3. Systems and software for the management of smart buildings

3.1. Introduction to smart buildings

The design and calculated performance of the buildings have changed throughout history. A century or two ago, many buildings were built from stone/brick or wood with basic heating, water and electrical systems. Modern houses, especially with very low energy consumption (so-called passive or nearly zero energy buildings) are being designed and built as dynamic and technically complex buildings [3.1]. The type and topology of modern building's systems and appropriate management software depend upon the context and building category, but usually have chosen related to the cost of the building over its lifetime, energy performance and thermal comfort in it [3.2, 3.3]. Reducing energy consumption has now become more important due to increasingly stringent regulations and awareness of climate change. This is recognised in modern buildings as a significant design criterion [3.4, 3.5]. Taking into account the operating costs it is clear, that a more suitable representation would be the ability to maintain value over a long period of time under changing use and external conditions. The two main drivers for building progression are:

- energy efficiency;
- thermal comfort and satisfaction.

Therefore, the advanced building should have its energy consumption minimised whilst consistently allowing the maximisation of the performance, comfort and satisfaction of its occupants over a long lifetime. It is possible only with use of smart controlled and managed systems with the “feedback” from the building itself.

Different levels of building complexity and “smartness” levels are summarized in Figure 3.1 [3.1], demonstrating that there are four aspects that vary:

- the methods by which building operation information is gathered and responded (intelligence or smartness);
- the interaction between the building and the occupants (control);
- the buildings physical properties - materials and construction;
- the methods by which building use information is collected and used to improve occupant performance.

For different categories of building, mentioned four methods are focused upon and utilised to different extents. Although each of the methods has developed over time to be more effective, they generally have been developed independently of each other.

Definition of intelligent building can be found in 1990 [3.6] as a building which totally controls its own environment, including the technical control of heating and air conditioning, lighting, security, fire protection, telecommunication and data services, lifts and other similar building operations; and - that is very important – a control is given to a management computer system. Such a definition does not suggest direct user interaction. Generally, smart building includes the integration of numerous systems which revolve around building operation, a basic example of which is the integrating of the building management system (BMS) with the lighting systems.

In 1995 an intelligent building was defined as a dynamic and responsive architecture that provides every occupant with productive, cost-effective and environmentally approved conditions through continuous interaction among its four basic elements: places (fabric;

structure; facilities); processes (automation; control; systems) people (services; users) and management (maintenance; performance) and the interrelation between them [3.7]. Furthermore, in 2009 the following definition of the intelligent building was developed [3.8]: “An Intelligent Building is one that is responsive to the requirements of occupants, organisations and society. It is sustainable in terms of energy and water consumption besides being lowly polluting in terms of emissions and waste: healthy in terms of well-being for the people living and working within it; and functional according to the user needs”.

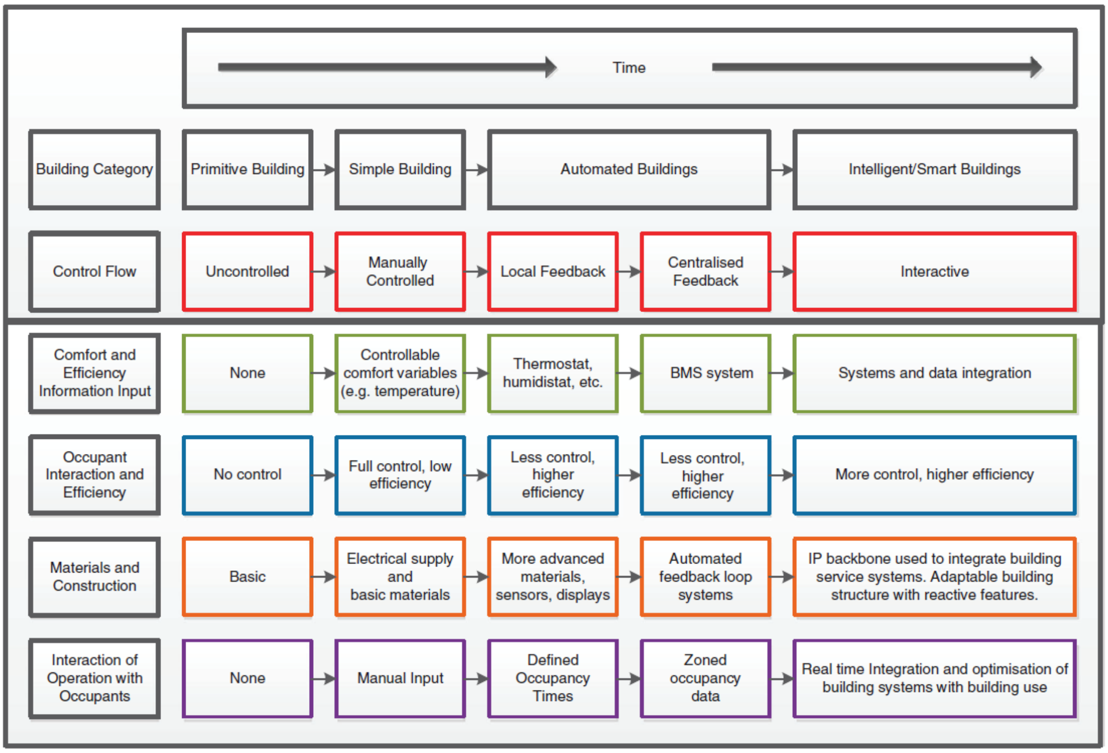

Figure 3.1. *Building progress [1]*

According to [3.1] smart buildings are intelligent buildings but with additional, integrated aspects of adaptable control, enterprise and materials and construction. Just as intelligent buildings were developed from automated buildings, smart buildings are developed upon intelligent building concepts. The development from the use of intelligent to smart sensors within buildings is just one example of the progression towards a smart built environment [3.2]. One of the latest definitions of a smart building [3.9] describes them as a part of the next generation building industry, suggesting that they address both intelligence and sustainability issues by utilising computer and intelligent technologies to achieve the optimal combinations of overall comfort level and energy consumption. The smart building has the ability to adapt to different situations using external context-related data surrounding the behaviour of the occupants. One of the questions is - how much control should be given to the occupant of a building in order to meet both comfort and energy performance criteria, and it is needed to create a convergence between building technology and the occupant.

A smart building is able to adapt its operations and physical form for these events. Intelligent buildings are generally reactive, meanwhile, smart buildings are adaptive. Examples of adaptability are the ability to account for:

- different people's perceptions of comfort at different times of day and year;
- changes in occupants or building use and varying occupancy data characteristics;
- varying of external weather conditions.

One of the most debated aspects around modern smart building design is control. Automated buildings tend to be designed to the theoretical climatic conditions, occupancy and use; and during the exploitation of a buildsing they may change. Many studies show that a degree of control in a workplace results in benefits such as increased comfort, lighting quality and occupant satisfaction. Comfort in a building is not one dimensional but has multiple variables [3.10]. For example, in winter, a room may be much colder than expected, which encourages the use of inefficient electric heaters, but the air quality may deteriorate, resulting in windows to be opened which will obviously negate the effect of electric heaters and may even have a cooling effect on surrounding rooms. There is a need to balance between allowing users to have control of their environment, and creating stable and comfortable conditions that allow the building systems to manage the energy consumption efficiently. The main aim of control within the smart building is to provide occupants with information so that they can adapt to the building, as well as the building adapting to their preferences and requirements.

