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INVESTIGATION ON THE HEATING SYSTEM OF THE MECHATRONICS RESEARCH CENTER BUILDING USING *OLAP* TECHNOLOGY

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Abstract

At the University of Debrecen, the Department of Electrical Engineering and Mechatronics operates in the Building Mechatronics Research Center, where researchers took the initial steps of constructing an intelligent and sustainable building, which involved the configuring of the research infrastructure and the measurement network. In this article, we present a possible application and several advantages of the developed measurement network, which are principally conducive to monitoring the energy consumption of the building to achieve energy efficiency.

Key words: data evaluation, heating system, intelligent building, OLAP

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1. Introduction

In the development of the industrial, public and residential buildings, the intelligent building represents the next level of development. For the proper functioning of a building of this type - similar to a living organism - it requires data of the real world through its "senses". In the case of a living organism, there are several sense perceptions that provide different data regarding the surrounding part of the real world, and the more information the brain (i.e., the central processing unit) receives, the more efficiently it can keep the body functioning correctly (Akintola et al., 2011; Busato et al., 2013). However, while a living being has a "built-in" data collector and data analysis system, in the case of buildings, we have to create this system (Ahmed et al., 2014; Mehta et al., 2014).

In the interest of creating smart buildings, we need different information – as comprehensive as possible - regarding the exterior and interior operation of the relevant building. In the Building Mechatronics Research Center, we have a goal to create an automatically controlled intelligent building. To achieve this goal – as I mentioned above – we must not only create the "senses" of the research center but also have the ability to analyze the collected data (Hou et al., 2006; Thomsen, 2002) . The first step of the implementation is to establish the "sense-organs" of the current building. To measure the inner and outer parameters of the research center, we installed sensors and built a comprehensive measurement network in the research center, which is able to collect and analyze the properties of the research center's environment (Larson, 2006; Yang et al., 2010; Zhao et al., 2013).

The aim of this article is to investigate the heating system of the research center with the help of the measurement network, which is currently available. The paper is organized as follows: Section

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2 provides a brief introduction about the structure of the heating system of the Building Mechatronics Research Center and describes the Online Analytical Processing (OLAP hereafter) technology, which is essential in this research. Section 3 presents three OLAP cubes for the heating system of the research center. Section 4 presents the summary. Section 5 provides the acknowledgements.

2. Experimental

2.1. Heating system of the Building Mechatronics Research Center

The heating system of the research center is composed of two Vaillant gas furnaces, with each of the boilers being connected to a Vaillant VRC 630 controller. In the system the hot water that is provided by the furnaces flows through a Spirovent BA050L air separator unit, and then the water passes through a Vaillant WH 40-type hydraulic separator. The gas boiler operates with the help of outer temperature meters, inner water temperature meters and regulators (João and João, 2010).

On both the producing and the consumer side of the hydraulic separator, temperature meters and flow meters were placed. It is possible to measure the temperature of the primary and secondary flow and return water and the volume flow on both sides with these Superstatic 440 and Supercal 531 type sensors. It is easy to investigate the operation method of the heating system and the operation of its parts, for example, the state of the hydraulic separator, which closely reflects the operation of the entire system. Later, we will describe an OLAP cube that is able to evaluate the data of these sensors. In Fig. 1, one part of the heating system is shown.

The following quote provides a description of the operational states of the hydraulic separation process. "The hydraulic separator, or decoupler, is a simple device that permits co-mingling of the primary and secondary circuits while also eliminating problems. It uses a common pipe between the primary and secondary circuits to create a place of low pressure loss where fluid from the circuits can blend and unite, or separate, as the system requires" (Brindamour, 2013).

Fig. 1. Heating system of the Building Mechatronics Research Center

Fig. 2 shows the three different states of the hydraulic separators; these states differs from each other in the values of the T1, T2, T3, T4, Vp and Vs, where: T1, T2, and Vp are the temperature of the flow, the temperature of the return water, and the volume flow of the producing or primary side, respectively; T3, T4, and Vs are the temperature of the flow water, the temperature of the return water, and the volume flow of the consumer or secondary side, respectively. There exists a fourth state that is used in the case when the system cannot determine in which state is the hydraulic separator.

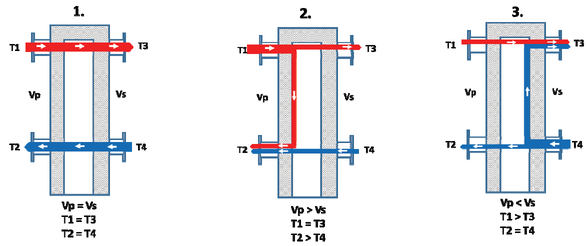

Fig. 2. States of the hydraulic separator

2.2. OLAP measurement method

"OLAP stands for On-Line Analytical Processing and is a technology used to collect, manage and process multidimensional data and provide fast access to this data for analytic purposes" (Codd, 2001). The basis of the OLAP concept was laid by the "father of the relational theory", E.F. Codd (Datawarehouse Concepts, 2012). In this article, Codd formulated 12 rules that should satisfy the OLAP software; afterward, researchers added another 38 rules to this list. The OLAP databases are designed to provide an overview analysis of what occurred. This technology is widely used in business reporting for marketing, sales and other various business fields.

In the Building Mechatronics Research Center, all of the advantages of OLAP were used to support the research center management. OLAP manipulates dimensional data, which enables fast execution of complex database queries, complex data views through data pivoting, complex data computations, and complex data modeling in real-time. OLAP uses the OLAP cube, which is a data structure that OLAP creates from the relational data. The OLAP cube can be considered as a multidimensional array.

