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Rehabilitation of the Utility Spaces and Boiler Room - Monnaie Royal Theatre

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Abstract. The building used for workshops and administrative services at the Monnaie Royal Theatre in Brussels was subjected to complete renovation, in an effort to make the work conditions for the administrative and technical staff at the theatre more comfortable, and the building more conform to fire safety regulations and more energy efficient. The objective of energy efficiency was achieved by renovation of the infrastructure of installations : central heating and cooling, water supply, sewage and gas pipes, electrical (power and control of equipment's, fire detection, lighting, and BMS (Building Management System) integration. Two major areas were assigned as utility rooms (in the basement) and the boiler room (on the roof , 4th floor).

1 Introduction

The purpose of this paper is to show the stages of rehabilitation of a heating and cooling system for a monument building, the Royal Theater of Monnaie in Brussels, Belgium, as well as the problems encountered and the solutions found in order to ensure a low-energy efficient system energy. The energy efficiency concept provides a powerful and cost-effective framework for reducing greenhouse gas emissions, fuel consumption, and operating costs.

Control and monitoring are provided by the BMS (Building Management System) system, which intervenes in the modulation and adjustment of four high-volume condensing boilers: three 850 kw heating boilers, a 100 kw ACM boiler, a 300 kw chiller, two 195 kw dry-cooler units, all pumps, and auxiliary control devices.

Water quality is a problem addressed in the paper in light of the requirements of preserving existing installations and protecting newly installed boilers.

The execution work has two stages:

Stage I. - centralized administration of the technical spaces - the distribution of the theater

Stage II. - connection of the second building through a technical and passage tunnel, crossing under a pedestrian street - the connection of the central installations with the terminal equipment inside the theater (13 central air treatment units)

1.1 Data about the building complex

1.1.1 Location

The address is Place de la Monnaie – 1000 Bruxelles, for the theatre building and for the administrative and workshop building it is 23, rue Léopold , and 41 rue Fossé aux Loups (Figure 1, Figure 2, Figure 3).

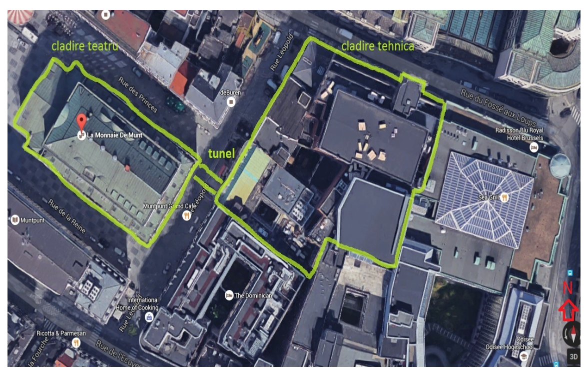

Fig. 1. Location of theatre and technical building

Fig. 2. Technical building façade at 23, rue Léopold

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Fig. 3. Technical building façade at 41 rue Fossé aux Loups

1.1.2 Landmark and Historical Place

The first Grand Theater was opened in 1700. In 1819, it was however demolished and rebuilt at the current location by the french architect Louis-Emmanuel Damesne on the site of the former ‘Herberge van Oistervant’ mint (‘La Monnaie’ is the French word for ‘coins’). It was considered one of the most beautiful theatres outside Italy. But by January 21, 1855, a serious fire reduced to ashes the entire building. There were only the four exterior walls. Fortunately, the Theatre of the Mint was quickly rebuilt. Joseph Poelaert took up both the design of the new building and the whole of the interior decoration. The new Theatre of the Mint reopened its doors in 1856. The major recent changes date back to 1985 when the stage tower was completely restored and the building, raised an additional volume.

In **1985** The Department of Public Works decided to renovate the building for technical, safety and aesthetic reasons. In **2000** there was the Inauguration of the New Monnaie workshops in the ancient Vanderborght buildings and the neo-classical building at no. 23 Leopold street just behind ‘La Monnaie’

There were two more renovation campaigns one between 2003-2007 and the other between 2015 – 2017 to better conform to the new fire safety regulations.