A smart building may collect information about current weather conditions and react to them by modifying HVAC operation with little control given. Occupants may be given a method to feedback on personal comfort and therefore indirectly control their own environment [3.11], or they may be given opportunities to open windows, but if conditions within the building fall outside of designated comfort conditions, then the building's intelligent systems will implement changes to rectify this.

The construction of a smart building needs to reflect and house the smart functions within it. It should be constructed of materials and contains features which will allow for accommodation of changes in use and climate. The internal structure should also reflect the dynamic nature of the building by being adaptable to the needs of the occupants. Based upon available occupancy data and/or PIR sensors, a smart building may be able to reduce heating/cooling/ventilation/lighting of zones during periods of known low occupancy.

It is important to define the bounds of a smart building. Fig. 3.2 expands upon Fig. 3.1 to draw upper and lower bounds to the definition of Smart Buildings.

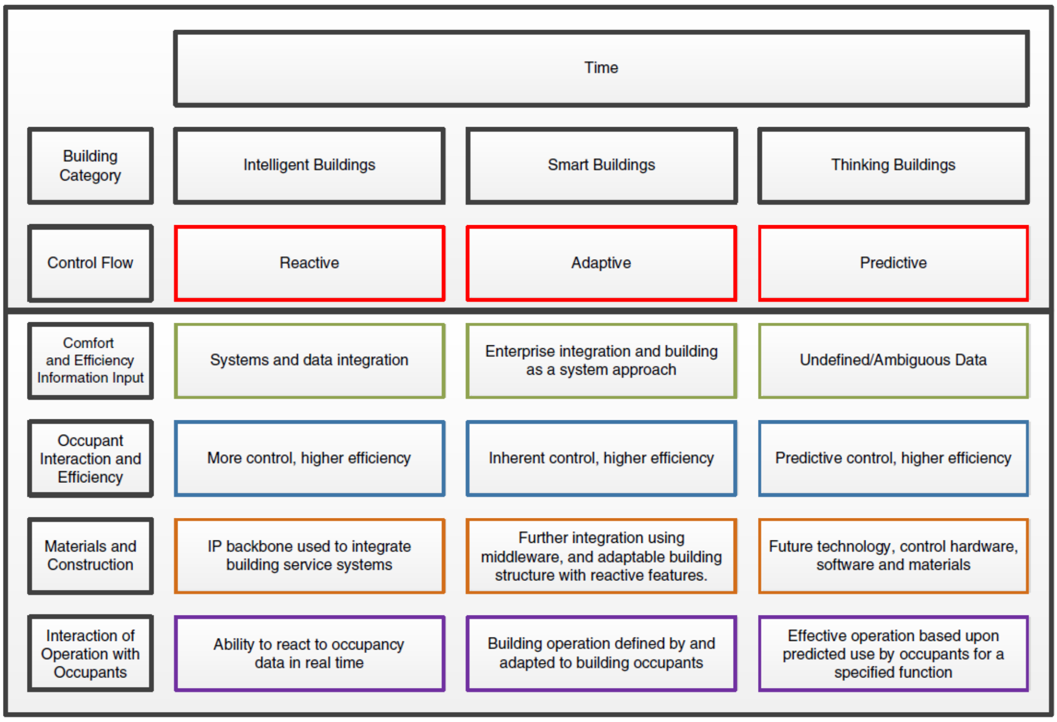

Figure 3.2. *Upper and lower bounds of a smart building [3.1]*

3.2. Control within smart buildings using management system

To be a smart building it is needed of a building management system also known as building automation system. Other terms used in smart buildings are called Building Management and Control System, Direct Digital Controls and Building Controls. The most common current industry term is Building Management System (BMS) or Building Management and Control Systems (BMCS). Other terms associated with control systems include Supervisory, Control and Data Acquisition (SCADA); Programmable Logic Controllers (PLC); Energy Management System (EMS); Data gathering panels (DGP); 'Front End' – legacy term used to refer to the BMS Operator Workstation; etc.

BMS systems are "Intelligent" microprocessor-based controller networks installed to monitor and control a buildings technical systems and services such as air conditioning, ventilation, lighting and hydraulics. Generally, the signals are sent to the actuators (outputs) from the controllers depending on the data from the sensors (see Fig. 3.3) after the processing with different algorithms. More specifically they link the functionality of individual pieces of building equipment so that they operate as one complete integrated system. Now installed in every major building or facility with the availability of direct integration into all other building services such as security, access control, CCTV, fire, lifts and other life and safety systems. Current generation BMS systems are now based on open communications protocols (see next chapter) and are internet-enabled allowing integration of systems from multiple system vendors and access from anywhere in the world.

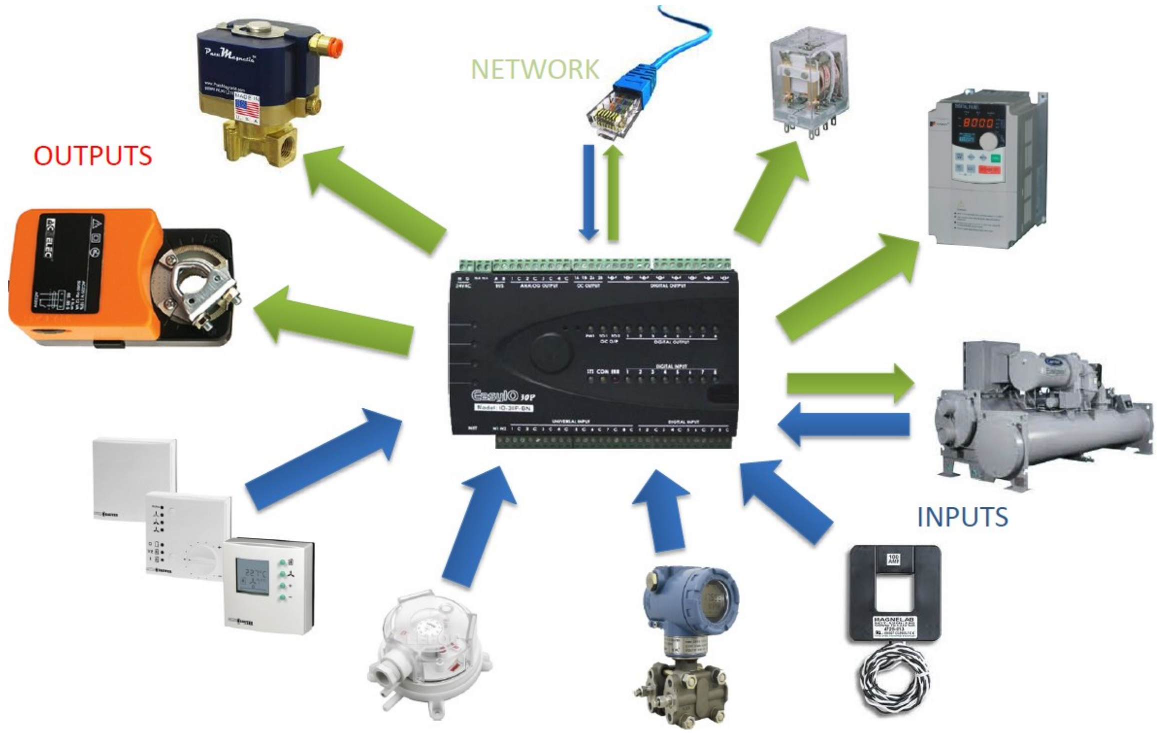

Figure 3.3. *Principle of BMS controller – outputs are depending on inputs*

BMS consists of software and hardware; the software program, usually configured in a hierarchical manner, can be proprietary, using specific protocols as C-Bus or Profibus. Vendors are also producing a BMS that integrates the use of Internet protocols and open standards such as DeviceNet, SOAP, XML, BACnet, LonWorks and Modbus. Building management systems are most commonly implemented in large projects with extensive mechanical, HVAC, and electrical systems. Systems linked to a BMS typically represent 40% of a building's energy usage; if lighting is included, this number approaches to 70% [3.14]. BMS systems are a critical component to managing energy demand.

