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Building heating technology in Smart Home using PI System management tools[☆]



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Summary For comfortable remote monitoring of some operational and technical functions inside own Smart Home building, it is possible to use a lot of useful programmes and tools. However, not each programme or tool is suited to this purpose, or it does not offer required functionality. The aim of this paper is to describe using an appropriate software tool of PI System for a real-time monitoring of acquired data from real technology parts located at a training centre of the Moravian-Silesian Wood Cluster. Then a superior system including applications of PI Coresight and PI ProcessBook is used for analysis and processing of these acquired data (e.g. by using the Dynamic Time Warping method for specific technological quantities). Each application has own advantages and disadvantages, which are evaluated in conjunction with possibilities of manipulating the data. In an experimental part, there are also applied a technological communication standard of BACnet to controlling heating, cooling and forced ventilation, and a software tool of DESIGO Insight for visualising the data in forms of tables, multi-layer graphs, and screens for a certain technology.

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Introduction

Modern buildings allow to unify monitoring and controlling of building automation and electronic systems under a common environment known as a Building Management System (BMS). Based on dynamic advancement of research and development of new technologies within Smart Home, Smart Home Care, Smart Metering, Smart Cities and their applications using alternative sources and energy savings, there was reacted to these trends by building a platform for testing of these technologies in the MSWC building. In (Costanzo et al.,

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2012), a system architecture for a load management in smart buildings is introduced and it enables an autonomous demand side load management in the Smart Grid (Costanzo et al., 2012). In case of using wireless technologies, according to (Batista et al., 2013) they are becoming an important asset in Smart Grid, particularly ZigBee devices. These smart devices are gaining increased acceptance not only for building and home automation, but also for energy management, efficiency optimisation, and metering services. In case of managing energy consumption in the smart building, it can be used Microgrid working as a local energy provider (Zhang et al., 2013). In this paper, some optimal scheduling of energy consumption in the smart buildings is studied using a mixed integer linear programming.

Smart Home technology

The Smart Home building

A smart one-floor wooden house (hereafter Smart Home; technical alias: MSWC building; floor area: 12.1 m × 8.2 m; (Fig. 1), which was built at the FCE (i.e. Faculty of Civil Engineering, VSB-Technical University of Ostrava) site as a training centre of the Moravian-Silesian Wood Cluster (MSWC), contains modern technologies for automated control of operational and technical functions (such as HVAC, heating sources, and regulation, etc.).

Features of used technologies

Technologies used in the MSWC building are divided into the two main categories (Fig. 2), thus: Building Heating Technology (BHT) – includes heating technology in the MSWC building (i.e. mutual connection among heat pump, solar panel, accumulation tank, floor heating, boiler, ventilation, air conditioning; (Fig. 3). Building Automation Technology (BAT) – provides interoperability between BACnet and other technologies to ensure automation of operational and technical functions in the MSWC building (i.e. regulation, data visualisation, data storage for databases, data processing)



Figure 1 MSWC building – view on this smart one-floor wooden house and installed technologies (i.e. a 2-U borehole heat exchanger with the fifth pipe for measuring some uninfluenced/influenced temperature profiles, and the solar collector system).

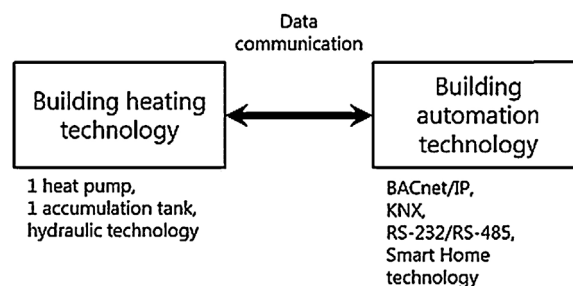


Figure 2 MSWC building – block scheme of the technological parts (Building heating technology, and Building automation technology).

with the option to connect additional technologies via corresponding interfaces.

Both technologies (i.e. the BHT and the BAT) allow focusing on development, innovation and sample implementation in real applications, whereas the main aim of this research within the BAT is currently focused on implementing smart systems.