2 Utilities

2.1 Initial heating and cooling facilities

The base station in the basement had 30-year-old equipment, namely 2 boilers with atmospheric burner on gaseous and oil fuel, developing a 2 x 764kW thermal capacity, a 600 liter day tank for oil fuel, a hydraulic separator, two WILO circulation pumps on each boiler, a manifold of DN300 with 10 circuits and 3 expansion vessels of 500 litres each.

There was a secondary station in the basement with 2 boilers of 240 kW each, two expansion vessels (2 x 300 litres), a manifold collector, pumps, three - way valves for workshops and the administrative area. The radiator pipeline distribution was made up of steel joint with copper in an advanced state of decay.

The cooling system for administrative offices si made of direct evaporative cooler units. Domestic hot water preparation is centralized only for administrative area, with tank accumulation, circulation pumps, and a water softening station.

2.2 Design brief and contractual requirements

Design theme [1]:
- Dismantling of existing installations
- Heating for 3 administrative buildings, workshops and theater with 4th floor thermal plant on the roof and two basement substations for workshops and administrative offices
- Replacement of domestic hot water distribution, pumps, valves, inserting two new heat exchangers
- A new split type cooling system: made up of a chiller and two drycooler machines for the theater building
- A BMS for monitoring, control and adjustment
- Power supply and indoor gas distribution

2.3 Heating system

2.3.1 Heating system concept

- 3 x 850 kW HOVAL gas fired condensing boilers, of large water volume, support the overall heating system
- 1 x 100 kW HOVAL condensing boiler for domestic hot water production
- GRUNDFOS variable speed pumps
- PNEUMATEX pressure maintenance systems
- Gas exhaust chimney
- Ventilation intake for combustion process

Two solutions were discussed:

- Version 1 : gas condensing boilers without large water content, constant speed pumps, hydraulic pressure separator (BEP)
- Version 2: gas condensing boilers with large water content so that the minimum water flow required to be as low as zero, and variable speed pumps

The second solution was implemented due to the high energetical efficiency [1, 3-5,7,8].

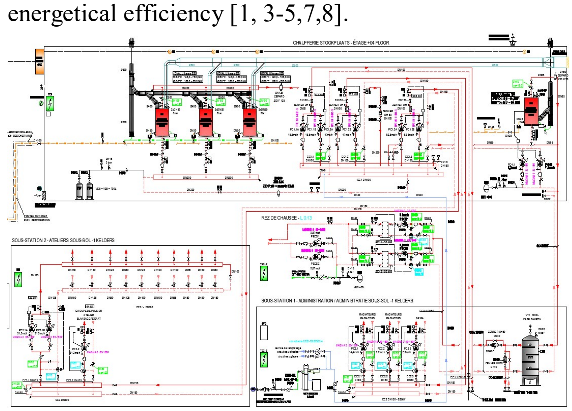

Fig. 4. Heating system general diagram

Fig. 5. Boiler plant new construction on terrace roof 4th floor: structure (left), finished (right)