Main benefits of the management system are as follows [3.14]:

- Data is consolidated onto a single system to improve reporting, information management and decision-making. Integrating and managing the HVAC, energy, security and safety applications from a single workstation allows facility-wide insight and control for better performance.
- Increased operational savings – Efficient resource deployment can result in reduced operational costs, empowering operators, simplifying training and decreasing false alarms.
- Energy efficient – Real-time view into facility operations and deep trend analysis provide data-driven insight to optimize your energy management strategies and minimize operational costs.
- Flexibility to grow and expand – The powerful combination of open systems protocols and a scalable platform means the BMS can help support growth and expansion of the system in the future.

- Reduced risk – Strategic mobile or desktop control, exceptional alarm management and integrated security solutions helps to see the big picture, helping to speed up response time and mitigate risks for the property, people and business.
- Possibility of wide individual control of separate room or group of rooms.

Typical system components used in BMS can be divided to tree groups: hardware (Fig. 3.4), field devices – sensors and actuators (Fig. 3.5) and communications or networking (Fig. 3.6). As BMS systems can be controlled by the technical or some of parameters monitored by ordinary user without any special education, there is wide range of user interfaces available for different BMS hardware and filed device components – from the basic LCD built-in display through to full graphic operator workstations with the web servers (Fig. 3.7).