Building heating technology (BHT)

The MSWC building is equipped with the BHT including a mutual connection of its main components (i.e. ground-water heat pump, solar system with vacuum pipes with a surface area of approximately 4 m², accumulation tank, floor heating, boiler, ventilation, air-conditioning (Fig. 3) to the 2-U BHE (Fig. 2). Joint implementation of HST (Heat Storage Technology), BHT and BAT therefore allows research of the possibility of excessive heat accumulation into the surrounding rock massif.

Building automation technology (BAT)

The control system, located in the MSWC building (Fig. 1), consists of an automation sub-station of DESIGO PX PXC100-E.D series (by SIEMENS) using a BACnet communication protocol for data exchange between its own components. The transfer medium used by DESIGO is Ethernet/IP. One of the basic characteristics is an open architecture of the system, which supports individual components or other systems with OPC, the Ethernet, and M-Bus (Fig. 4). The state and change of monitored values is monitored by using a PXM 20E control panel (Fig. 4).

All components of this control system – used for regulation of heating and cooling sources and all the securing, control and auxiliary BAT elements – are located in one central location; this switchboard therefore contains communication modules for an HVAC unit, bus system, and data collection, specifically: temperatures (HST, BHT, BAT); relative humidity and CO₂ concentrations (BAT); pressures (HST, BHT); heat consumptions (BHT); electricity consumptions (BHT). Let us add that the DESIGO PX PXC100-E.D automation station is used in the MSWC building to control and regulate ventilation, heating and air-conditioning (Fig. 4). In addition to programmable control and regulation functions, this substation includes integrated functions of so-called *higher control* (such as alarm control, time programmes,