2.3.2 Boiler room heat source

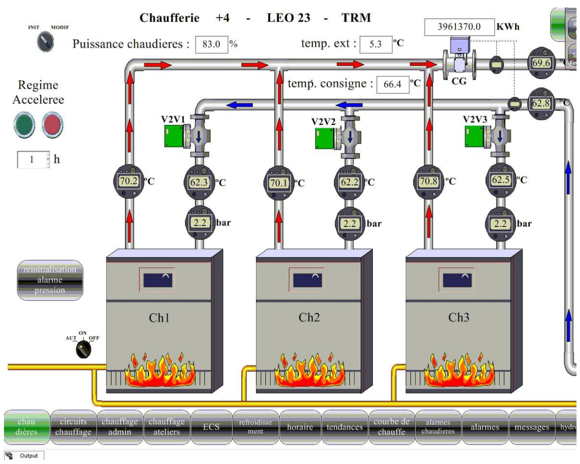

Fig. 5. Heating system diagram - boilers

The three boiler units work together in a “cascade system” because of multiple benefits:
- High turndown capability when only one boiler is required
- Flexibility with footprint allowing installation in irregular spaces
- Increased reliability with heat provided by several boilers
- Service and maintenance is simplified
- Smaller boilers can be maintained by a single engineer on site
- Simple spare part management
- Different rated outputs can be cascaded and control boilers by priority, delivering excellent efficiency; in the example shown in Figure 5 the capacity used is 83%.

From the BMS perspective, if you there is no circulation of water in the pipes , the flow switches on the boiler return pipe change color from black to a red impulse. If the boilers are in authorised mode, they change color from black to green, if one of them is in alarm, it becomes a red impulse.

The prescription of boiler input ratio can be changed by switching off the auto/manual switch and selecting manual input and enter the value in the numeric field.

2.3.3 Boiler room main manifolds

There are four main distribution circuits (Figure 6):

- CC1.1 – Theatre
- CC1.2 – Administrative offices
- CC1.3 – Workshops
- CC1.4 – Domestic hot water production

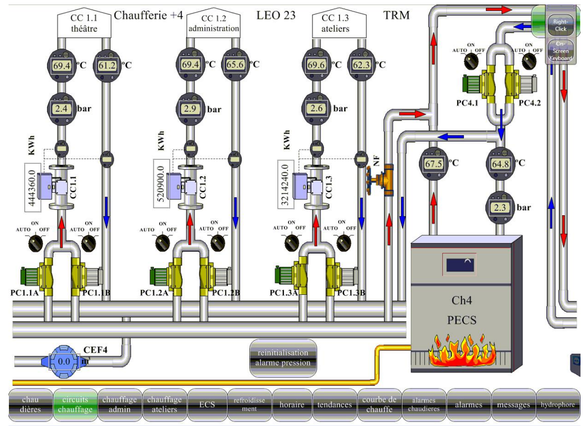

Fig. 6. Heating system diagram – main manifolds

Each circuit is equipped with two centrifugal pumps, a lead and a backup. The operation between the pumps is systematically altered to achieve equal wear using timed alternation - where the lead and backup pumps are switched by an automatic timer controlled by the BMS.

As in the case of the other boilers, for the fourth one can visualise on the BMS display the supply and return temperatures, the return pressure and water flow alarm. If the boiler is authorised, it changes colour from black to green, if there is an alarm, it becomes a red impulse. The prescription of boiler input ratio can be changed by switching off the auto/manual switch and selecting manual input and enter the value in the numeric field.

Every pump can be started / stopped with the aid of a three position selector (Auto – 0 – Manual). In automatic mode, the pumps alternate every 24 hrs. In manual mode, the pump can be stopped if the selector is in “0” position and started if the selector is in “manual” position. When the pump is stopped the BMS displays a black symbol, when the pump is in motion it becomes green, in case of an alarm, it becomes red.

2.3.4 Connection to the theatre building – CC1.1

In order to connect the heat source with the terminals in the theatre building, an underground tunnel was devised to house (Figure 7) :

- 2 heating DN100 distribution pipes (CC1.1),
- 2 cooling water DN125 pipes
- 2 domestic hot water DN65 pipes
- ventilation ducts

The construction of this tunnel was the final stage in the installation project. It was a cumbersome endeavour because the site contained archaeological artefacts and they had to be carefully moved and evalued, street access was closed off. The tunnel between the Monnaie theatre and its workshops measures sixteen metres, under

Leopold street. It is aimed at routing decors to the stage and allowing a direct and discreet access for the artists and the personnel.