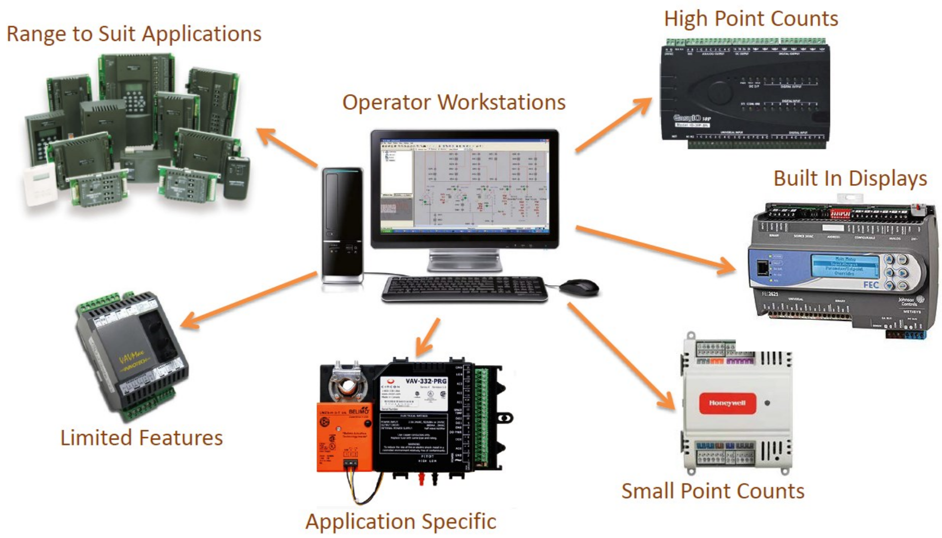

Figure 3.4. *Typical BMS system components – hardware*

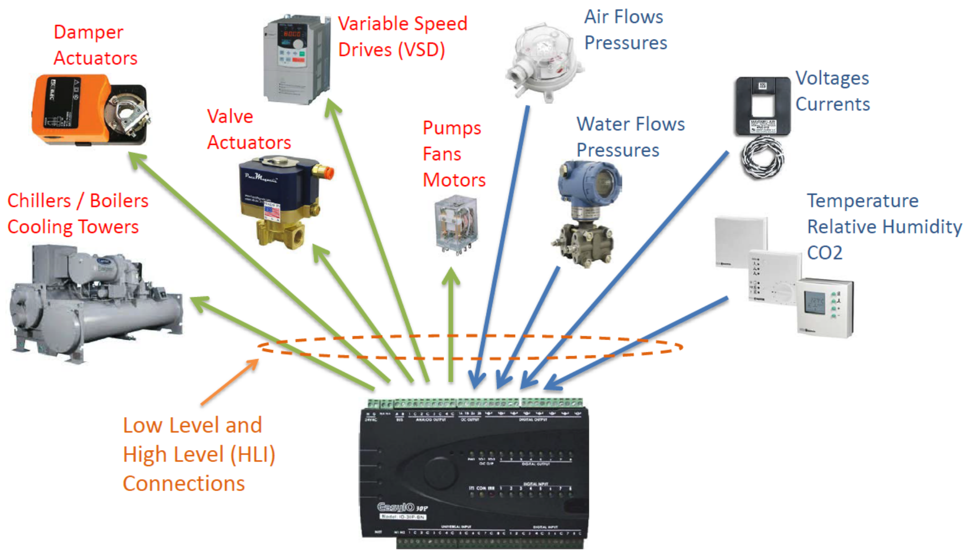

Figure 3.5. *Typical BMS system components – field devices*

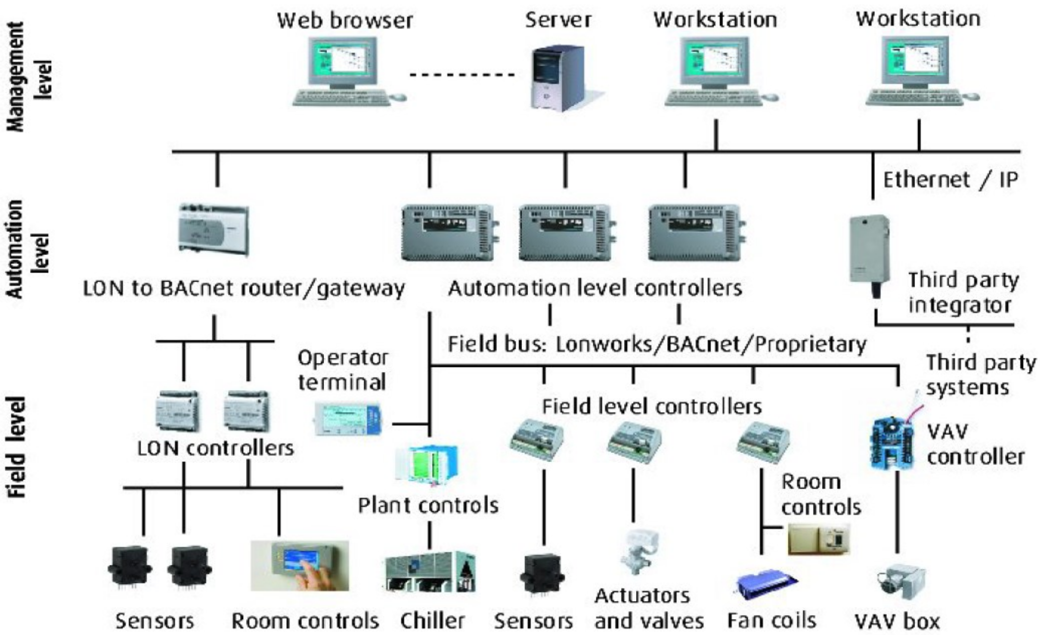

Figure 3.6. *Typical BMS system components – networking*

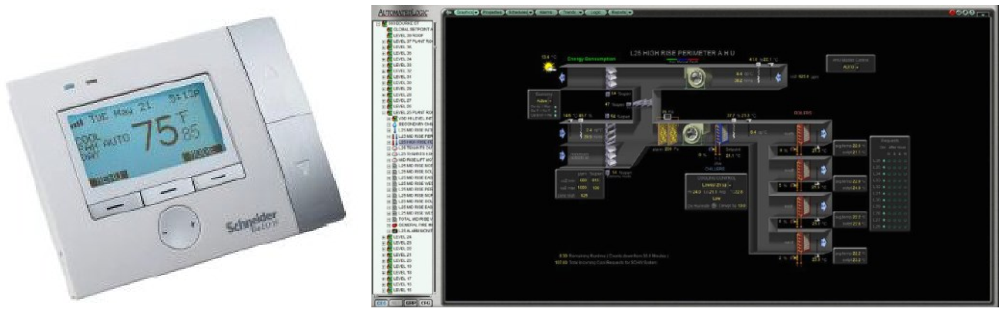

Figure 3.7. *BMS user Interfaces: from LCD built-in display to web servers*

Any modern BMS system should provide at least following features:

- Control of all installed building systems and services
- Energy management and reporting
- Graphic user interface (GUI)
- Real-time monitoring and logging of building operation and performance
- Time scheduling of building systems
- Fault management and alarming; user event management

The main and most important are building control applications including:

- Zone temperature monitoring and control
- Zone variable air volume (VAV) control to zones
- Zone air quality (at least CO_2) monitoring and control
- Air handling unit supply air temperature, flow and pressure control
- Main plant chiller and boiler sequencing
- General exhaust fan control
- After hours building control

Another important opportunity of BMS use is energy management and reducing of operational costs, which includes such features:

- Optimal start and stop of whole plant
- Building warm up and cool down cycles
- Night purge (passive night cooling)
- Automatic seasonal plant sequence selection
- Seasonal temperature setting adjustments
- Load based control strategies
- Occupancy control and control setback

Approximate estimated lifecycle for the main components of BMS is as follows:

- BMS field controllers – 15 to 20 years
- Field devices – 15 to 20 years
- BMS computer hardware – 3 to 5 years
- BMS software – major releases 3 to 5 years

3.3. Overview of systems and protocols for a smart building control

Building automation systems are a combination of many different devices and equipment, all communicating over a local or larger network [3.15]. These systems communicate with a wide variety of devices, from life-space positioned sensors and lights to technical-space located equipment such as chillers, boilers, air handlers and electrical panels. Regardless of the originating protocol from local controllers on different floors or zones, data may be forwarded to the cloud using another protocol via gateways. Monitoring dashboards in the local Facility Manager (FM) office or at corporate headquarters can see real-time visualizations of energy performance and issues.

To enable all this communication, dozens of different protocols have been developed over the years of smart building evolution. Protocols are the accepted rules and standards that allow communication and data-sharing between building automation equipment. Devices and systems that conform to a given protocol can communicate easily with each other, but not necessarily with other protocols. Thus, some protocols, like BACnet and LonWorks, are made for nearly every type of building automation equipment [3.16]. This is why most building automation systems are based on one of these two protocols. Other protocols are more specialized, e.g., the DALI protocol was created just for lighting systems, and Modbus was designed primarily for industrial control. Making things even more complicated, sometimes different protocols can work together and sometimes they can't. For example, BACnet and LonWorks can both work with DALI lighting systems, but not with each other (at least not easily). There is a separate category of wireless protocols, for those devices such as occupant sensors and room controllers that communicate using RF signals.

Some protocols are proprietary, but most today are open. That means their characteristics are published and may be used by anyone freely or by license. Open protocols usually have the backing of some combination of corporations, user groups, or professional societies. Some protocols are regional and others global, and each has its own set of specializations and capabilities that make it preferable in certain applications. Unlike proprietary protocols, which are owned and protected by a company, open protocols are supported by the products and services of many different companies and organizations. This provides users with a much wider choice of devices or systems that can be employed to meet specific applications or needs. Each protocol maintains standards and certifications through its own independent organization (such as bacnet.org and lonmark.org). Guidelines are updated as technology and needs evolve. Advantages of open protocols include:

- Supported by multiple manufacturers, software vendors, and install organizations
- Widely available third-party software for user interface, trend reports, alarming, and other applications (much like apps for smart phones)
- Easier communication with subsystems such as lighting and chiller controllers
- Active community groups for support, freeware, and leverage with vendors
- Ability to stay current and add capabilities in the future

One very essential point is choice to use of wired or wireless communications, or a combination of both. The most common wireless options utilize a wireless-specific protocol. Most control devices - such as room controllers, occupancy sensors, ventilation fan controls, and door sensors - are available with either wired or wireless communications. It is important to note, that device power is handled independently from device communications. Devices will require electrical wiring to connect to the building's power system (some new products with low energy requirements now use batteries or energy harvesting technology for power generation).

Advantages of wireless communications include:

- Ease and low cost of installation, especially for existing buildings
- Scalability through easy addition of devices
- Compatibility usually available with wired protocols, e.g. BACnet, LonWorks, Modbus
- Large facilities and campuses where it's not practical to run wiring between zones

Advantages of wired communications include:

- New construction where running wires is not a significant extra expense
- Where high-energy equipment could interfere with wireless
- Where performance and reliability is critical

While there are many protocols in the BMS market, very different approaches often co-exist within a single building (Fig. 3.8). Open protocols can usually communicate with each other, because gateways and APIs have been developed by the various user groups and vendors. Each protocol has its own advantages and adherents, and a mixing of them may be the most effective way to optimize a building system to particular needs and budgets.