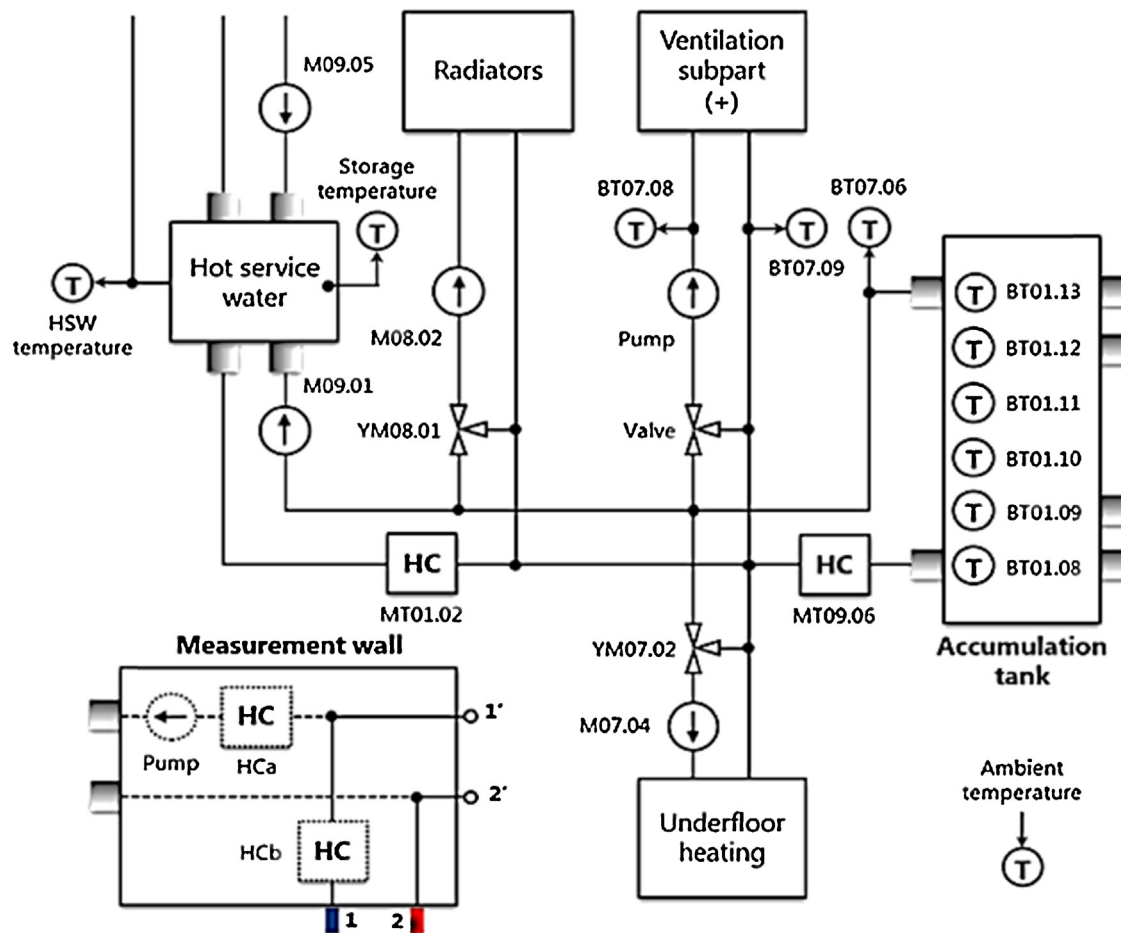


Figure 3 MSWC building – block scheme of the BHT part and the HST part.

storage of measured data, remote access, access protection for whole network with the option for defining user profiles and categories, etc.). The complete technology is visualised using a DESIGO Insight software tool, which is modular, object-oriented and clearly designed software for this control station. The visualisation application is divided into a basic set and some extension modules in accordance with needs of a certain technology (Vanus et al., 2013a,b).

Methodology of implementing PI System management tools

Features of PI System

The PI System (hereinafter referred to as PI) is a designation for a software tool provided by an American company of OSIsoft, LLC. Individual programmes or programme groups can also be operated separately. For example, PI is used in business infrastructure for data and event management in real time. The PI also enables data storage and searching for required trends, as well as analysis, distribution and visualisation of the data from various data sources.

It can be subdivided into the following function blocks, thus: data source – block for control system connection; server block; client block. The first block represents a

physical interconnection of the data sources with the control system or a PI Server when using a manual input, separate database systems and/or legacy data. The second described block is the PI Server, which is a software for processing of the transferred data. The PI Server receives these data in form of so-called PI events, consisting of a time stamp, a value or a status, and additional attributes. The third block is a block marked as PI Clients (OSIsoft, 2014). They are software programmes used by end users to view and analyse the data. These measured data are visualised using a desktop or Web applications in PI Coresight (Fig. 5).

Desktop applications include (a) PI DataLink; (b) PI ProcessBook; (c) PI DataAccess. The Web applications include (a) PI Web Parts; (b) PI Active View; (c) PI Coresight.

Implementation of the PI System in the MSWC building

In the MSWC building, the OPC server is used as a PI data source, based on the BACnet technology and visualised using the DESIGO Insight software tool (Fig. 4). This OPC server communicates with a PI OPC interface, which forwards the data to the PI Server (Fig. 5). It communicates with a client station where individual applications are running. These applications – connected to the PI – can be programmed by using tools of PI API, PI SDK, or their combination. The PI