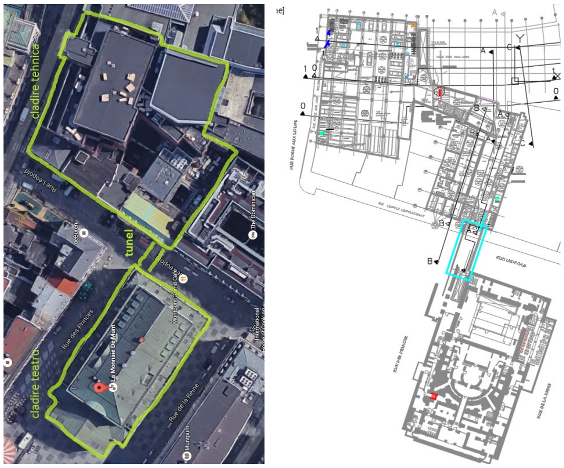

Fig. 7. Underground tunnel for CC1.1

Site works consist of the realization of the tunnel (unearthing, walls, soil and ceiling), and the installation of technical connections (ventilation, heating, electricity, water, Internet) between both buildings and reconstruction of the rail and waterways network after the creation of the tunnel.

2.3.5 Substation 1 – CC1.2

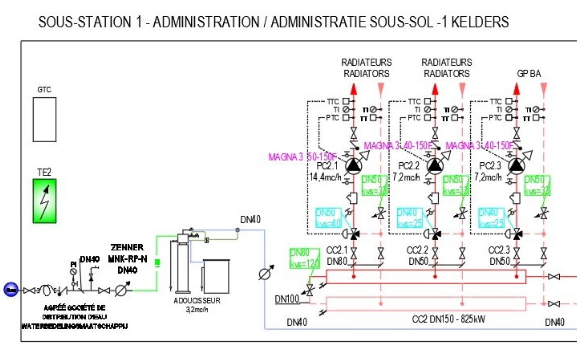

Fig. 8. Heating system diagram – substation 1

Substation 1 (Figure 8) is located in the basement in a separate room, and houses two manifolds supply/return DN 100 for heat circuit distribution to all the office radiators and to an air handling unit heater battery. Every circuit is equipped with a balancing valve, a pump, two temperature sensors placed on the supply and return pipes and a pressure sensor on supply. Every pump can be started / stopped with the aid of a three position selector (Auto - 0 – Manual). In Automatic mode, pumps work to an hourly program. The temperature value can be changed by passing the selector in manual position, and by typing the desired value.

2.3.6 Substation 2 – CC1.3

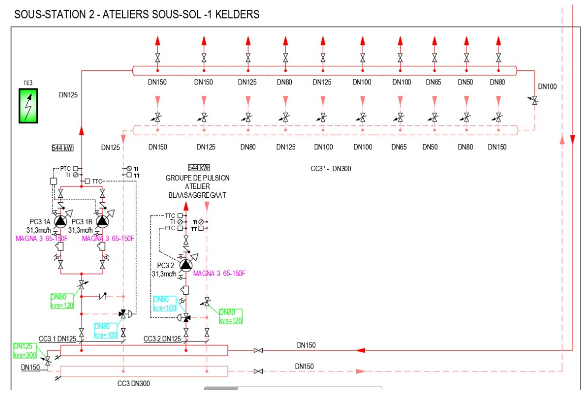

Fig. 9. Heating system diagram – substation 2

Substation 2 (Figure 9) is located in the basement in a separate room, and houses two manifolds supply/return DN 300 for heat circuit distribution to all the workshop radiators and to an air handling unit heater battery. Every circuit is equipped with a balancing valve, a pump, two temperature sensors placed on the supply and return pipes and a pressure sensor on supply. The supply circuit for radiators is equipped with two pumps alternating every 24 hrs. Every pump can be started / stopped with the aid of a three position selector (Auto - 0 – Manual). The temperature value can be changed by passing the selector in manual position, and by typing the desired value.