An engineer might want to analyze the temperature of the building by date, by gas consumption, by energy consumption, or by outer temperature. These different analysis criteria are the dimensions of the OLAP cube. To use OLAP cubes, we must create a star or snowflake schema from a relational database, or create a database with this structure in the first place; this schema is either able to include view tables only or the underlying database structure can consist of real database tables.

The center of the star or snowflake schema will be the fact table of the cube, and others will be the dimensional tables. Each of the dimensional tables is linked to the fact table. We must establish one table for every dimension of the cube. The fact table contains the facts and metrics about the business or, in the case of the research center, the management process. After this brief introduction, we can describe the primary steps of designing and creating an OLAP cube (Codd, 2001; Colossi and DeKimpe, 2010):

1. Consultation with the end user about the information needs.
2. Select the fact data.
3. Determine the dimensions. Construct the hierarchies in the dimensions, if it is necessary.
4. Describe the relationships between dimensions and facts. i.e., define the model.
5. Create database views or temporary database tables to realize the facts and dimension tables.

More details about the OLAP technology are in the following web page and book (Datawarehouse Concepts 2012; Thomsen, 2002).

3. Results and discussion

In the research center to investigate the heating system we design three OLAP cubes, which analyze the heating system from three different points of view:

– The first cube (Cube 1) can show on one part the average gas consumption of the research center in the function of the inner temperature, outer temperature and the heating energy demand through a predefined date interval. It can also investigate the average heating energy demand of the research center in the function of the inner temperature, outer temperature and the gas consumption through a predefined date interval.
– The main task of the second cube (Cube 2) is to analyze the temperature of the radiators in the research center depending on the flow temperature of the furnace. The measurement data on which this cube based was collected through a heating and a cooling period as well.
– The third cube (Cube 3) was described for checking the state of the hydraulic separator based on the calorimeters located in the heating system.

Process of creating the OLAP cubes

Claim surveyor step: The above-mentioned three cases determine the end user's information needs, so we satisfy the first step of the process.

Cube 1

Model construction step: The second, third and fourth steps can be considered to be one step in which the model is made. The structure of the first cube is shown in Fig. 3. This cube consists of two facts tables and four dimension tables. The two facts Tables in this schema are the Fact Data Gas Consumption and the Fact Data Heating Energy D table, which contain gas consumption and heating energy demand and exactly as many key values for as many dimension tables that are linked to them.

There are four dimension tables, so we can show the fact data from four aspects. One of these aspects is the inner temperature dimension, one is the outer temperature dimension, one is the date-time dimension, and two are the gas consumption and the heating energy demand. It is possible to show the fact data as a function of two or more dimensions in the same time.

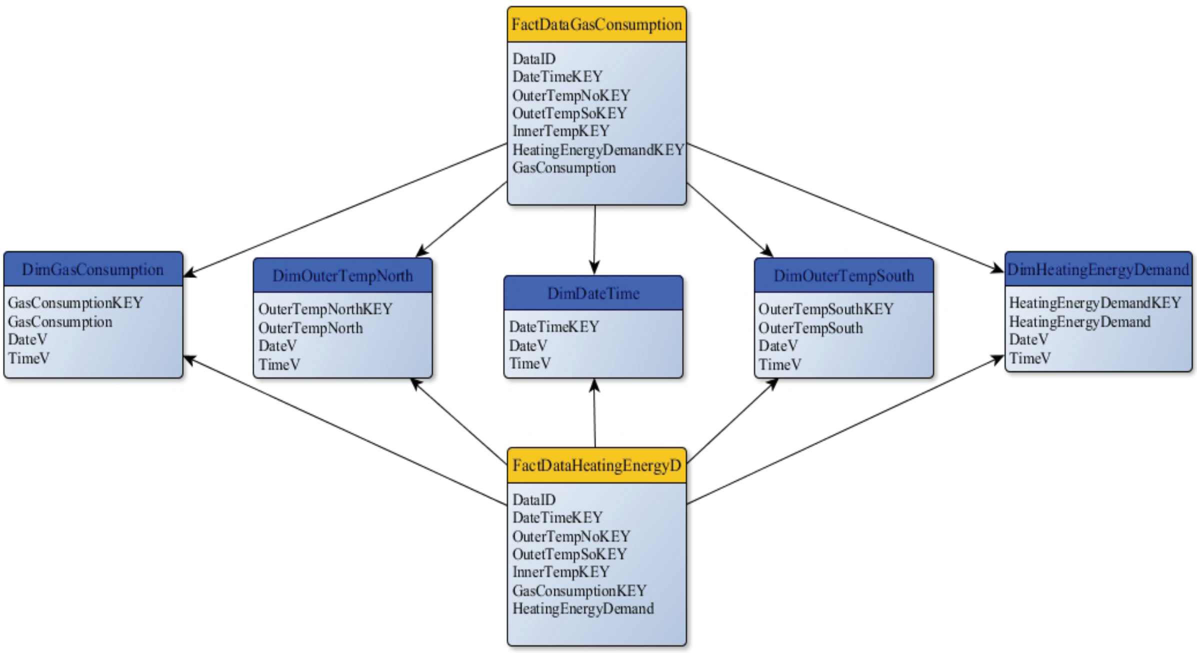

Fig. 3. Scheme of Cube 1

Implementation step: To realize the plans of Cube 1, we collect the different data into a MySQL OLTP data collector database. There are four types of data in the cube; these data come from three different devices, which have a direct connection with the data collector database:

♦Wireless Sensor (UCMote Mini v2.0): inner temperature,

♦Integrated Meteorological Station (VaisalaWX510): outer temperature,

♦ Building Management System (Schneider Andover Controls):

- Gas Flow Meter (Superstatic 440): gas consumption,
- Heat Flow Meter (Supercal 531): heating energy demand.

