Analysis of Building Management Systems to Ensure Optimal Working Environment

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Abstract. The design of an intelligent building management system is a fundamental problem in designing new modern buildings. The energy management structure is a set of main input devices and relationships between them. The paper presents the issue of thermal comfort conditions with regard to intelligent buildings. Thermal comfort describes the human satisfactory perception of the thermal environment. It refers to a number of conditions in which the majority of people feel comfortable. Thermal comfort is dependent on multiple factors such as indoor environmental conditions, user behavior and properties of building materials. For inclusion in the design process this data must first be categorized in a standardized manner. We present some aspects related with the impact of the new digital, communication and facilities technology development in the implementation of building management systems. This systems are used for monitoring, controlling and ensuring the control, comfort and efficiency in use of intelligent buildings. The integration becomes possible due to the applications of advanced IT technologies.

Keywords: Intelligent · Management · System · Building

1 Introduction

Although the successful use of advanced technologies, including information technologies, is the main feature of intelligent buildings, the implementation of technologies should not be the sole objective of intelligent buildings. Performance is definitely a key objective of intelligent buildings, although performance can be interpreted very differently as discussed above. As regards the hardware facilities, intelligent buildings cannot be separated from the architecture design, building façades and materials, which are among the essential elements of intelligent buildings note that the first paragraph of a section or subsection is not indented.

Intelligent architecture refers to build forms whose integrated systems are capable of anticipating and responding to phenomena, whether internal or external, that affect the performance of the building and its occupants. Intelligent architecture relates to three distinct areas of concern: intelligent design, appropriate use of intelligent technology, intelligent use and maintenance of buildings.

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Intelligent design requires that the building design responds to humanistic, cultural and contextual issues; that it exhibits simultaneous concern for economic, political and global issues; and that it produces an artificial enclosure which exists in harmony with nature. Existing in harmony with nature includes responding to the physical laws of nature and the proper use of natural resources.

Appropriate use of intelligent technology. The mere availability of a large variety of smart materials and intelligent technologies often results in their use in inappropriate situations. Integrating intelligent technologies with an intelligent built form that responds to the inherent cultural preferences of the occupants is a central theme in intelligent architecture. As an example, in areas where people place a high premium on operable windows for conservation of electricity, the most appropriate and efficient air- conditioning strategy for a building may be the use of thermal mass and night- time free cooling instead of a high-tech air-conditioning system. In other cases, the use of carefully selected electric lighting and environmental control strategies may be more appropriate.

Intelligent use and maintenance of buildings. Truly intelligent architecture incorporates intelligent facility management processes. For a design to be intelligent it must take into consideration the life cycle of a building and its various systems and components. Although an intelligent building may be complex, it should be fundamentally simple to operate, be energy and resource efficient, and easy to maintain, upgrade, modify and recycle [1–3].

2 Energy Efficiency and Energy Management

The demand for electrical energy has increased tremendously over the last 25 years; its importance is such that it is now a vital component of any nation's economic progress. Increase in population has increased the energy requirements, coupled with the industrialization & socio-economic responsibilities; the energy supply has not kept pace with the demand. This has led to a bleak energy scenario whereby power generation and utilization from alternate energy sources has become very much a necessity.

The impact of rising energy cost has a disastrous impact on the day-today activities of industrial and domestic consumers wherein the prices of commodities, products and even essential services tend to cost more. One option is to improve the working efficiency of the process and systems. This will ensure the reduction in the product cost in addition to efficient energy management. The other option is the use of energy derived from non-conventional energy sources i.e.; ensure a balance between conventional and nonconventional energy sources in the process [4].

Energy management embodies engineering, design, applications, utilization, and to some extent the operation and maintenance of electric power systems to provide the optimal use of electrical energy [5]. The most important step in the energy management process is the identification and analysis of energy conservation opportunities, thus making it a technical and management function, the focus being to monitor, record, analyze, critically examine, alter and control energy flows through systems so that energy is utilized with maximum efficiency [1]. Every industrial facility in a particular location is unique in itself; hence a systematic approach is extremely necessary for reducing the power consumption, without adversely affecting the productivity, quality of work and working conditions [6, 13].