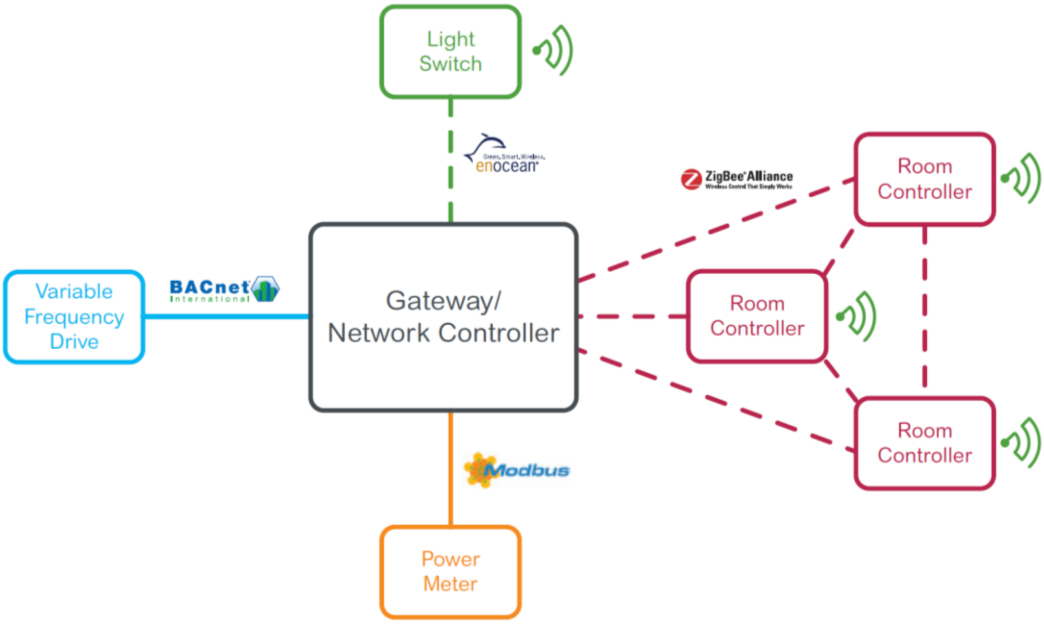

Figure 3.8. *Example of various connected devices via multiple protocols [3.15]*

3.4. Most popular BMS protocols

BACnet® (Building Automation and Control networks) protocol is focused exclusively on building automation. It was created in 1987 at Cornell University, Ithaca, New York, and became an ANSI standard in 1995 under the auspices of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). BACnet is a worldwide standard used by more than 800 vendors across hundreds of devices. BACnet clients must be backward compatible to ensure interoperability with multiple generations of devices within an installation. BACnet supports most building operations, including HVAC, lighting, fire protection, and physical security (access control, intrusion) devices. This protocol is supported and maintained by ASHRAE Standing Standard Project Committee 135. Products are certified for compliance and interoperability through BACnet International via the BACnet Testing Laboratories (BTL). Main features of BACnet are summarized in Table 3.1.

LonWorks® (Local Operating NetWORK) is a widely used standard for many types of control applications, including building automation. It was created by the manufacturer Echelon in 1988, and in 1999 it was accepted as a standard by ANSI for control networking (ANSI/CEA-709.1-B). The majority of LonWorks devices involve buildings projects, including HVAC and lighting. The protocol is also used in many other markets such as outdoor lighting, transportation, utility, process control, and home automation. The protocol's largest application area is in building automation and is an international standard, with millions of installed devices around the world. LonWorks is supported by LonMark® International, an independent consortium of manufacturers that promote efficient and effective integration of open, multi-vendor control systems. The organization develops standards and provides device certification. Main features of LonWorks are summarized in Table 3.1.

KNX is a worldwide communication standard for home and building control. It was created in 1999 by Konnex Association (now KNX Association), and is a combination of three previous standards: European Home Systems Protocol (EHS), BatiBUS, and

European Installation Bus (EIB or Instabus). The KNX Association administers the standard, providing vendor- and product-independent commissioning software for standardized commissioning procedures (ETS). KNX Association has about 400 member companies in 38 countries, offering more than 7,000 certified products for building automation, which are handled by approximately 48,000 certified KNX-partners in 138 countries. KNX Association is a non-profit organization governed by Belgian Law. KNX is used in residential and commercial building automation for HVAC, lighting, security, remote access, blind and shutter control, visualization, and energy management.

DALI (Digital Addressable Lighting Interface) is the leading protocol for the control of lighting in building automation. Developed by a group of manufacturers led by Phillips, the protocol was first drafted as an open standard in 2000 as an alternative to Digital Signal Interface (DSI). DALI 2 replaced the original DALI protocol in 2014 and is backward compatible with it. DALI provides exceptionally fine-grained control over lighting, with each device being separately addressable. 256 levels of brightness are possible. Features include remote control, integration with fire and emergency lighting systems, balancing of light output as LEDs age, and the ability to adjust lighting load based on electricity demand. DALI is used exclusively for lighting and related controls. DALI devices include fluorescent HF ballasts, low voltage transformers, PE cells, motion detectors, wall switches and gateways to other protocols. The protocol is administered by the DALI working party (AG DALI), ensuring that DALI compliant products will have the highest levels of interoperability with other DALI products. Testing can be done either by an approved test house or by DALI members themselves using DALI software.

C-Bus is a communications protocol based on a seven-layer OSI model for home and building automation. It was created by Clipsal Australia (now part of Schneider Electric) for the Clipsal brand of home automation and building lighting control. Usually used for lighting control, but can also control pumps, motors, and virtually any other type of electrical load. C-Bus became an open protocol in 2008. C-Bus provides a great deal of flexibility in switching and control – functions can be changed, added, removed, moved, or reprogrammed at any position on the network without cumbersome hard-wiring. It uses a dedicated low-voltage cable up to 1000 m to carry command and control signals, making it suitable for large commercial applications. The protocol is administered by the C-Bus Enabled Program, which provides certification and support to third-party developers for the design and development.

Modbus® is a serial communications protocol developed by Modicon (now Schneider Electric) in 1979. Originally created for use with Modicon's programmable logic controllers (PLCs), it was released as an open protocol in 2004 and has become a *de facto* standard for connecting a wide range of industrial electronic devices. The Modbus protocol uses a client/server architecture to manage communication between a host and intelligent devices, especially sensors in data acquisition systems. In building automation, it is used to control equipment such as chillers, boilers, and fans. Modbus is used to communicate between intelligent devices and sensors and instruments, and to monitor field devices using PCs and human-machine interfaces. Modbus is most widely used as an industrial protocol, but is also popular in building, infrastructure, transportation, and energy applications. Noted for its flexible and open communications, Modbus is one of the most widely used protocols in the world. The protocol is administered by the Modbus Organization, a group of independent users and suppliers of automation devices.

M-Bus (meter-bus) is a European standard for the remote readout of consumption meters (water, heat, gas, electric meters, as well as valves and actuators) in homes and buildings. It was developed in the 1990s at the University of Paderborn, in conjunction with Texas Instruments Deutschland GmbH and Techem GmbH, and is now widely used in many European countries for smart metering. M-Bus makes it possible to read meters remotely from a host computer or handheld device. In building automation, M-Bus can be linked to the building system to provide integration with other systems such as HVAC and lighting. It is also sometimes used for alarm systems and flexible illumination systems. The protocol is based on the ISO-OSI Reference Model to provide openness and easy integration with other protocols. M-Bus is administered by the M-Bus User Group, which conducts occasional seminars and user group meetings.