After collecting the data, we select the requested data, and with the help of a Java desktop application, we produce the facts and dimension tables in a previously created SQL Server 2012 data analyzer database.

Evaluation step: Cube 1 provides widespread evaluation of the possibilities for the data of the heating system. To obtain the valuable information, the cube can be opened in Microsoft Excel application, which provides a notably user-friendly interface.

It is easy to create different queries and diagrams using this OLAP cube. To represent the gas consumption and the heating energy demand of the research center, numerous pivot-chart reports are available. Fig. 4 shows the average gas consumption as a function of inner or outer temperature. Fig. 5 shows the average gas consumption as a function of outer temperature. Fig. 6 shows the average heating power demand of the primer side as a function of the date. Fig. 7 shows the average boiler loss energy as function of the date.

Cube 2

Model construction step: One part of the second cube's schema is shown in Fig. 8. This cube consists of 19 facts tables and two dimension tables. The 19 facts tables are for the 18 different temperature sensors that were placed on the radiators of the different rooms in the research center and 1 temperature sensor that was built in to the heating system; these sensors are the FactDataBoilerRoom, FactDataElvisLab, FactDataHydraulicLab, FactDataKitchen, FactDataElectroLab, FactTableRobotLab, and so on. The facts tables contain the inner temperature of the current room except for the FactDataBoilerRoom which comprise the flow temperature of the furnace. We obtained two dimension tables, so we can show the facts data from two different points of view. One of these is for the outer temperature dimension and one is for the date-time dimension.

Implementation step: To realize the plans of Cube 2, we perform the same process as in the case of Cube 1. After collecting the data into the data collector database, we pick the relevant ones and provide these to the Java application that makes the facts and dimension tables in the analyzer database. In this cube, there are three types of data, which are provided by three different devices:

- Wireless Sensor (UCMote Mini v2.0): inner temperature,
- Integrated Meteorological Station (VaisalaWX510): outer temperature,
- Building Management System, Temperature Sensor (Schneider Andover Controls, Pt500): furnace flow temperature.

Evaluation step: Using Cube 2, we can obtain considerable valuable information regarding the operation of the heating system, primarily regarding how the furnace control operates. We made several diagrams to obtain answers to our questions, for example, one room is cold while the other is hot.

Fig. 9 shows the furnace flow temperature and the outer temperature as a function of the date over a week. Fig. 10 shows the furnace flow temperature and the outer temperature as a function of the date over a day. Fig. 11 shows the temperature of rooms on the ground floor and the outer temperature as a function of the date over a week. Fig. 12 shows the temperature of the rooms and furnace flow temperature as a function of the date over a week.

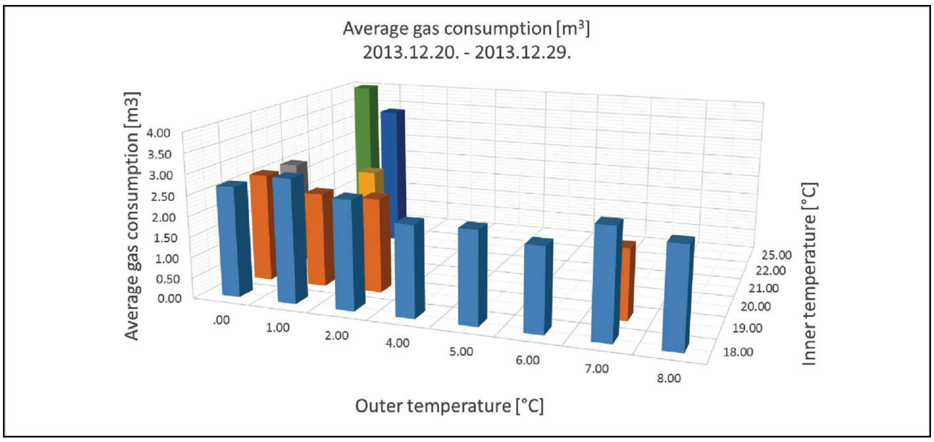

Fig. 4. Average gas consumption as a function of the inner and one outer temperature