Building management systems is specialized software application (Sauter-Reliance) solution that enables regular energy data gathering and analysis, used as a tool for continuous energy management. The main advantage of building management application is the possibility of data collection, processing, maintenance, analysis and display on a continuous basis. A modern management system is integrated into an organization's systems for online process monitoring and control. This system provides sensitive information to manage energy use in all aspects and is therefore an important element of an energy efficiency [6–8].

3 The Building Management Systems of the Research Centre

Our building have a low-energy construction (with a heat energy consumption of less than 15 kWh/(m^2.year)) with a higher equipment level of the building (intelligent building) in terms of diversity of sources of heat, cold and energy. The main objective is to understand the functioning of all intelligent building systems and ensure optimal use of all energy sources.

The Research Centre building has intelligent control systems for lighting, exterior blinds, thermal control and air conditioning. And as separate subsystems connected similarly as the measurement of power consumption. For research activities it is equipped with a photovoltaic system on the roof - that is why it also includes a cable route to the roof. Building's Ethernet is connected by a multi-fiber cable in the date center in the basement (Fig. 1).

Fig. 1. Photovoltaic system on of the building. Last panel tracks the Sun

The whole building is functionally divided into three parts - on five floors. The first underground floor disposes of a building, technical and storage premises. At the entrance through the foyer and in the lobby there is a porter's lodge and facilities for its staff and in the hallway of the lounge. On the second to fifth floor, other research center premises.

3.1 Measurement and Regulation

The measurement and regulation systems are divided into two parts measurement and regulation of the device in technical room and measurement and regulation in rooms. Measurement and regulation in the technical room in order to control the production of heat, hot water and water for heating. It is used for radiator, floor, ceiling heating and in the summer also ceiling cooling. The source of heat and cold is preferably a group of heat pumps if the geo-drills are not sufficient, then a gas boiler and a chiller on the roof.

On the floors there is a special regulation - regulation of heat in the building by means of controlled floor heating distributors or ceiling panels with its own autonomous systems. It is also heated and cooled by air conditioning, and intelligent measurement and control system is also mounted for lighting and external blinds. And as separate subsystems connected similarly as measuring the consumption of electric power over Ethernet, with the possibility of software management on control computer in network protocol – building automation and control network.

3.2 Heating and Cooling Systems

To ensure the heat demand, the following heat sources are installed: condensation boiler, two ground-to-water heat pumps, a gas heat pump with combined air-to-water and ground-to-water operation, and a solar system for heating support, hot water and heat storage into the earth tank. For heat storage, a heat storage vessel is installed independently, in which heat is stored from heat sources - heat pumps and a solar system. The following cold sources are installed to ensure the need for cold: two ground-water heat pumps, a gas heat pump with combined air-water and ground-water operation. For cold storage, a cold storage vessel is installed independently, in which cold is stored from cold sources geo-bores and heat pumps (Fig. 2).

Fig. 2. Sources consist of heat pump for transformation heat and cold from earth and air. Left is combined heat pump of systems air-water and earth-water, middle and right is heat pump of system earth-water

The whole heating system is divided into six separate branches connected to individual pump groups: hot water heating, radiators, underfloor heating, ceiling cooling and fan coils. Each branch is controlled by equithermal control using an algorithm to calculate operating temperatures via the measurement and regulation system and a three-way valve to maintain a stable branch temperature. Each branch has a set maximum and minimum operating temperature according to the nature of the heat exchange system used.

The first prerequisite for switching the system to heating mode is to set the three-way valves to the transfer position of the heat transfer medium. This ensures that the entire system will only heat.

Solar system - when the bivalent hot water tank is heated, the three-way valve switches and the heat storage tank is heated. In case of excess heat in the solar system, the three-way valve is switched and the heat is stored in the ground tank (Fig. 3).

Fig. 3. Distributor and collector of heat and cold to heat exchanger systems of building.