OPC is a global software interface that enables the exchange of data among devices, control systems and applications from different vendors. It is used in building automation to provide connectivity between different protocols. It enables different systems such as security, lighting, elevator, and HVAC to be networked using a single connectivity standard. It was originally developed in 1996 for machineto-machine communication in industrial settings, and was limited to Windows® platforms. In 2008 a newer and more open standard of the protocol, OPC Unified Architecture (OPC UA), was introduced and has been adopted in other applications including building automation. OPC UA is notable for its cross-platform service-oriented architecture, enabling interoperability across many types of equipment, systems, and databases. It can be thought of as a universal translator for linking disparate systems. It works with virtually every control system on the market, and can communicate with major building automation protocols such as Modbus, BACnet, and LonWorks. OPC specifications include transmission of real-time events and alarms, and interfacing of real-time data to various types of devices. The protocol is administered by the OPC Foundation, an independent group of more than 450 manufacturers, suppliers, and integrators. OPC is a de facto global standard used North and South America, Europe, Israel, China, Japan, Southeast Asia, and Australia.

EnOcean® standard for wireless networking was originally developed as a commercial venture of Siemens AG. It became an open protocol in 2008 when the EnOcean Alliance was formed by EnOcean, Texas Instruments, Omnio, Sylvania, Masco, and MK Electric. The standard specifies the use of energy-harvesting technology that does not require batteries or other power sources. EnOcean devices utilize kinetic and thermal energy-harvesting techniques such as solar cells, making them economical to use and environmentally friendly. The most typical applications in building automation are for occupancy sensors, lighting controls, key card switches, and other room control applications. The protocol is administered by the non-profit EnOcean Alliance, comprised of some 350 member companies.

ZigBee® is a wireless standard for home and commercial use developed by the ZigBee Alliance, established in 2002. ZigBee is based on an IEEE 802.15.4 standard. The latest version of the standard is known as ZigBee Pro and was published in 2007. A major feature of the ZigBee protocol is its mesh network topology that is self-healing and autorouting. Mesh networks do not depend on any single connection; if one link is broken, devices search through the mesh to find another available route. This capability makes a ZigBee-based network very reliable and flexible. Typically, ZigBee devices are used as room and HVAC controllers, as well as door/window contacts and occupancy sensors. The protocol is administered by the ZigBee Alliance, an open, non-profit association of approximately 400 members.

Matrix of most popular open protocols used in smart building BMS systems is shown on Fig. 3.9 [3.15]. This list represents native support of each protocol. In many cases gateways can be added that enable the support of additional protocols.

Table 3.1. *Main features of most popular BMS protocols*

Protocol	Topology	Media	Transport protocols	License
BACnet	Daisy chain, star or mixed topology	Twisted pair (<1500 m), fiber optics, wireless	IP, Ethernet, LonTalk, Zigbee, ARCnet, MS/TP	Free
LonWorks	Daisy-chain, star or mixed topology	Twisted pair (< 2700 m), power lines, fiber optics, wireless	IP-aware applications or remote network-management tools using IP tunnelling	Paid by product manufacturer
KNX	Tree, line and star topologies (or a combination)	Twisted pair (KNX TP, < 1000 m), Power Line(KNX PL), Radio frequency (KNX R), IP/Ethernet (KNXnet/IP)	with other protocols via gateways	Paid by product manufacturer
DALI	Line or star topologies (or a combination)	Single pair of wires (< 300 m); wireless extension available	with other protocols via gateways	Free to members
C-Bus	Free topology architecture	Unshielded twisted pair (< 1000 m)	Proprietary (allows for integration with DALI, OPC, Web Services and ZigBee). Data can be transported over RS232 and TCP/IP	Free
Modbus	Line topology	Two-wire, four-wire, wireless mesh	IP, Ethernet. Data can be transported via ASCII, RTU	Free
M-bus	Line topology (technically not a network)	Twisted pair; wireless version available (868, 433, 169 MHz)	Not defined in standard; gateways are available for IP	Free
OPC	Server-client	OPC client applications can communicate with OPC servers via any appropriate communication technology, such as TCP/IP, HTTP, HTTPS, or XML		Paid by product manufacturer
EnOcean	Point-to-point communications	Wireless (< 30 m)		Paid by product manufacturer
ZigBee	Mesh network (self-healing)	Wireless (< 100 m)		Fee only for commercial use

		Wired Protocols												Wireless Protocols	
		BACnet /IP	BACnet MS/TP	LonWorks /IP	LonWorks FTT-10	KNX	DALI	C-Bus	Modbus RTU	Modbus TCP	M-Bus	OPC	Web Services	EnOcean	ZigBee
Building Management Systems	Availability														
SmartStruxure™ solution	Global	x	x	x	x				x	x			x		
SmartStruxure™ Lite solution	Global	x							x				x	x	x
Building Insights	North America	x							x				x		x
Building Insights Pro	North America	x							x				x	x	x
Light and Room Control Systems	Availability														
C-Bus Systems Offer (with controllers)	APAC						x	x				x	x		x
DALIcontrol Systems Offer	APAC						x					x	x		
KNX Systems Offer (homeLYnk and spaceLYnk)	EMEA, APAC					x									
SE7000 Series Room Controllers	Global		x		x										x
SE8000 Series Room Controllers	Global		x						x						x
Emergency Lighting Solutions	Availability														
Emergency Lighting	EMEA				x		x		Slave						
Residential Systems	Availability														
KNX Systems Offer (homeLYnk)	EMEA, APAC					x									
C-Bus Wiser™	APAC							x							x
Wiser™ Air	North America												x		x
Wiser™ Smart	Europe												x		x
Home Insight™ Cloud	EMEA, APAC	x				x	x		x	x			x		
Ulti ZigBee	APAC												x		x
Power Meters	Availability														
EM3500 Series Energy Meter	Global		x		x				x						
EM4200 Series Enercept Power & Energy Meter	Global		x						x						
BCPM	North America								x	x					
CM4000T	North America								x	x					
EM4000 Series	North America								x	x					
EM4300 Wireless Meters	Global														x
Enerlin'X Com'X (Com'X 200/210, Com'X 510)	Global								x				x		x
iEM3000 Series	EMEA		x		x				x	x	x				
E5600	North America								x						
ION6200	Global								x	x					
ION7300 Series	Global								x	x					
ION7550/7650 Series	Global								x	x					
ION7550 RTU	Global								x	x			x		
ION8650 Series	Americas								x	x					
ION8800 Series	Global								x	x					
PM3000 Series	Global								x	x					
PM5000 Series	Global								x	x					
PM700 Series	Global								x	x					
PM800 Series	Global								x	x					
PM8000 Series	Global								x	x					
Field Devices	Availability														
CWLP CO2 Sensor (Veris Industries)	Global		x						x						
HWLP Humidity Sensor (Veris Industries)	Global		x						x						
Services	Availability														
Building Analytics	Global	x	x	x	x				x	x		x	x		

Figure 3.9. *Matrix of most popular open protocols used in smart building BMS systems [3.15]*

3.5. An example of systems and software use in a real nZEB building

As an example of number of systems used for a management of existing building, the nearly zero energy building is chosen. The building in relatively new, it was built only in 2016 (see Fig. 3.10). The main building parameters are summarized in Table 3.2.