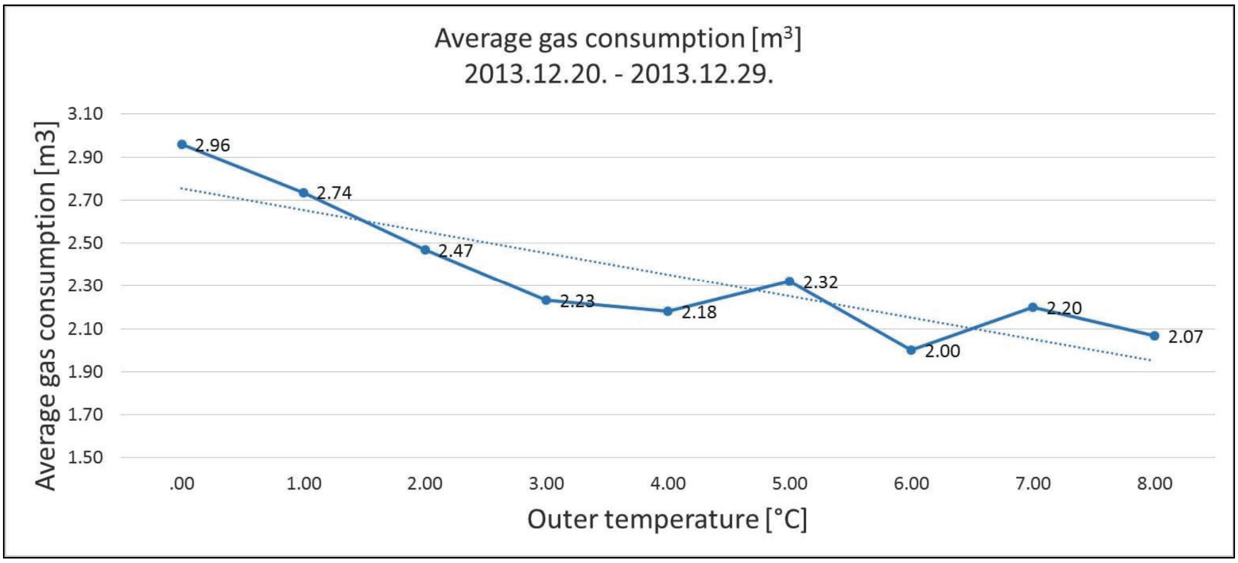

Fig. 5. Average gas consumption as a function of the outer temperature

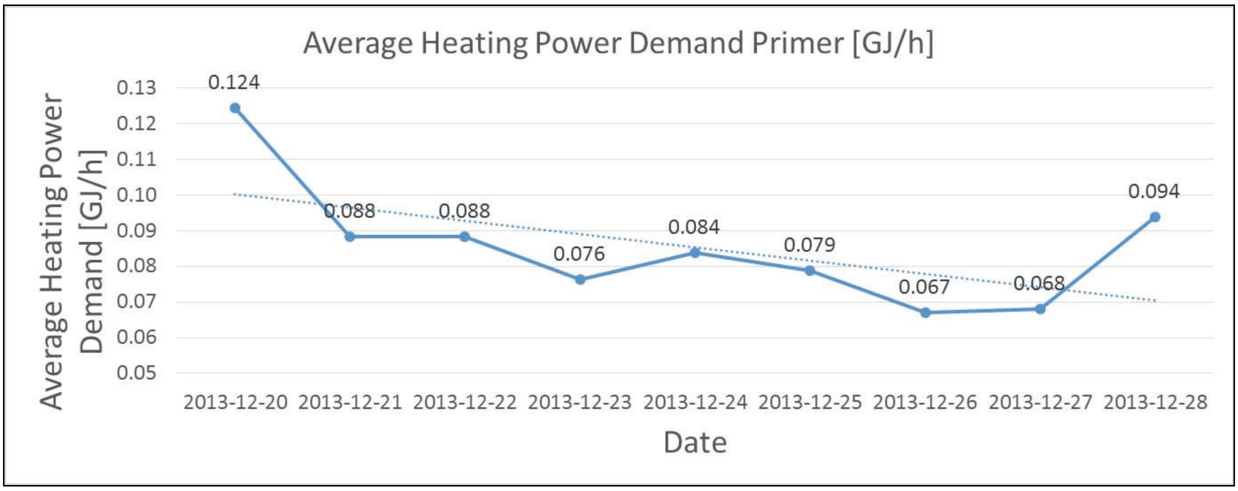

Fig. 6. Average heating power demand of the primer side as a function of the date