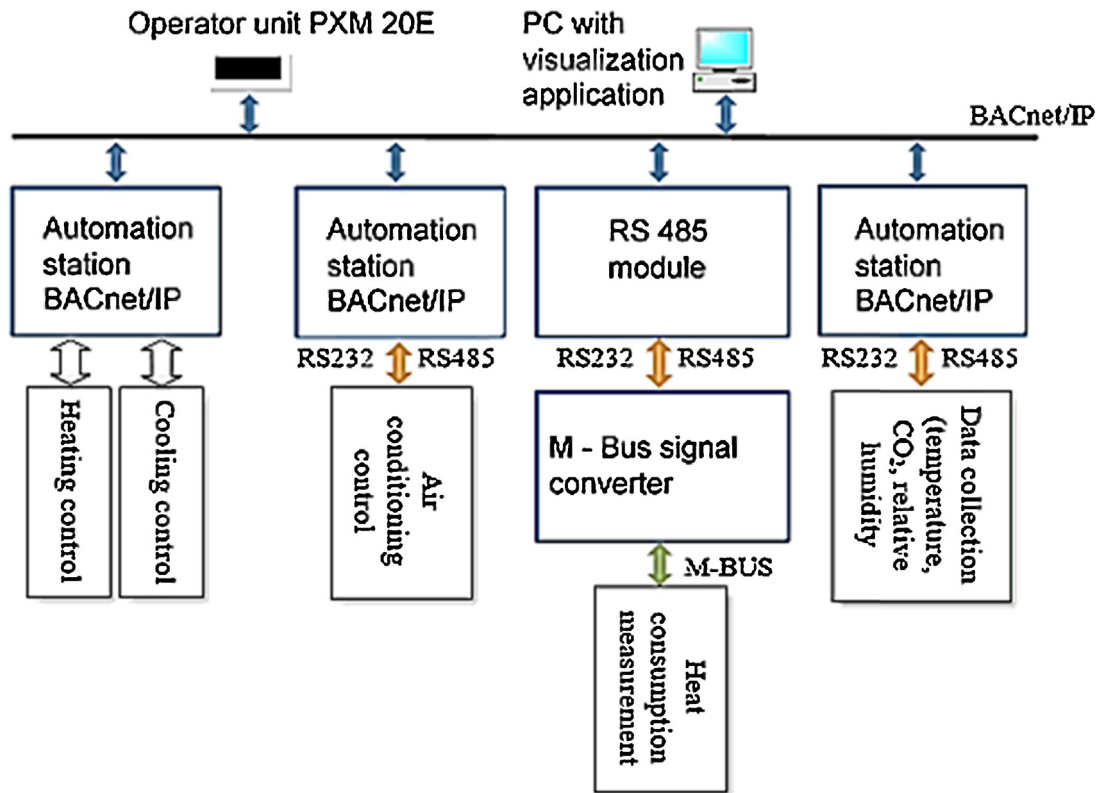


Figure 4 MSWC building – block scheme of the BAT part (including communication modules for the BHT part).

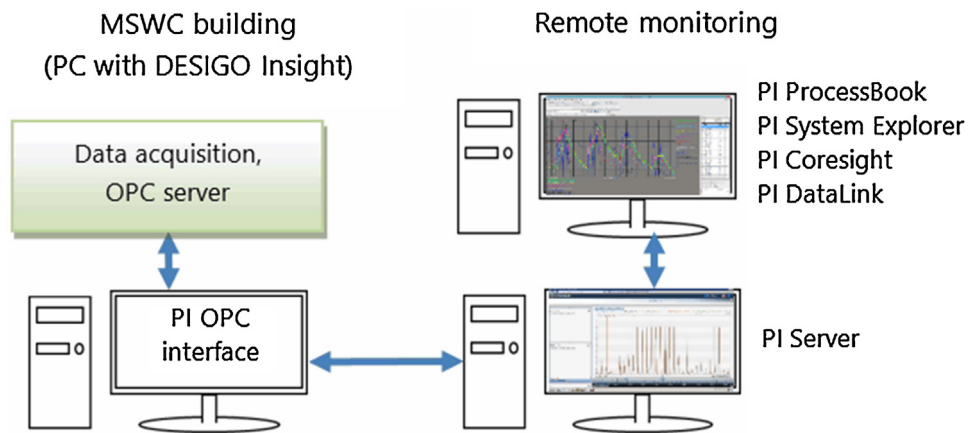


Figure 5 Block diagram illustrating data transfer from an OPC server (located in the MSWC building) to the PI Server.

API (i.e. PI Application Programming Integration) and the PI SDK (i.e. PI Software Development Kit) are dynamically connected libraries used by the applications to communicate with the PI Server.

Methodology of the experimental part

Conceptualization

There is some comparison of the features between the software applications of PI Coresight and PI ProcessBook in the experimental part of this paper. This comparison is

conceptually focused on possibilities of a fast statistical analysis (FSA; used for the acquired data) and a graphical visualisation (used for monitoring of the operational and technical functions in the MSWC building). For a mutual comparison of calculated statistical values, there were chosen measured temperatures (i.e. labels from BT01.08 to BT01.13) inside the accumulation tank (Fig. 3), and temperature (i.e. BT07.08 label) measured at the inlet of the ventilation subpart (Fig. 3).

