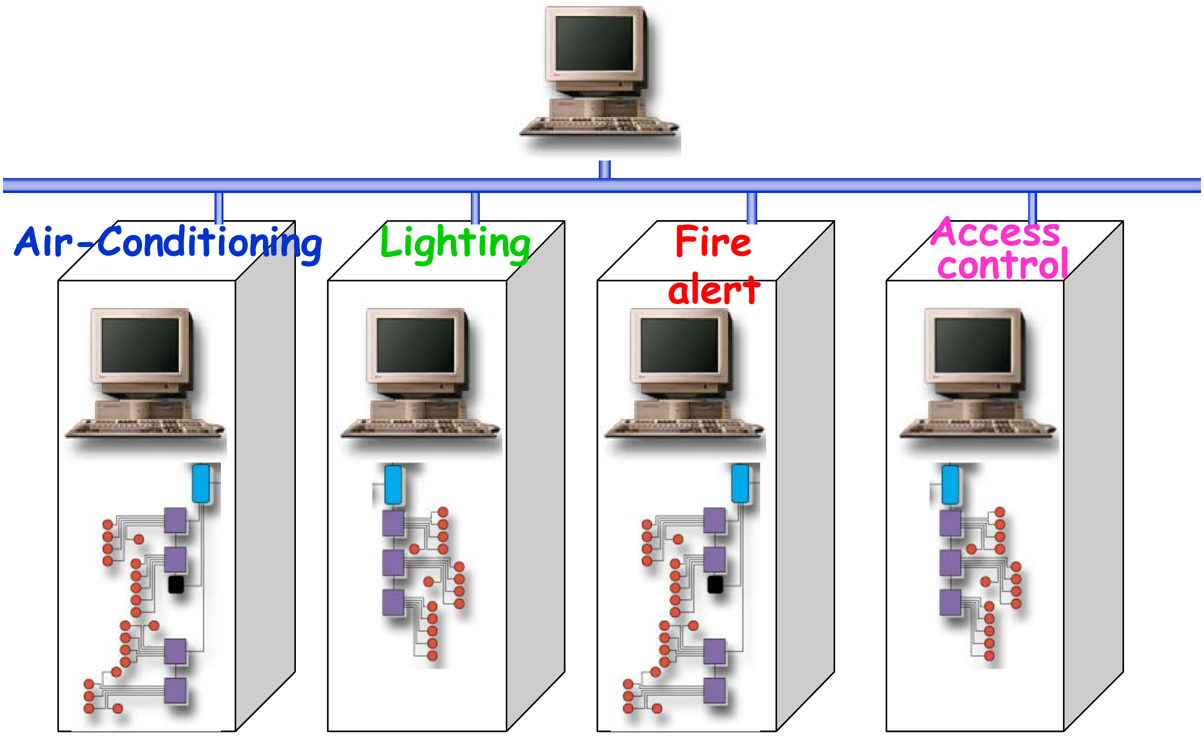

Figure 3 Integration of installations

Commissioning of building HVAC systems and installations for improved energy performance is another development direction for BEMS. Where the primary goal of building commissioning from an energy perspective, is to verify and optimize the performance of energy systems within a building. For the moment there are not any universal definition of commissioning. There has to be developed a common understanding of what commissioning covers and how and when it shall be done.

Commissioning can occur:

- During the production (design and construction) of a new building or the retrofit of an existing building
- When building owners want to verify, improve and document the performance of a building in use.
- During the life span of the building in order to check that the performance is optimized, named continuous commissioning.

The most interesting development is in the combination of computer simulation models and the measurement available trough the BEMS. Computer simulation based on first principle models may be applied in all phases of the building process.
In the design phase simulation tools may be used to ensure that the specification are satisfied and to compare different solutions.
In the commissioning phase simulation tools may be used to design controllers and to verify that the building and installations fulfill the specifications even if the design conditions are not present.

In the operating phase the simulation models may serve as a tool for continuous commissioning

A detailed simulation model at this level requires detailed information about the building, the installations and the use of the building. The simulation models will also demand and continuous updating and calibration to account for changes in the building and the installations as shown in Figure 4.