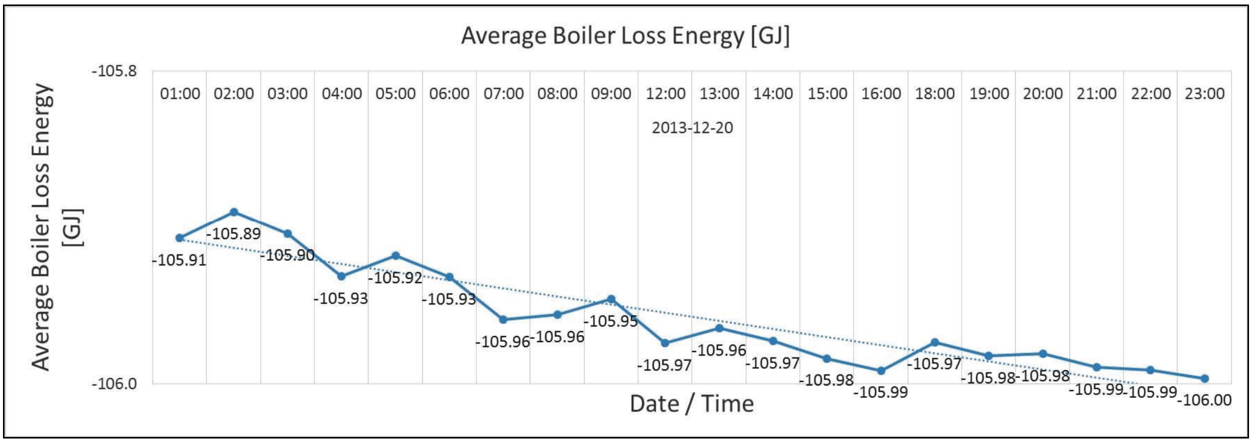

Fig. 7. Average boiler loss energy as function of the date

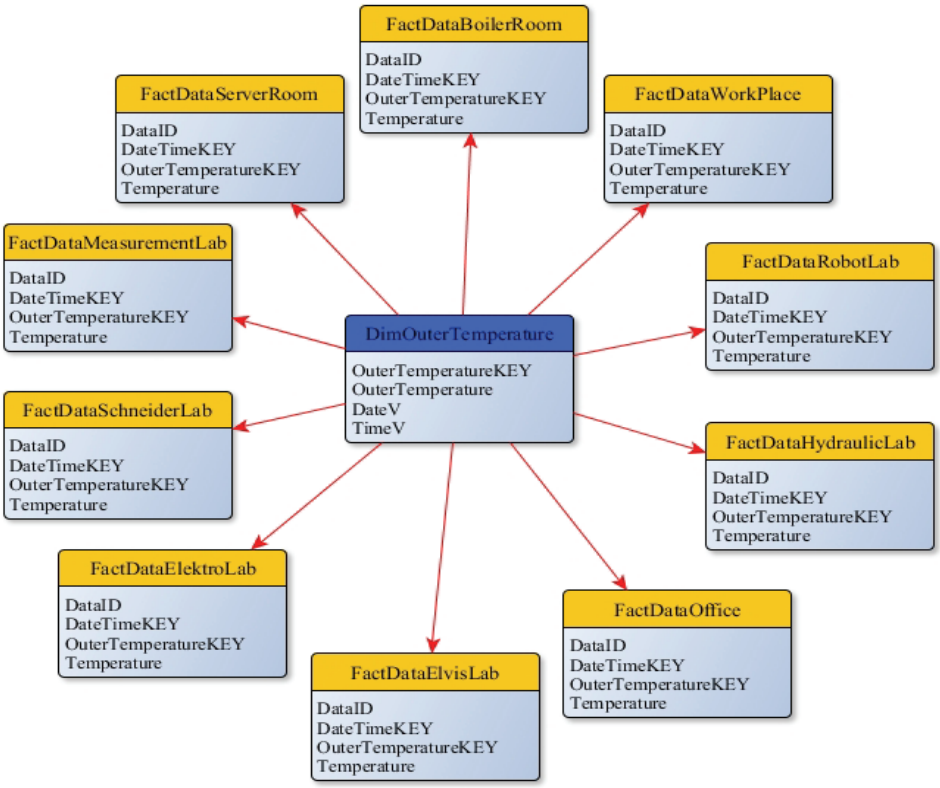

Fig. 8. Scheme of Cube 2

.Cube 3

Model construction step: Fig. 13 shows the structure of the third cube. This cube contains seven facts tables and two dimension tables; except for two tables, each of facts tables is for one sensor in the heating circuit. The facts tables are as follows:

- FactDataHydraulicSeparationStatus,
- FactDataPrimaryVolumeFlow,
- FactDataSecondaryVolumeFlow,
- FactDataPrimaryInletFlowTemperature,
- FactDataSecondaryOutletFlowTemperature,
- FactDataPrimaryInletReturnTemperature,
- FactDataSecondaryOutletReturnTemperature.

The facts tables contain the volume flow, the temperature of the flow and temperature of the return on the primary and secondary side of the hydraulic separator and the current state of the hydraulic separator. The states of the hydraulic separators are shown in Fig. 13. We have two dimension tables, so we can show the facts data from two different points of view. One of these is for the outer temperature dimension, and the other is for the date-time dimension.

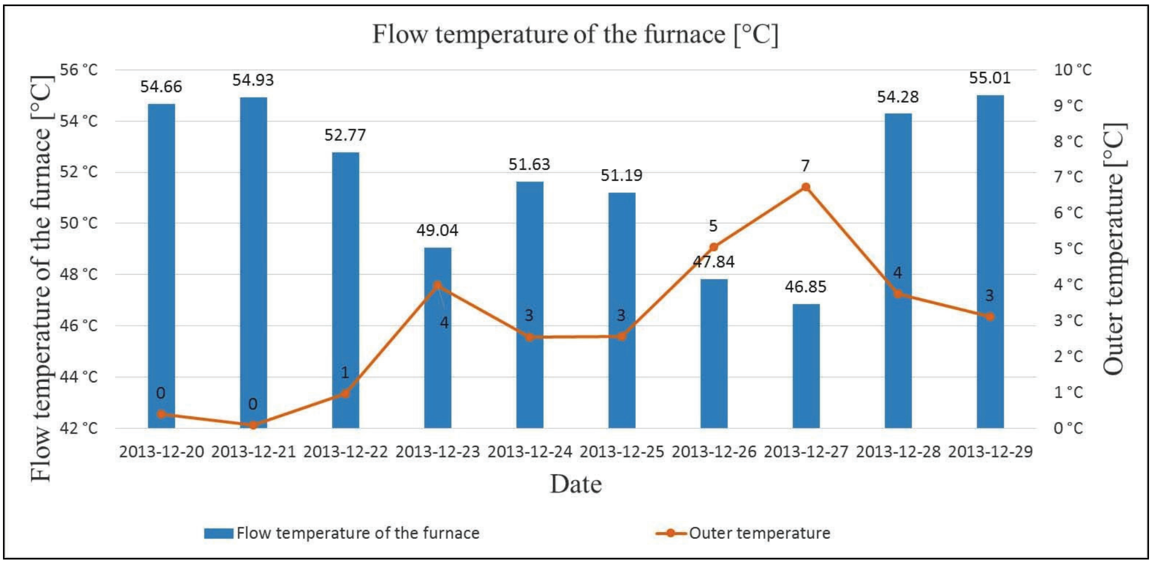

Fig. 9. Furnace flow temperature and outer temperature as a function of the date (one week)