A method based on dynamic programming or dynamic time warping (DTW) is useful in order to find an optimal time alignment, and to calculate a distance between a vector of unknown behaviour for a time-dependent measured

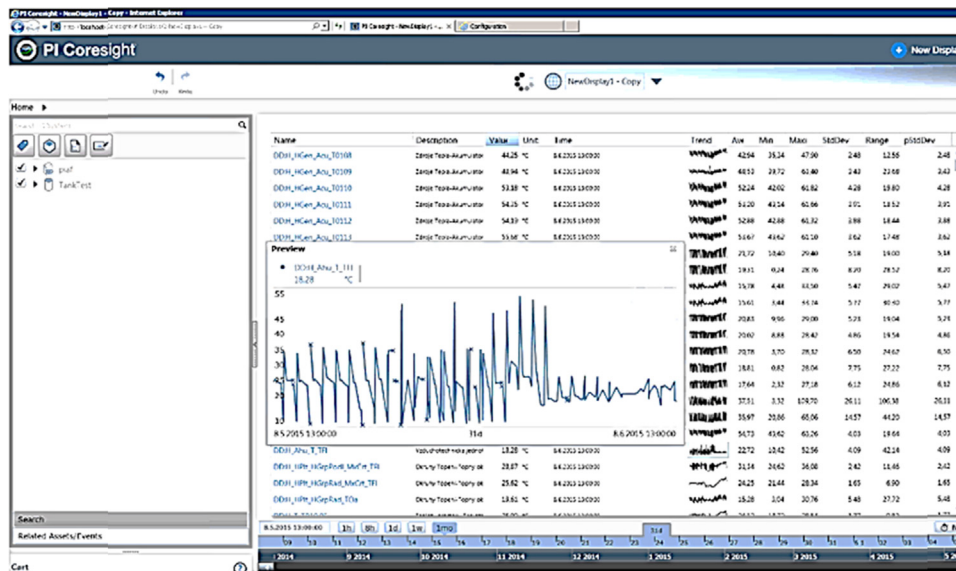


Figure 6 PI Coresight – table-based and graph-based summarisations of measured and statistically processed temperature data (i.e. labels from BT01.08 to BT01.13, and BT07.08).

quantity, $v(t)$, and a vector of a reference sample for the time-dependent measured quantity, $v_{ref}(t)$, within a certain closed time interval $[a, b]$ (e.g. day, week, or month; also [Tables 2–4](#)). This analysis is valid for an idle operation mode, therefore it can be expected with similar values of these distances at defining overlap time intervals.

Using the PI Coresight

The PI Coresight is a Web-based application (based on the “thin client” model), operating via a Web browser. It provides creating some trends and monitors, and analyzing information about ongoing processes in the MSWC building. The PI Coresight allows: (a) to search and display time-series or other PI data ([Fig. 6](#)); (b) to create a process visualisation with a possibility to record the data for further analysis ([Fig. 6](#)); (c) to display a PI ProcessBook screen ([Fig. 5](#)); (d) to

share this screen with other authorised users (i.e. the users who have access to the PI Coresight).

Using the PI ProcessBook

The PI ProcessBook allows not only a real-time instant access and a data visualisation, but also (in the past tense using interactive) graphical screens ([Fig. 7](#)). The data can be visualised through some trends, dynamic symbols, tables, numerical values for subsequent processing and analysis of the acquired data. These visualisation screens can be gradually changed and adapted to new conditions and needs of users. For a fast statistical data analysis, it is possible to use a table ([Fig. 7](#)) including some basic statistical parameters of the measured data source (i.e. Average, Minimum, Maximum, Range, Standard deviation, Time interval, etc.; [Table 1](#)).