When heating with a gas boiler, which is connected to the system via a hydraulic switch to the manifolds, if the heat pumps are not in operation, the solar system does not heat the storage tank, the heat transfer medium goes directly to the manifolds for hot water. The return heating water is returned through an accumulation tank in which the excess heat from the gas boiler is stored. If the temperature from the storage tank is sufficient for heating, the gas boiler is switched off if not the heat transfer medium is heated to the desired temperature. Any heat source is connected to the duct in a storage vessel and can be used for heating.

The first prerequisite for switching the system to cooling mode by automatically switching the three-way valves to the heat transfer medium passage position. This ensures that the entire system will only cool, except for the heating of the hot water, which can still be heated.

It will preferably be cooled by a passive cooling system, i.e. by cooling only from boreholes by adjusting the three-way valve. These heat transfer fluid flows will be driven by the pump groups through the exchanger. If passive cooling is not sufficient by adjusting the three-way valve, the heat pump duct will open and these will accumulate the cold of the cold storage tank (Fig. 4).

Fig. 4. Panels of solar system on the roof of building.

The hot water is heated in the bivalent hot water tank using hot primary water from the manifold so that if necessary, the hot water circulation pump blows hot water into the hot water tank. The tank is also charged from solar heating, which is automatic and independent.

If the hot water tank temperature drops below 50 °C, the circulation pump will be started and will continue to run until the hot water tank temperature reaches 55 °C. For homogeneity of hot water in the bivalent tank, a three-way regulating valve is opened a valve that returns a portion of the water from the hot water outlet to the return from the circulation circuit according to the hot water outlet reference temperature. The monitoring of the critical temperature of the bivalent storage tank is used for emergency discharge of the hot water storage tank in case of overheating (from the solar system in summer) above 75 °C. The hot water is then discharged into the drain by the solenoid valve at its outlet and the tank is cooled to 75 °C - the maximum operating charging temperature of the tank. Charging another heat storage tank from a solar unit that is connected in parallel from its output is through its pump. Thus, any excess heat from the bivalent storage tank is preferably stored therein in the event of an excess of thermal energy in the solar system, the heat is stored in the ground storage tank.

A separate autonomous measurement and regulation system is used to control the heat on the floors of the building. In addition to the function of heat and cooling (one type of its installation is distributed over the floor), in scientific experiments measurement and regulation on floors measure the consumption of single-phase electrical circuits - selected circuits of 230 V sockets, but there can also be light circuits. It is a ratio measurement that is realized by measuring transformers up to 63 A. These are simply mounted on a rail by snapping the measuring transformer circuit and around the phase conductor of the circuit under test, while this phase is also connected through the measuring module - three-circuit modules are installed by network analyzers.

The measurement can also be done in three phases on the entire sub circuit - other connection. In order to make this possible, sub-distributors have been designed for the size of the sub-distribution boards in the framework of the heavy current, where on rails a width of 50 cm is possible to install this configuration of the control information system. The connection is thus preferably close to the potential el. The measuring transformers concept enables their variable connection and disconnection either above the part of the secondary distribution lines or in a separate second switchboard for measurement and regulation, fitted next to the secondary switchboard and connected by bushings.

Installation of electrical measuring system energy is exclusively in the secondary switchboards on the floors of the building. They work autonomously on their own Ethernet connected network – building automation and control network protocol. The other polarized pair of wires is used for supplying (26 V) between the rails - through the connection modules or even in the floor space outside them. It is applied in the installation of heat and cooling - thermostats, person detectors, window contacts. Blinds and ventilation lighting - hygrometers, CO_2 sensors, luxmeters, person detectors. The installations are connected to the Ethernet within the building via communication control modules to the internet protocol - building automation and control network as transmission network.

In this way, the installations are connected within the storey and the whole building, but also between the groups of e.g. heat and cooling and electrical measurements. The program components then enable visualization, reports, statistics and control, according to access rights and the scope of installed correct and user program resources.