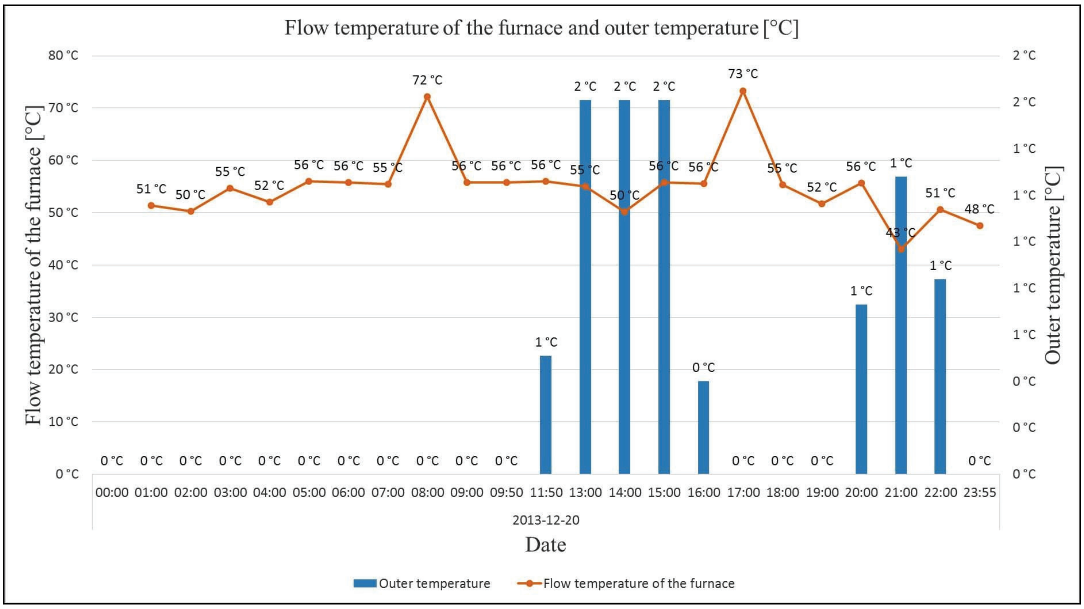

Fig. 10. Furnace flow temperature and outer temperature as a function of date (one day)

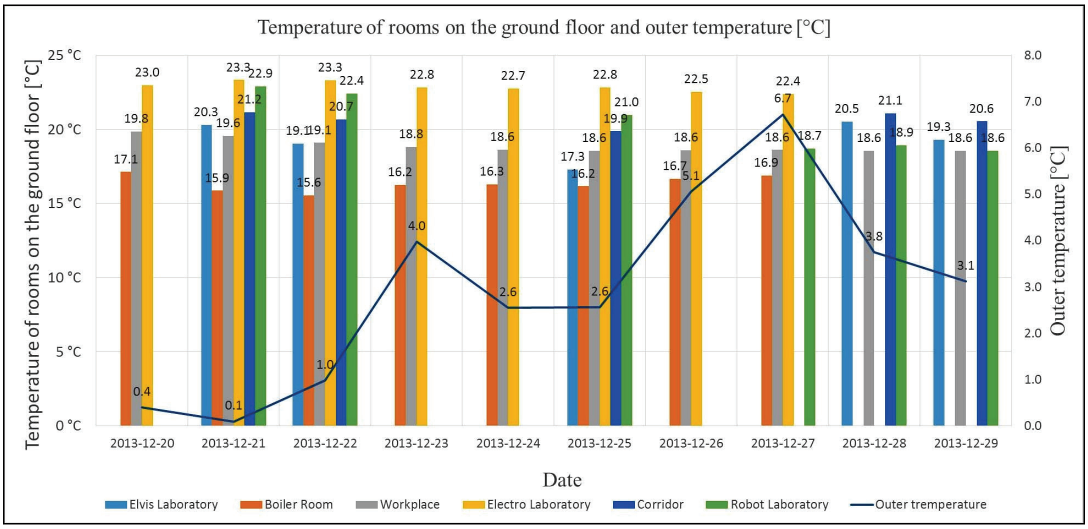

Fig. 11. Temperature of rooms on the ground floor and the outer temperature as a function of the date (one week)

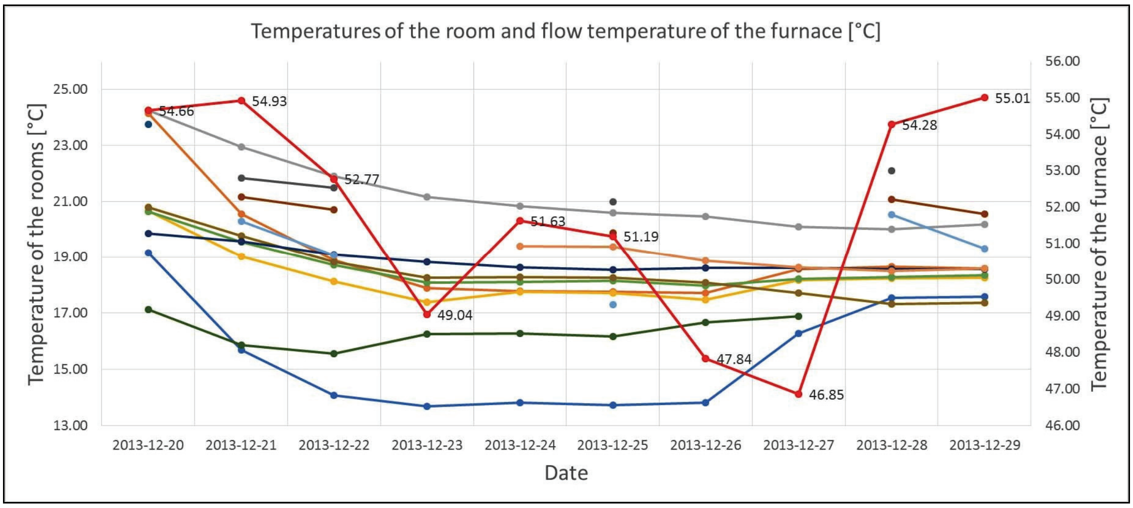

Fig. 12. Temperature of the rooms and the furnace flow temperature as a function of the date (one week)