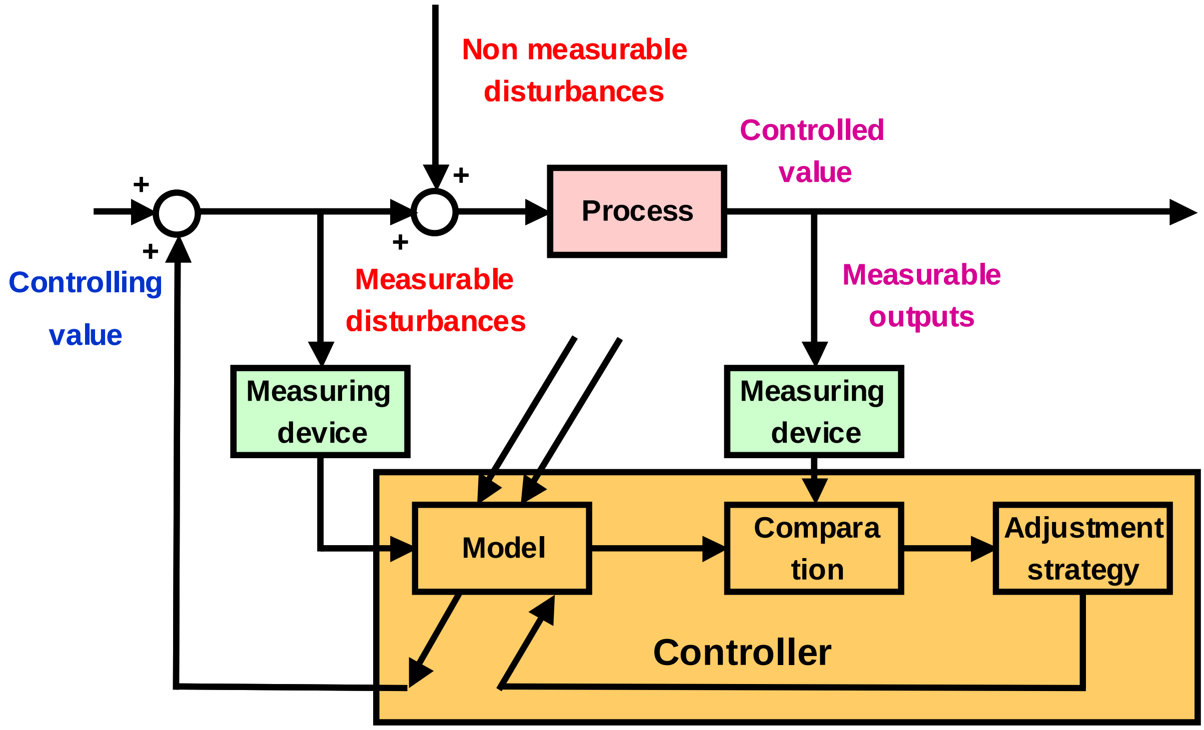

Figure 4 Process and simulation model

4 INTERACTION WITH OTHER SMARTBUILD STRATEGIES AND TECHNOLOGIES

4.1 O&A and User Needs

The operation and automation system is there to full fill the users demands to the indoor climate. It is therefore essential with a tight cooperation between the user needs and the O&A system especially at the field net level.

The interaction between the user and the BEMS will occur at different levels as shown in Figure 2.

- The occupants of the building communicate with the components at the field level.
- The operation staff communicating with the computer at the automation level.
- The management treating historical data at the management level.

Our impression is that the User Needs project is mostly concerned with the end user of the building. The end user shall tell the system what he wants and the system shall respond on this demand. In BUSS system where the input is moved to the and users computer it could be interesting to look into what kind of response the system should give to the end user.

An end user that feels that the temperature is too high in a room will turn the thermostat down. Depending on the design and outdoor conditions the room will reach the new temperature about one hour later. If the system tells the person that it will reach the new temperature in about one hour he may be satisfied with that. If the system don’t give any feedback the user may be impatient five minutes later and turn the thermostat further down the final result could be a to low temperature some hours later.

At the automation level and management level the user interface is very flexible and programmable. The software will be delivered with a standard user interface that can be changed to accommodate different user needs. The users at this level will get what they want (or what they can afford to pay for). Their problem is maybe to describe what they want.

4.2 O&A and Environmental criteria

One of the purposes to the BEMS is to keep the indoor climate at desired levels with a minimum of energy use. Reduction in energy use in buildings is a contribution to more environmental friendly buildings. There are some challenges in this area:

- The energy use is not a design goal.
- The expected energy consumption is not calculated in the design phase.
- The subject responsible for each profession tries to minimize the energy consumption for their systems without looking at the energy consumption for the whole building.
- The BEMS usually measures the total energy consumption without any subdivision other than electrical and thermal energy

If it is possible to improve in these areas the BEMS will work better and possible reduce the energy consumption in the building further.

As long as the energy use not is a design goal and expected energy use not is detailed calculated in the design phase there are no target to compare the actual energy consumption against when the building is taken in use. The BEMS will only notify the staff if the energy consumption increase compared to the energy use in earlier periods.

An integrated design with a target for energy use will probably reduce the energy consumption.

A better subdivision of the energy measurement will improve the function of the BEMS since it will be easier to detect errors or wrong operation of the installations.

4.3 O&A and indoor environment

One of the purposes to the BEMS is to keep the indoor climate at desired levels with a minimum of energy use. One interesting field with an increasing interest is demand control. Earlier investigations have shown (Livik&al) that an office is occupied about 50% in the working hours. Heating, cooling and ventilation is mostly done to satisfy human demands to the indoor climate. With improved BUSS technology and better components it should be possible to make robust systems for demand controlled heating, cooling and ventilation. The potential for energy savings are largest for ventilation and heating. The capacity in the cooling system is often a limitation for increasing the temperature when the office is empty. A system for reducing the indoor temperature must have an optimum start stop function if the user should be satisfied.