2.3.7 Hot water production station – CC1.4

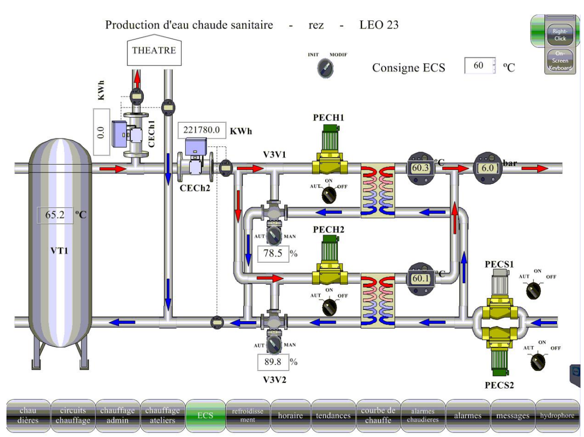

Fig. 10. Heating system diagram – domestic hot water

The reservoir VT1 (Figure 10) with a 1000 litre capacity is connected to the main manifold (the secondary source) and the smaller 100 kW condensing boiler as a primary source of heated water. It is located in the basement where the original reservoir was, so as not to overcrowd the new boiler room on the 4th floor. The temperature in the reservoir must be at least 60 °C. In the example above in fig. 7 it is 65.2 °C. This is important because it inhibits Legionella and other bacteria to develop. Both thermostatic regulating valves on the primary circuit of the heat exchanger ensure a temperature of 45 °C on the secondary side of the exchanger. Between one and three o'clock at night, the “Légionnelle function” is active, and the temperature of water goes up to 65 ºC.

The hot water station composed of 2 plate heat exchangers, 2 primary pumps, 2 recirculating pumps, valves, 3-way thermo static valves, expansion vessels and accesories is located on the ground floor in a separate room, closer to where the offices are. Every pump can be started / stopped with the aid of a three position selector (Auto - 0 – Manual). In Automatic mode, primary pumps work to an hourly program. The secondary recirculating pumps also work on an hourly schedule but alternate every 24 hrs. The temperature value can be changed by passing the selector in manual position, and by typing the desired value.

2.4 The problem of water treatment

In a complex work in which a new distribution system and old terminals must be connected, the is a problem of circulation and treatment of heat-carrying agent.

We have the following premises:
- design requirements: the design theme required the washing of the old heating system with trisodium phosphate (Na_3PO_4) to ensure an anticorrosion protection film as well as pH and hardness and conductivity measurement
- boiler supplier: requires very low conductivity -thus demineralization of water throughout the system, in the new and the old plant in order not to affect the stainless steel / aluminum of internal boiler exchanger

Volume de remplissage maximal basé sur la norme VDI 2035

	Dureté totale de l’eau de remplissage jusqu’à ...							
[mol/m³] [1]	<0,1	0,5	1	1,5	2	2,5	3	>3,0
f°H	<1	5	10	15	20	25	30	>30
d°H	<0,56	2,8	5,6	8,4	11,2	14,0	16,8	>16,8
e°H	<0,71	3,6	7,1	10,7	14,2	17,8	21,3	>21,3
~mg/l	<10	50,0	100,0	150,0	200,0	250,0	300,0	>300
Conductance [2]	<20	100,0	200,0	300,0	400,0	500,0	600,0	>600
Dimension de chaudière individuelle	**volume de remplissage maximal sans démineralisation**							
de 50 à 200 kW	PAS D‘EXI		50 l/kW	20 l/kW	20 l/kW			
de 200 à 600 kW	GEN-	50 l/kW	50 l/kW	20 l/kW			toujours déminéraliser	
sur 600 kW	CE							

[1] Somme des alcalis terreux
[2] Si la conductance en µS/cm dépasse la valeur du tableau, une analyse de l’eau s’impose.

Fig. 11. Water hardness in relation to boiler capacity

Thus there is a contradiction between the design requirements to protect the anticorrosion facility with a trisodium phosphate film (Na_3PO_4), i.e. adding salts in water and the supplier's requirements to have a demineralised thermal agent.