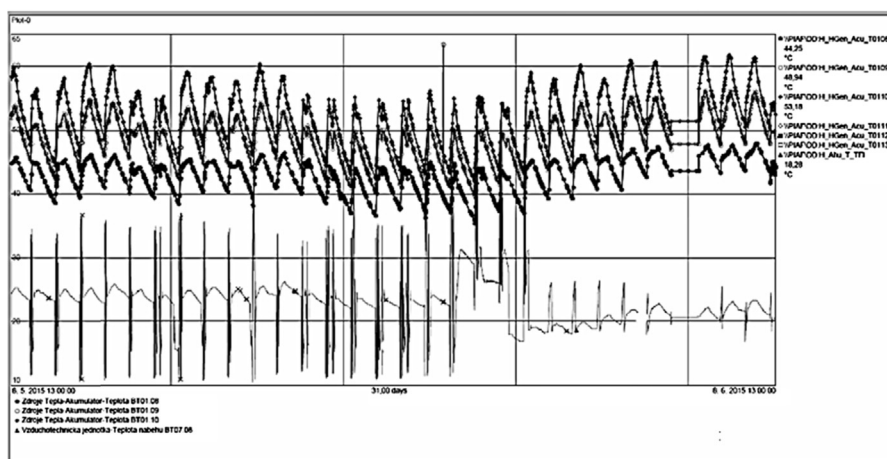


Figure 7 PI ProcessBook – time-dependent trends of measured and statistically processed temperature data (i.e. labels from BT01.08 to BT01.10, and BT07.08); compare with [Fig. 6](#).

Table 1 PI ProcessBook – table based summarisation of measured and statistically processed temperature data (i.e. BT01.08, BT01.09, BT01.10, and BT07.08).

Statistics	BT01.08	BT01.09	BT01.10	BT07.08
Data type	Float 32	Float 32	Float 32	Float 32
Average	42.94 °C	48.53 °C	52.24 °C	22.72 °C
Minimum	35.34 °C	39.72 °C	42.02 °C	10.42 °C
Maximum	47.90 °C	63.40 °C	61.82 °C	52.56 °C
Range	12.56 °C	23.68 °C	19.80 °C	42.14 °C
StdDev	2.48 °C	3.43 °C	4.28 °C	4.09 °C
P StdDev	2.48 °C	3.43 °C	4.28 °C	4.09 °C
Time range	From 8 May 2015 (1.00 p.m.) to 8 June 2015 (1.00 p.m.)			

Table 2 Using the DTW method – summarising calculated values of the Euclidean distances, i.e. time interval of day and temperature sensors labelled as BT01.08, BT01.09, BT01.10, and BT07.08.

Day	BT01.08	BT01.09	BT01.10	BT07.08
BT01.08	0	1.047×10^{-4}	1.076×10^{-4}	0.064
BT01.09	1.047×10^{-4}	0	5.582×10^{-5}	0.052
BT01.10	1.076×10^{-4}	5.582×10^{-5}	0	0.042
BT07.08	0.064	0.052	0.042	0

Day – results are valid for 10 May 2015 only.

Using the Dynamic Time Warping (DTW) method

For recognition of operational and technical functions in Smart Home, a DTW method was used. According to an algorithm, described in (Chen et al., 2010; Vanus and Koziorek, 2014), compressed unknown behaviour of the vector of measured non-electrical (typically temperature) quantity, $v(t)$ in °C, with a weights vector, $w(t)$ in °C, has been gradually compared with each reference sample behaviour of the measured non-electrical quantity, $v_{ref}(t)$ in °C, with a reference weights vector, $w_{ref}(t)$ in °C.