The regulator switches the valve circuit of the floor or ceiling wiring, as required by the thermostat. If it is lower than the equithermally set water in the heating system, the control will switch off the water supply to the zone's heating circuit. If a higher temperature is required than is sent in the form of equithermal water in the distribution, the control will switch on the supply until the temperature rise reaches the setpoint in the heating zone. The system works similarly in cooling in the summer, with the difference that the ceiling panel system is preferably used for cooling. In order for the regulation to function up to plus values, the equithermal water must be slightly elevated from the against the equilibrium curve. Heating and cooling blocks the opening of windows, or automatically the absence of people - a centrally adjustable energy saving program. On occupancy sensors, it is possible to press the upper part of the sensor to switch the presence signal to permanent, regardless of its passive infrared detector for a maximum of 4 h (then switches itself to the normal state of guarding the space). The system also allows lighting control - luxmeter controllers and dimming or switch controllers, blinds, meteo controllers as well as air controllers - controllers - humidity sensors, CO_2 (input 0–10 V, contacts) flap control output 0 (1) -10 V, contacts. Everything can be managed by an extension application in the local area network. Local area networks are interconnected into one unit.

The controller is integrated into the M&C in the technical room and proportionally controls the valve head with diameter nominal 15 $kvs = 2.5\ m/s^2$, which is located under the ceiling on the pipe in technical room on the machine diagram room at the outlet of the common branch "cooling ceilings" - "stair" (all cooling ceilings on the floors of the stairs). The control valve is at the outlet and the mechanical return valve (which adjusts the flow rate in the staircase cooling ceiling circuit. Cooled ceilings in the staircase are connected from a pipeline which is led vertically upwards in the central pillar of the staircase. The valve is controlled by a separate new reference thermometer and hygrometer on the 1st floor (to be placed on the non-dazzling side of the pillar). If the temperature rises above 21 °C in the summer, the ceilings will start to cool to their maximum cooling capacity in this space, unless condensation occurs - according to the dew point that is still calculated, as in room configurations in rooms in the ceiling cooling section. The temperature of the cold water is the same as in the entire cooling of the ceiling in the building. From, the cold water outlet - ceiling cooling, The valve can also be operated independently according to requirements of inputs: thermometer (Nickel 1000), outputs: 0–10 V hygrometer: 0–10 V control head and valve actuator head according to implementer 0–10 V proportional, 24 V supply of valve head. Input 2 × 0−10 V and output 1 × 0−10 V in measurement and regulation configuration (Fig. 5).

Fig. 5. Base station controlling of heating, cooling and ventilation systems.

3.3 Blinds and Lighting

These installations from distribution modules in separate switchboards are divided on floors according to the suitability of the place (for air-conditioning, blinds - actuators and their modules) or the suitability of the control points (on the wall in the box hl = 40 mm - for lux meters, hygrometers and passive infrared sensors) at a height of 120–140 cm as light switches. The connection between them and the switchboards of the installation is a four-wire cable. The routes descend from separated or safety low voltage horizontal installation routes in a double ceiling (space height approx. 50–60 cm). Connection of installation switchboards as well as local area network connections is from the closest installation point.

Lighting is chosen according to light comfort, which is continuously variable through dimmers. Dimmable elements – light-emitting diode lights are required as well as central adjustment and lighting scene programs (alternative to dimmable controls that are designed - the target is digital addressable lightning interface control of dedicated lights) as well as individual lighting. Ventilation serves as additional heating or cooling, it regulates the air quality in the building (humidity and CO_2). For scientific purposes, air flow is also measured by the measurement and regulation system. Channels. Blinds can be controlled from different places and in groups, they automatically unfold in glare, roll in windy weather, and follow the meteorology module, which is on each floor.

4 Thermal Comfort

Human thermal comfort is an important issue in the built environment. Environments either too cold or too hot can be dangerous to human life. Less satisfactory environments may lead to discomfort, resulting in a loss of productivity. When the environment is cold, the reduction of the flow of blood to the skin results in a low skin temperature. The spontaneous activity, like shivering, will occur to increase the production of heat energy. In a hot environment, large amount of heat has to be dissipated from the human body due to metabolism and physical activities. Then, blood flow to the skin is increasing and sweat is secreted from the sweat glands. When sweat evaporates, latent heat is absorbed and a thermal equilibrium can be achieved [9, 12].