In order to evaluate the actual situation as well as possible and 4 samples were collected for analysis from 4 different locations:
- softened water station,
- water from the central heating system
- substation 1- substation 2

Analyses were performed for conductivity, PH and salts:

No.	Analysis	UM	H2O after treatment	H2O Boiler plant	H2O CC1.2	H2O CC1.3
1	Conductivity	µS/cm	801	1030	1038	1077
2	pH	unit. pH	7,65/8,00/8,44	6,78/7,54/7,77	7,50/8,05/8,18	9,38/9,89/9,68
3	Na^+	mg/L	180±5	275±5	265±5	250±5
4	K^+	mg/L	0,5±0,2	1,0±0,2	1,0±0,2	1,0±0,2
5	Ca^{2+}	mg/L	19±1	<0,2	<0,2	<0,2
6	Mg^{2+}	mg/L	2,6±0,2	<0,2	<0,2	<0,2
7	PO_4^{3-}	mg/L	3±5	31±5	31±5	30±5

Observations:

1. Conductivity is determined by the presence of salts, namely the presence of sodium salts, i.e. NaCl (sodium chloride) used to regenerate the ion exchanger (cationite).

2. The softening system does not change the conductivity of the treated water because there is only a substitution of calcium ions with sodium ions on the ion exchanger, therefore the conductivity cannot fall below 800 µS / cm unless another water purification stage, or a reverse osmosis plant, were to be installed after the softening plant. In this case the conductivity may drop below 80 ... 90 µS / cm, and if a two-stage installation is used, the conductivity may drop below 10 µS / cm. This would not be efficient because the water in the new plant would mix with the water in the old plant that could never be brought to the required parameters because all components either pipes or equipment had accumulations of impurities over 30 years. Installation and operating costs would increase considerably and would be repetitive. Adjacent to the above solution, the intercalation of a heat exchanger in the boiler room between the boilers and the main distribution, with additional extra costs, was discussed, but then the efficiency of the condensing system would be lost.

3. The presence of phosphates in the circuit is determined by traces of trisodium phosphate (Na_3PO_4), used in the flushing stage. The presence of phosphate ions is beneficial as it results in the formation of a protective layer of iron phosphates on the inner surface of the pipes and heating elements, this layer having a protective role against corrosion.

Conclusions:

Rehabilitation of monument buildings implies both consolidation, modernization, replacement, but also energy efficiency [9], [10]. All together are a difficult task due to the restrictions resulting from the building typology. This problem is present and as presented in the paper it is a very fine balance between the choice of the technical solution, the equipments, the routes and the connection between the circulation of the thermal agents from different areas of the installation.