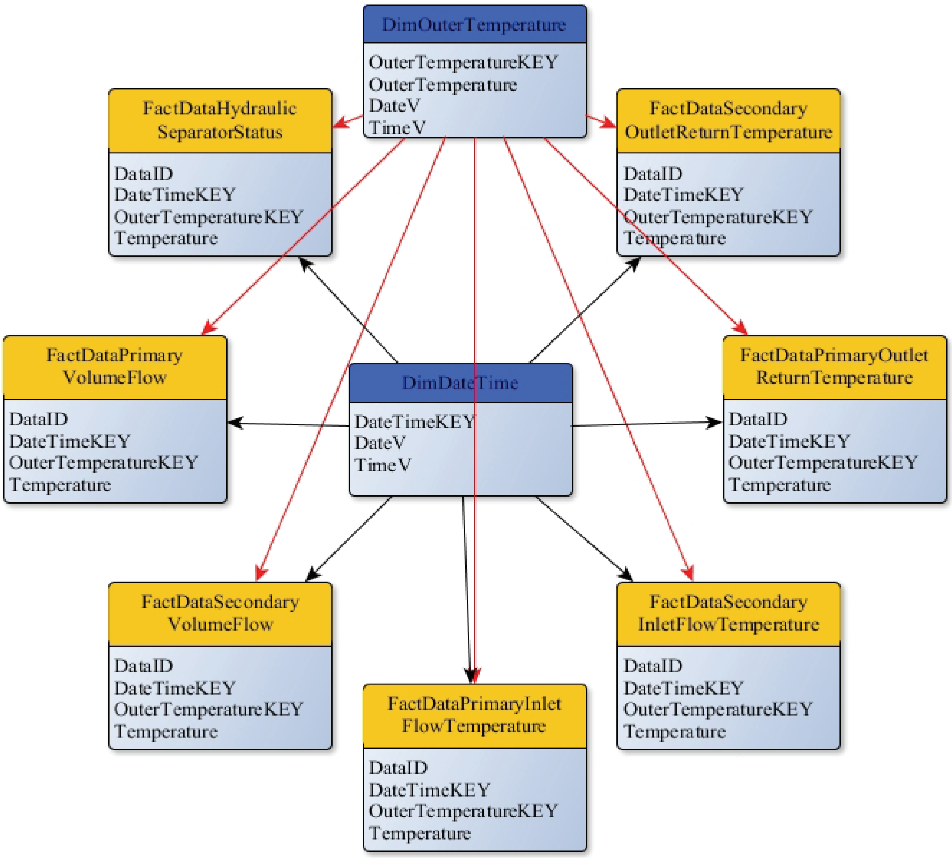

Fig. 13. Scheme of Cube 3

Table 1. Values from one day when the furnace was turned on

Date Outer temperature [C°]	State of the hydraulic separator	Primary inlet flow temperature [C°]	Primary outlet return temperature [C°]	Secondary inlet flow temperature [C°]	Secondary outlet return temperature [C°]
2013.12.25.					
0.0	2	55.27	20.03	46.06	21.4
0	2	47.42	20.03	45.19	21.4
3.0	2	50.36	19.99	41.98	21.28
4.0	2	49.42	20.00	41.29	21.33
5.0	2	48.05	20.03	42.62	21.4
6.0	2	39.92	20.03	39.83	21.4

Implementation step: To realize the plans of Cube 3, we perform the same process as in the cases of Cube 1 and Cube 2, except that in the case of this cube, the state of the hydraulic separator is not a measured quantity; therefore, we must calculate it from the other measured physical quantities. In this cube, there are three types of data, which is provided by three different devices:

- Integrated Meteorological Station (VaisalaWX510): outer temperature,
- Building Management System(Schneider Andover Controls):
  - Temperature Sensor (Pt500): primary and secondary side flow and return temperature,
  - Heat Flow Meter (Superstatic 440): volume flow of the primary and secondary side.

Evaluation step: From the charts of Cube 3, we can obtain information about the operation of the hydraulic separator that was built in to the heating system of the research center.

Table 1, presents the values from one day when the furnace was turned on. Table 2 presents the values from one day when the furnace was turned off. Fig. 14 shows the properties of the furnace as a function of the outer temperature, and Fig. 15 shows the volume flow of the primary and the secondary side as a function of the date.

Table 2. Values from one day when the furnace was turned off

Date Outer temperature [C°]	State of the hydraulic separator	Primary inlet flow temperature [C°]	Primary outlet return temperature [C°]	Secondary inlet flow temperature [C°]	Secondary outlet return temperature [C°]
2013.12.22.					
0.0	2	53.65	21.09	44.81	4.01
0.1	2	55.65	20.99	45.09	0
0.2	2	55.69	20.99	45.13	0
0.3	2	55.70	20.99	45.16	0
0.5	2	55.69	20.99	45.19	0
0.6	2	54.17	20.80	44.27	11.05
0.7	2	54.74	20.88	44.58	6.31
0.8	2	54.27	20.99	45.05	0
1.0	2	53.20	20.70	43.96	16.58
1.1	2	52.43	20.60	43.90	22.1
1.2	2	52.88	20.60	43.38	22.1
1.3	2	52.66	20.60	43.24	22.1
1.4	2	52.87	20.60	43.27	22.1
1.5	2	52.90	20.58	43.20	22.08
1.6	2	51.95	20.52	42.59	22.04
1.7	2	53.02	20.54	43.22	22.05
1.8	2	52.91	20.55	43.15	22.06
1.9	2	44.93	20.51	37.91	22.02
2.0	2	48.47	20.42	40.42	21.95
2.2	2	51.83	20.42	42.41	21.95
2.3	2	51.84	20.42	42.37	21.95
2.4	2	51.78	20.42	42.30	21.95
2.5	2	51.53	20.42	42.17	21.95
2.6	2	50.45	20.42	41.85	21.95