Space temperature uniformity, asymmetry of the radiation temperature, and turbulence intensity of the flow air affect thermal comfort. People are capable of detecting heat and they can feel changes in temperature globally on the entire surface of the body but also locally on body parts. It has been shown that humans can acclimate to ambient temperature physiologically and psychologically. It is therefore important to address the issues of thermal comfort in the interiors (buildings) and to experimentally determine a suitable way of creating the optimal conditions of the environment.

The goal is to ensure a sense of satisfaction from the environment and also to increase work performance and a sense of comfort. We use the Dantec ComfortSense system to investigate operating conditions comply with International Standards EN 13182, ISO 7726, 7730, ASHRAE standard 113 and ASHRAE standard 55 [10, 11].

4.1 Ashrae Standard 55

ASHRAE Standard 55 (Thermal Environmental Conditions for Human Occupancy) is a standard that provides minimum requirements for acceptable thermal indoor environments. It establishes the ranges of indoor environmental conditions that are acceptable to achieve thermal comfort for occupants. Percent dissatisfied (PD) represent percentage of people predicted to be dissatisfied due to local discomfort. Predicted mean vote (PMV) is an index that predicts the mean value of the votes of a large group of persons on the seven point thermal sensation scale.

Predicted percentage of dissatisfied (PPD) is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people determined from PMV [8, 10].

Index PPD is expressed according to the relation:

$$PPD = 100 - 95.e^{-(0{,}03353.PMV^4 + 0{,}2179.PMV^2)} \tag{1}$$

PMV index predicts the mean comfort response of a larger group of people.

5 Measurement in the Building with BMS

The measurement was carried out in the Research Centre of the University of Žilina in July. The room is located on the first floor on the southwest side. The room is located in the middle of the building. The room has a rectangular floor plan with dimensions of 3.40 × 5.70 × 3.00 m.

All intelligent control systems are installed in the room. There is a room sensor - movement of workers in the room, CO_2 sensor, humidity sensor, fire sensor, open window sensor, temperature sensor and lighting sensor. The windows are fitted with external blinds with the function of shading according to the intensity of solar radiation.

Heating is provided by underfloor heating. Cooling is provided by an acoustic cooling ceiling and a central ventilation system with support for heating and cooling. The influence of intelligent control system on ensuring optimal operating conditions in space - thermal comfort has been studied. Three basic types of cooling system settings have been investigated. Setting the intelligent control system for the cooling section to 17 °C (system: -5 °C), 22 °C (home position), 27 °C (system: $+5$ °C).

The positions of the measuring probes are located in the living areas of the rooms. These are known places of residence of workers. These places are defined as workstations or seating positions depending on the function of the space. The measurement takes place in the center of the room or 1 m from the wall inwards from the center of the largest window. Measurements shall be made at locations where the extremely high values of thermal parameters are estimated or observed. The operating temperature is measured or calculated at 0.6 m for seated persons and 1.1 m for standing persons.

The following figure shows graphical measurement results for various settings of the building measurement and control systems (Fig. 6).