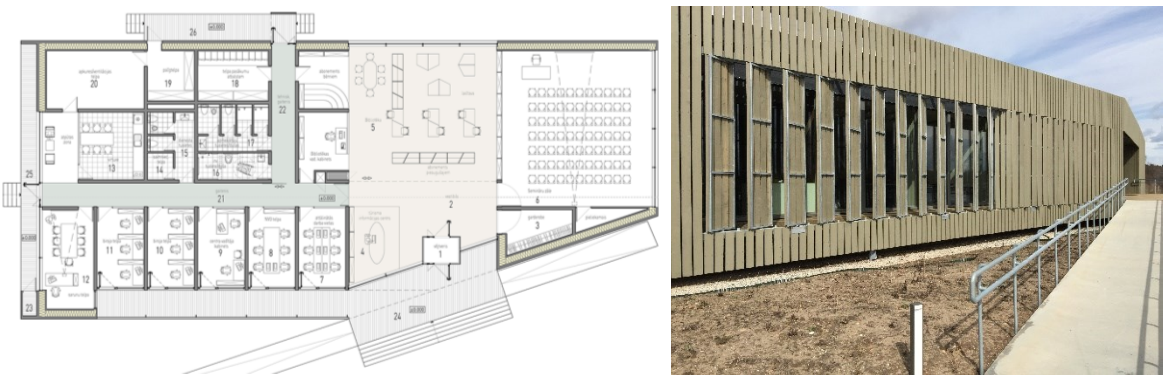

Figure 3.10. *Studied nZEB building*

Table 3.2. *Main parameters of studied nZEB building*

Parameter	Value
Location	Ungurpils, Latvia (57°46′19″N, 24°48′46″E)
Year of construction	2016
Threated floor area	521 m^2
No. of occupants	25
Building volume	1569 m^3
Airtightness	0.3 h^{-1}
Indoor temperature*	18°C (summer) / 25°C (winter)
Heating demand*	15.1 kWh/m^2
Cooling demand*	2.2 kWh/m^2
Heating load*	19 W/m^2
Primary energy*	51 kWh/m^2

** - data from PHPP calculation*

The systems used in this nZEB building are:

- Heating is provided by the geothermal heat pump with borehole heat exchanger and underfloor heating system
- Cooling is provided by the geothermal heat pump with borehole heat exchanger and underfloor cooling system
- Domestic hot water is provided by the same geothermal heat pump and solar collectors placed on the roof
- Ventilation is provided by the compact HVAC unit with a counterflow heat recovery exchanger with efficiency up to 93 % and highly efficient EC fans
- Lighting is provided by the electricity and PV panels with batteries for energy storage

General scheme of combined heating/cooling systems in studied building is shown on Fig. 3.11 – as it seen, it integrated different technologies, energy exchangers and control points, as well as dozens of sensors.

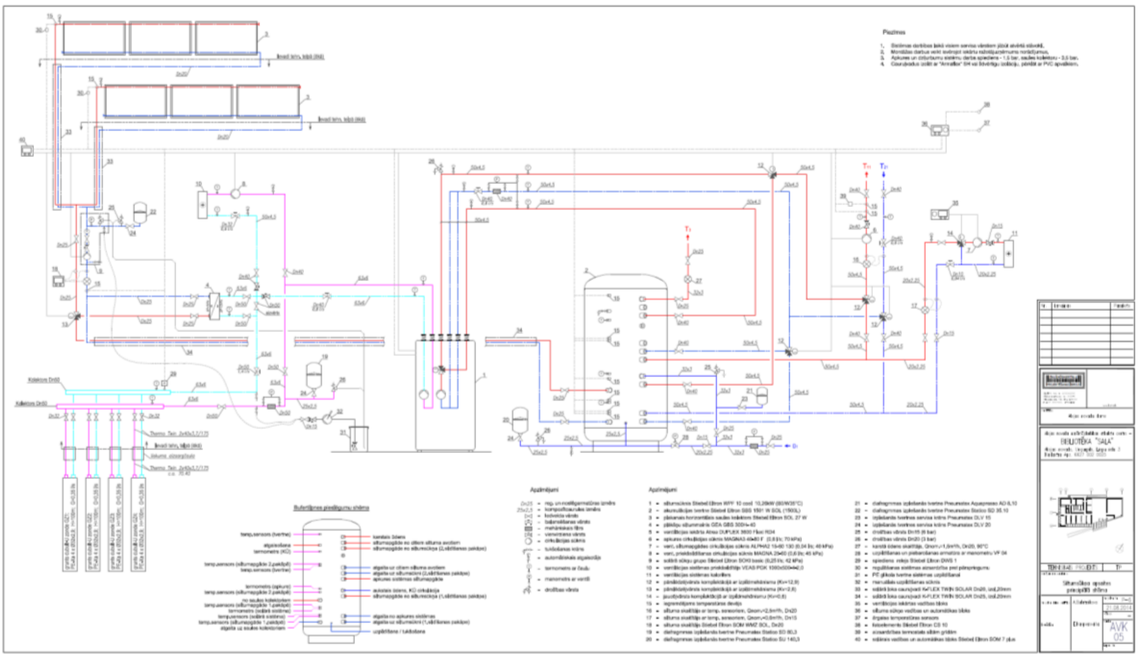

Figure 3.11. *Scheme of combined heating/cooling systems in studied nZEB building*

After detailed analysis of the existing systems with control points, sensors and software possibilities on site, it has been found that smart or at least user-friendly management of the building's systems is not provided – all the different systems are regulated and controlled practically independently and integrated building management system (BMS) is not implemented. It has also been revealed that not all the energy consumers are measured and sometimes it is impossible even to clarify direction of energy flow (e.g. heating or cooling). Therefore, a detailed plan has been developed for recording and analysis of all the produced and consumed energies, as well as environmental parameters (see Table 3.3).

Table 3.3. *Summary of existing and planned measured and recorded parameters included in BMS*