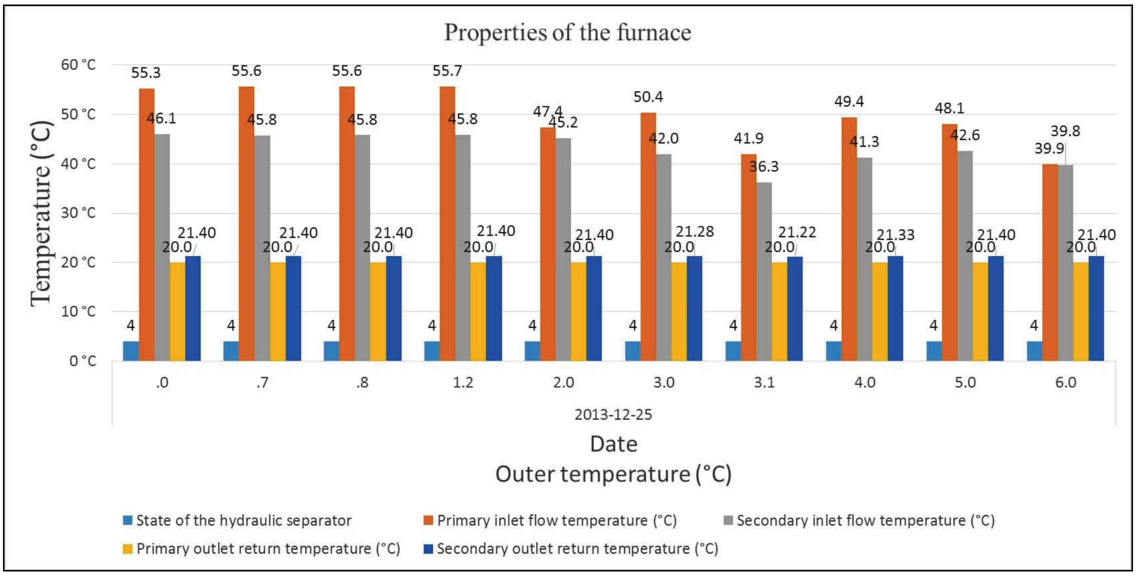

Fig. 14. Properties of the furnace as a function of the outer temperature

4. Conclusions

The aim of this study was to develop a new measurement methodology for building automation and energy management. The proposed methodology is based on OLAP (On-Line Analytical Processing) information processing technology, which enables the researchers to focus on the report making (visualization) of the energy consumption inside the building.

This paper presented an application of OLAP based analytics for building heating control. A heterogeneous measurement system was developed to collect heating data.

The measurement data were collected and sorted using OLAP technology, and various reports were presented. The reports indicate various aspects of energy consumption: temperatures and thermal zones.

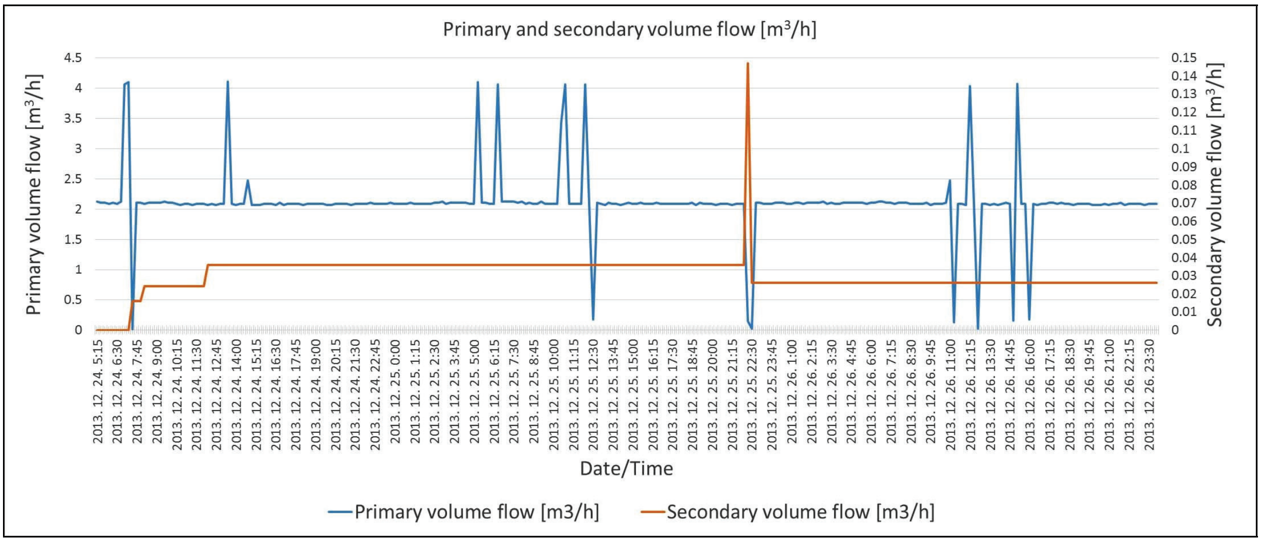

Fig. 15. Volume flow of the primary and the secondary side as a function of the date

Acknowledgments

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