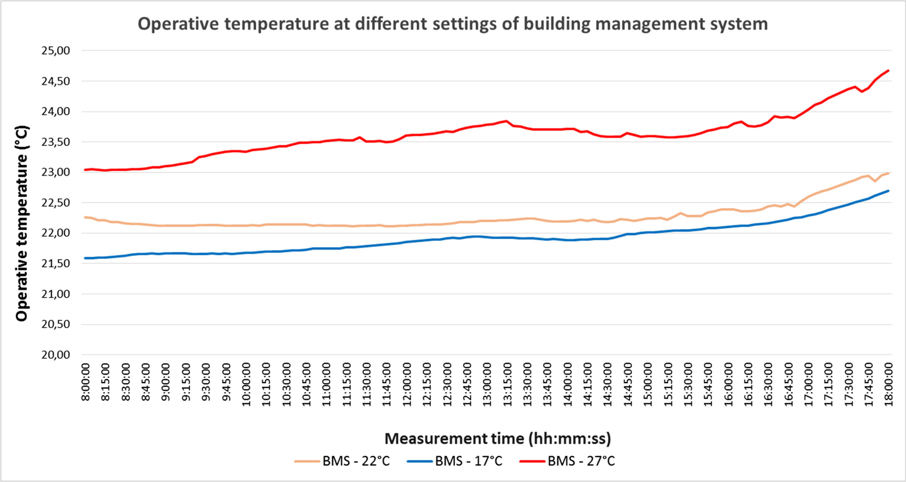

Fig. 6. Operative temperature at various setting of the intelligent building management and control system

The main parameters that were measured are the outdoor temperature, the operating temperature in the room and the setting of the intelligent control system for the cooling sections in the summer.

PPD parameters were also evaluated in the evaluation of the impact of the working environment on the thermal comfort of workers. These parameters determine the mean warmth of a group of people and the predicted percentage of dissatisfaction with the operating conditions. They are designed for each measurement day with respect to the setting of the intelligent control system (Fig. 7).

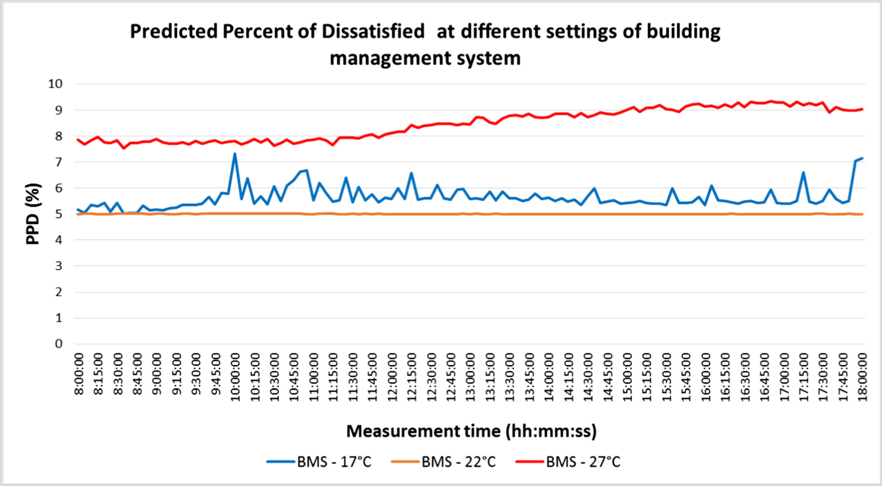

Fig. 7. PPD parameters and different settings of building management system

6 Conclusion

Our aim is to create conditions for the implementation of applied research in the field of low-energy construction and technology for the construction of low-energy buildings, high-efficiency energy sources using renewable energy sources and fossil fuels, the optimal control, optimal control of energy consumption in buildings and premises suitable choice of hot and cold sources, ensuring optimum energy consumption, safety and comfort in intelligent passive buildings, reducing the emission load environment. Our main priority is to establish a functioning, modern system and achieving economic, environmental and proper functioning of several systems.

Three different setting states have been evaluated. The position of the blinds was also evaluated in down position. The intelligent control system can adjust the blinds in seven other positions, which will be subject to further investigation. Thermal comfort is ensured in the range of optimal values of operative temperature, including the values of other microclimatic variables. The optimum temperature is the range of temperatures that the employer should strive to maintain at his workplace all year round. The permissible temperature is a limit value that the workplace temperature should not exceed even if the employer is unable to maintain optimal temperatures. The optimum operating temperature range in the office space is set at 23–27 °C. This condition was not exceeded in any of the room settings examined.

The function of the correct setting of the intelligent control system has been confirmed in every state under investigation when connected on. In all cases, the PPD parameters are comfortable - neutral. The function of the correct setting of the intelligent control system has been confirmed in every state under investigation for connecting on.

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