	System + Subsystem	Variable or process (energy, type, etc.)	Parameters
Heating + DHW	Geothermal heat pump	Electricity (pumps, automatics, etc.)	Electricity, kWh
			Enter temperature
			Exit temperature
		Total generated heat energy	Electricity, kWh
			Enter temperature
			Exit temperature
	Solar collectors	Electricity (pumps, automatics, etc.)	Electricity, kWh
		Total generated heat energy	Useful energy (delivered to the buffer tank), kWh
			Return energy (delivered to the ground), kWh
			Enter temperature
			Exit temperature
	Accumulator (buffering) tank	Temperatures at different levels	Submersible temperature sensors
	Underfloor heating (UPONOR)	Heat exchanger in the floor	Heat energy, kWh
			Enter temperature
			Exit temperature
	Ventilation pre-heater	Heat carrier from the buffer tank	Heat energy, kWh
			Enter temperature
			Exit temperature
	Ventilation heat supply (calorifier)	Heat exchanger behind the heat exchanger	Heat energy, kWh
			Enter temperature
			Exit temperature
	Domestric hot water	Heat energy from the tank for the preparation of hot water	Heat energy, kWh
			Enter temperature
			Exit temperature
Ventilation	Air intake in the building	Airflow	Electricity, kWh
			Temperature before the heat exchanger
			Temperature after the heat exchanger
			Airflow (m3/h)
	Exhaust from the building	Airflow	Temperature before the heat exchanger
			Temperature after the heat exchanger
			Airflow (m3/h)
	Humidification	Humidification up to 30% in winter	Electricity, kWh
			The amount of water consumed, in kg or l
			Humidity of supply air, %
			Air humidity after humidification, %
Cooling	Geothermal heat pump	Electricity (pumps, automatics, etc.)	Electricity, kWh
			Enter temperature
			Exit temperature
		Total generated energy	Heat (cooling) energy, kWh
			Enter temperature
			Exit temperature
	Solar collectors	Electricity (pumps, automatics, etc.)	Electricity, kWh
			Enter temperature
			Exit temperature
		Total generated energy	Return energy (delivered to the ground), kWh
			Enter temperature
			Exit temperature
	Buffer tank	Temperatures at different levels	Submersible temperature sensors
	Underfloor cooling (UPONOR)	Heat exchanger in the floor	Heat (cooling) energy, kWh
			Enter temperature
			Exit temperature
	Ventilation pre-cooler	Heat carrier from the buffer tank	Heat (cooling) energy, kWh
			Enter temperature
			Exit temperature
Indoor lighting		Electricity	Electricity, kWh
Facade lighting		Electricity	Produced electricity (up to the battery), kWh
			Used electricity (taken from the battery), kWh
Indoors		Indoor air parameters	Average air temperature in the building
			Air temperature in separate rooms
			Average humidity in the building
			Humidity in separate rooms
			CO2 sensor in room No. 6
			CO2 sensor in the exhaust air duct
Outdoors		Outdoor parameters	Outdoor temperature
			Outdoor humidity
			Solar radiation density, W / m2
			Wind speed, m / s
			Wind direction

The BMS system is created to help not only show, but also analyse and predict the interconnection between different systems, thus increasing the efficiency of the whole building. The biggest challenge during the planning and integration of the BMS system for this building was a connection of all the existing and newly installed systems, sensors and actuators in one place using **Niagara** framework [3.17]. The protocols used to connect all the systems are: *BACnet*, *KNX*, *Modbus* and *M-Bus*, some additional drivers and hardware adapters were installed to ensure the operation in one system.

At the moment, there is not enough data to conclude the effect of installation and configuration of the BMS in this nZEB building, but after at least couple of months of system running it will be clear about effect of these changes.

3.6. Analysis and conclusion

Analysis of different available BMS systems and protocols for a smart building data records, intelligent management and appropriate control, as well as an working with a real nZEB building with initially segmental and individual systems show that the biggest challenge is integration of all the data/systems in one central unit. Each manufacturer or producers of one system (e.g. ventilation, heat pump or specific sensors/meters) are using particular communication protocol, which is very well optimized for this type of application and use of different protocols requires at least additional driver, but most often – some kind of hardware converter or adaptor, meaning additional expenses.

Only by getting a comprehensive information about all the measurements and system operation together it is possible to realize a really smart management of the building, avoiding conflicts between different systems and providing the increasing of overall energy efficiency. Thus, for example opened window decrease the temperature near it during a winter and heating system (or local heater) will increase the power in this room or even in all the building, at the same time, if the BMS receives the signal from the window open/close sensor (e.g. [3.18]), it will not affect the functioning of the heating system until window is opened or even couple of minutes later. Or, the long-time opening of the window when mechanical ventilation system is operating will cause minimizing or even stop the ventilation system to decrease uncontrolled convective heat losses and to exclude possible inflow of any outdoor chemical and microbiological contamination; a message to cell phone can be sent too.

The “smartness” of the building can be reached only when all the essential parameters- both environmental and measurements from the running systems can not only be measured and recorded, but also used to analyse, control and manage not only the same, but also another systems (for example, strong wind induces the opening of external window blinds or heating/lighting power depends on occupancy in the room). Intelligent programming of BMS response action using maximum possible actuators (e.g. airflow, heating power, lighting, shading), forecasting of all possible scenarios is absolutely necessary to achieve this goal.

Recommendations

Use of BMS system in a nZEB building is one of the key factors to reach the required energy efficiency of a building and to make is really smart, but it is very important to follow the following points in achieve these goals:

- All the main systems must have the ability to read the built-in sensors readings and runs actuators remotely.
- All the main systems must have the ability to be managed using BMS as a single system (not independently from each other).
- Al the systems must have to support a single BMS protocol (or with the ability to convert native protocol).
- Energy meters must be installed on separate systems to individually record and accordingly manage different building systems (heating, DHW, cooling, etc.)

Literature

[3.1] A.H. Buckman, M. Mayfield, Stephen B.M. Beck, (2014) "What is a Smart Building?” Smart and Sustainable Built Environment, Vol. 3 Issue: 2, pp.92-109, https://doi.org/10.1108/SASBE-01-2014-0003

[3.2] Shabha, G. (2006), “A critical review of the impact of embedded smart sensors on productivity in the workplace”, Facilities, Vol. 24 No. 13, pp. 538-549.

[3.3] CABA (2008), Bright Green Buildings: Convergence of Green and Intelligent Buildings, in Sullivan, F. (Ed.), Continental Automated Buildings Association (CABA), Ottawa, pp. 1-220, available at: www.caba.org

[3.4] Sinopoli, J. (2010), Smart Building Systems for Architects, Owners and Builders, Butterworth-Heinemann, Oxford.

[3.5] GhaffarianHoseini, A., Dahlan, N.D., Berardi, U., GhaffarianHoseini, A., Makaremi, N. and GhaffarianHoseini, M. (2013), “Sustainable energy performances of green buildings: a review of current theories, implementations and challenges”, Renewable and Sustainable Energy Reviews, Vol. 25 No. 1, pp. 1-17.

[3.6] Powell, J.A. (1990), “Intelligent design teams design intelligent buildings”, Habitat International, Vol. 14 Nos 2/3, pp. 83-94.

[3.7] Everett, R. (2008), “The ‘building colleges for the future’ program. Delivering a green and intelligent building agenda”, New Review of Information Networking, Vol. 14 No. 1, pp. 3-20.

[3.8] Clements-Croome, D. (2011), “Sustainable intelligent buildings for people: a review”, Intelligent Buildings International, Vol. 3 No. 2, pp. 67-86.

[3.9] Wang, Z. , Wang, L. , Dounis, A.I. and Yang, R. (2012b), “Multi-agent control system with information fusion based comfort model for smart buildings”, Applied Energy, Vol. 99, pp. 247-254.

[3.10] Leaman, A. (2000), “Reviews”, Building Research & Information, Vol. 28 No. 4, pp. 291-303.

[3.13] Yu, D.-Y. , Ferranti, E. and Hadeli, H. (2013), “An intelligent building that listens to your needs”, Symposium on Applied Computing, Coimbra, March 18-23.

[3.14] https://en.wikipedia.org/wiki/Building_management_system

[3.15] http://blog.schneider-electric.com/wp-content/uploads/2015/11/SE-Protocols-Guide_A4_v21.pdf

[3.16] http://blog.schneider-electric.com/building-management/2015/11/20/finally-simple-guide-understanding-open-protocols/

[3.17] https://www.tridium.com/en/products-services/niagara4

[3.18] https://www.smarthome.com/insteon-2843-222-wireless-open-close-sensor.html