A matrix of Euclidean distances (at considering the closed time interval), $D_{a,b}$ in °C, is calculated by using this formula, thus (Chen et al., 2010; Vanus and Koziorek, 2014):

$$D_{a,b} = \left\{ \sum_{i=1}^N [v_{ref}(t=b)_i - v(t=a)_i]^2 \right\}^{\frac{1}{2}}$$

$$= \sqrt{\sum_{i=1}^N [v_{ref}(b)_i - v(a)_i]^2} \quad (1)$$

For determining a degree of similarity for time-dependent trends of the measured temperature data (all in °C) in the accumulator tank (Fig. 3), relevant temperature sensors labelled as BT01.08, BT01.09, BT01.10 (Fig. 6 or Fig. 7), has been chosen. For a comparison with a different measured temperature, a relevant temperature sensor labelled as BT07.08 and related to the inlet of the ventilation subpart (Fig. 3), has been also used. The first approach based on using a mutual correlation method (related to corresponding time-dependent temperature trends) was

rejected, because it was not possible to secure the identical length (i.e. identical number of samples at an identical time) of the measured data from different data sources. So, the second approach is based on using the DTW method to determine the degree of similarity between corresponding samples.

Results and discussion

Results of using the DTW method

Results of usage of the DTW method are summarised in the following tables including calculated coefficients related to the Euclidean distances (Eq. (1)), thus: Day (i.e. 10 May 2015; Table 2); Week (i.e. from 10 May 2015 to 17 May 2015; Table 3); Month (i.e. from 10 May 2015 to 9 June 2015; Table 4).

Discussion

All of the above used tools have their justification and usefulness for the BMS. In terms of the overview of instant conditions for individual technologies with possible alerts to threshold situations and alarms, the PI ProcessBook is very useful. On the other hand, in terms of the possibility of easy access to the acquired data and measured temperature values via some Web-based application or via a smart phone, the PI Coresight is sufficient and better than using the PI ProcessBook.

From the results of using the DTW method (Tables 1–3), there is an expected similarity between time-dependent trends for the temperature sensors of BT01.08, BT01.09, and

Table 3 Using the DTW method – summarising calculated values of the Euclidean distances, i.e. time interval of week (7 days) and temperature sensors labelled as BT01.08, BT01.09, BT01.10, and BT07.08.

Week	BT01.08	BT01.09	BT01.10	BT07.08
BT01.08	0	8.193×10^{-5}	7.971×10^{-5}	0.060
BT01.09	8.193×10^{-5}	0	5.186×10^{-5}	0.052
BT01.10	7.971×10^{-5}	5.186×10^{-5}	0	0.043
BT07.08	0.060	0.052	0.043	0

Week – results are valid for date interval from 10 May 2015 to 17 May 2015.

Table 4 Using the DTW method – summarising calculated values of the Euclidean distances, i.e. time interval of month (30 days) and temperature sensors labelled as BT01.08, BT01.09, BT01.10, and BT07.08.

Month	BT01.08	BT01.09	BT01.10	BT07.08
BT01.08	0	1.047×10^{-4}	1.075×10^{-4}	0.062
BT01.09	1.047×10^{-4}	0	5.582×10^{-5}	0.062
BT01.10	1.075×10^{-4}	5.582×10^{-5}	0	0.061
BT07.08	0.062	0.062	0.061	0

Month – results are valid for date interval from 10 May 2015 to 9 June 2015.

BT01.10 (Fig. 3), due to short Euclidean distances in order of $10^{-4} \text{ }^\circ\text{C}$ or $10^{-5} \text{ }^\circ\text{C}$.

Naturally, at the idle operation mode, there are long Euclidean distances between a group of the temperature sensors of BT01.08, BT01.09, BT01.10 and the BT07.08 temperature sensor. The daily and weekly results (Tables 2 and 3) are comparable with the monthly result (Table 4), because this operation mode has been fixed for a long time and appropriate time intervals overlap.

Conclusion

The aim of this paper was to describe a functionality of technologies of the BHT part and the BAT part, and an inter-connection with a superior system in the form of the PI System. It is able to remotely monitor the operational and technical functions in the MSWC building.

From a practical viewpoint, possibilities of the PI Core-sight and the PI ProcessBook were compared and evaluated in dependency on performing the real-time fast statistical analysis of the measured temperature data. To get more information about interactions among these data, the DTW method was preferred.

In the future, it is planned to use this method for analyzing these interactions not only at a standard operation mode, but also at non-overlap time intervals.

Conflict of interest

The authors declare that there is no conflict of interest.

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