A system for night setback implemented at the university in Trondheim has a connection between the light system and the heating i.e. if the light is off the heating is off. The temperature in the office is then to low when the occupants arrives in the morning. The clever occupants understand how the system operates and starts to leave the office with the light on to get a warm and comfortable temperature when they arrives in the morning. This is an example on a bad implementation of demand control that not satisfies the end user. A better implementation would have used the light as an indicator for when the person in that particular office arrives and adjusted the heating system such that the office is warm when he arrives, and keeps the office warm until he leaves. (Diplom)

There is also a wide comprehension that ventilation system in buildings usually not functions as intended. If this is correct it should be possible to detect the problems related to temperature and airflow levels trough the BEMS. Problems with the air quality related to contamination in the air handling system will be difficult to detect since it is hard to measure the air quality. But it could be possible to measure the moisture level at critical points in the ventilation system. Since moisture usually is unwanted in the ventilation system and represents a risk for microbiological growth this could act as warning for the operation staff.

4.4 O&A and Implementations Strategies

Implementation strategies is interpreted as a common project that will work with implementation of all the other subtasks.

4.5 O&A and Integrated Design

The BEMS will usually cover technical installations from several professions it will therefore benefit from an integrated design. The purpose of the BEMS to keep the indoor climate at desired level with minimum use of energy will benefit from a better integration in the design phase of the building. An integrated design phase with a target for the total energy consumption and detailed calculations of the expected energy consumption will be valuable aid for the operating staff.

4.6 O&A and Building Integrated Energy Systems

Building integrated energy systems tries to exploit available energy in the exterior climate to maintain the indoor climate at desired level without use of purchased energy. This is a new challenge for the BEMS since this energy traditionally have been treated as a disturbance for the system. The purpose and the goal is the same as with traditional systems but the building integrated energy system sets new demands to the control system and control algorithms.

A building with a passive solar heating system and ventilation system who uses free-cooling during the night will need a better control system than a building with a heating system and a mechanical cooling system. Since the building often are used as a storage of thermal energy it is necessary with predictions for the heating and cooling load in the future to make the correct decisions and thereby the optimum operation of the system. For instance: an afternoon should you try to heat the building with available solar radiation or should you shield the building and prepare for free cooling during the night?

Ventilation systems that exploit natural driving forces as wind and buoyancy is harder to control than mechanical systems where the mechanical driving forces are 100 times the natural forces (which then are treated as disturbances). This put new demands to the control system and the operation of the system.

4.7 O&A and Lighting Systems

The lighting system will usually be a part of the BEMS and thereby be controlled trough the BEMS. The lighting system is also a major contribution to the cooling load in building. Both these facts lead to a linkage between O&A and Lighting systems. There are two obvious strategies to decrease the energy consumption for lighting is to use energy efficient lighting systems combined with sophisticated control systems and increase the utilization of daylight. Both these strategies involve the control system. The use of control system is already implemented in many buildings but it can be further improved. The use of daylight must be controlled together with shading devices to minimize the total energy consumption to cooling and lighting.

4.8 O&A and Building Integrated Photovoltaic Systems (BIPV)

In systems where the building integrated photovoltaic system have several functions and not are façade elements only there can be some connection between the O&A and BIPV. The double façade at the university in Trondheim is an example of a system where there is a need for a better control system. The double façade acts as an air duct for cooling the photovoltaic cells during the summer and as an extra insulation during the winter. The control of the damper should then be optimised through the BEMS. Also if the operation of dampers is dependent of the outdoor climate they can achieve information about wind speed, wind direction, outdoor temperature and rain through the BEMS.

4.9 O&A and Systems for Heating, Cooling and Ventilation

Control of the heating, cooling and ventilation system has always been one of the main purposes with BEMS. The development in computer technology and the new opportunities to optimize the operation of the systems are maybe not fully exploited today. The BEMS have the opportunity to measure almost all the relevant conditions in the building in a integrated system. The BEMS and the operators of the system are not exploiting all this information. This task is to complicate for the operator but the BEMS could use this information to verify that the operation of the system is optimized.

4.10 O&A and Heat pumps

Operation of heat pumps is one of the critical factors for successfully implementation of heat pumps in the building energy system. The BEMS controls both the heating and cooling system and can therefore ensure an optimum operation of the heat pump.

Heat pumps will usually benefit from a low supply temperature. An optimized operation of the heating system is therefore a benefit for the heat pump. CO_2 heat pumps will also benefit from a low return temperature in systems with variable flow in the heating system it is possible to set a heating curve to minimize the return temperature.

4.11 O&A and thermal energy storage

Thermal energy storage is in many senses the same as using the building as a thermal storage although there are possible to control the charge and discharge progress better. To ensure an optimum usage of the storage there are necessary with predictions for the heating and cooling load in the future to make the correct decisions about charge and discharge of the storage. For instance: an afternoon should you try to fill the storage with heat for use during the night or should you cool down the storage during the night to cover a cooling load the next day.

Thermal energy storage could also be used to take advantage of fluctuations in energy prices during the day. It is also here necessary with predictions of future heat load to use the thermal energy storage in an appropriate way.

It is also possible to reduce the maximum load to heating or cooling by using the thermal energy storage actively.