2.5 Cooling system

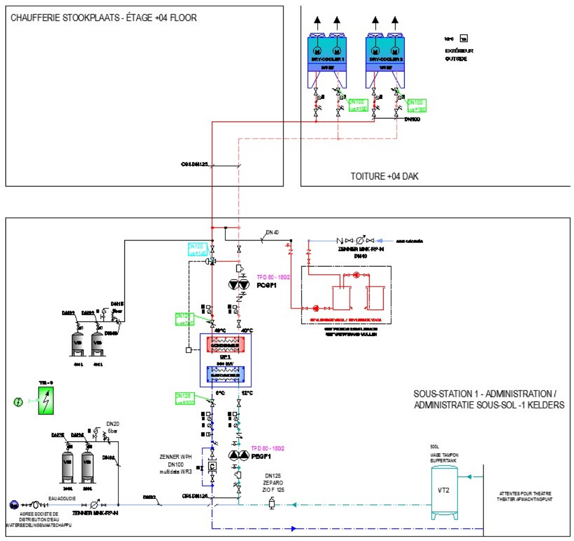

Fig. 12. Cooling system general diagram

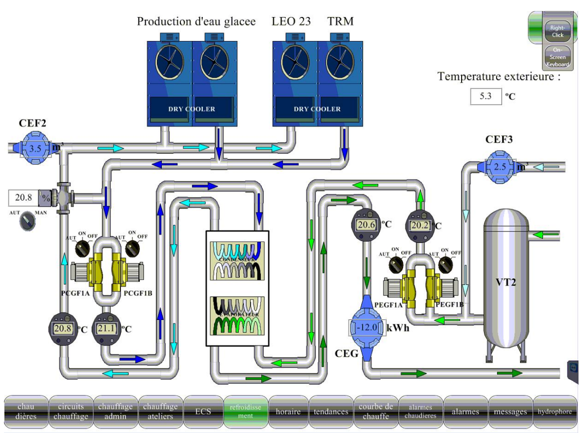

Fig. 13. Cooling system BMS diagram

The cooling system comprises :
- 2 x 195 kW “silent” cooling tower units located on the roof on the 4th floor
- chiller with a cooling capacity of 300kw
- 2 expansion vessels with variable pressure membranes on the distribution to dry coolers
- 2 expansion vessels with variable pressure diaphragm on chiller distribution
- variable speed twin (double) pump
- 500 liter buffer tank

The BMS display controls the pumps of the evaporator and condenser and to see the temperatures of both tower and chiller circuits. The BMS link can also start or close two dry coolers together. A switchflow sets off an alarm if there is no circulation of water in the evaporator circuit and the pumps are working. Every pump can be started / stopped with the aid of a three position selector (Auto - 0 – Manual). The temperature value can be changed by passing the selector in manual position, and by typing the desired value.

2.7 Buiding management system

The automation system controls the heating and cooling systems of 4th floor and basement with four electrical panels TE1, TE2, TE2P e TE3 containing also power and automation circuits and an industrial PC which also serves as operator interface. Automation equipment is modular, with the possibility of extension by adding more modules local or remote.

All panels are equipped with ILC 151 Phoenix Contact control units and modules of inputs / outputs working in stand-alone mode. However all the controllers are connected to a ModBus IP bus that allows the exchange of data between them and / or the industrial PC.

TE1 is located on the 4th floor in the boiler room and manages 3 boilers, heating circuits, the boiler for domestic hot water circuit, 4 groups of double pumps. The 3 large boilers have their own automation panels work in the master-slave system with the first boiler as the master and the other as slave. The capacity of the boiler is controlled by BMS using an analog input 0 - 10V reacting to the outside temperature. The fourth boiler is used for producing hot water and has a temperature of 65 °C limitation in the BMS. TE1 also monitors the gas detection panel: in case of gas alarm, the fire alarm control panel cuts the power to the electrical panel.

TE2 is located in the basement and manages the heating for the administration offices: two circuits for radiators, the circuit for heat batteryof the air handling unit and domestic hot water circuits, and the circuits for drycooler and chiller pump groups.

TE2P is located on the ground floor and manages the hot water service circuits. The two 3-way valves which regulate the water temperature are integrated in the primary circuit of the heat exchanger and the temperature sensors are located in the secondary circuit.

TE3 is located in the basement and manages the radiator heating of the workshops and the ventilation unit heating battery.

All circuits for temperature control use immersion temperature sensors and 3-way valves. The industrial PC communicates on a bus Ethernet with the controllers of the 4 panels and reads the variables which portray the image of the process in real time.

All trials are shown on six pages among which we can navigate using page indicators.

3 Energy consumption

The graph below shows the registered thermal energy consumption related to the heating system during a period of 30 days (from 15.12.2018 – 14.01.2019). Heat meters on general and secondary branches of installation provide valuable data needed for billing and optimisation of the network performance. The flow is measured using bi-directional ultrasound based on the transit time method, with proven long-term stability and accuracy. All circuits for calculating and measuring are collected on a single board, providing a high level of measuring.

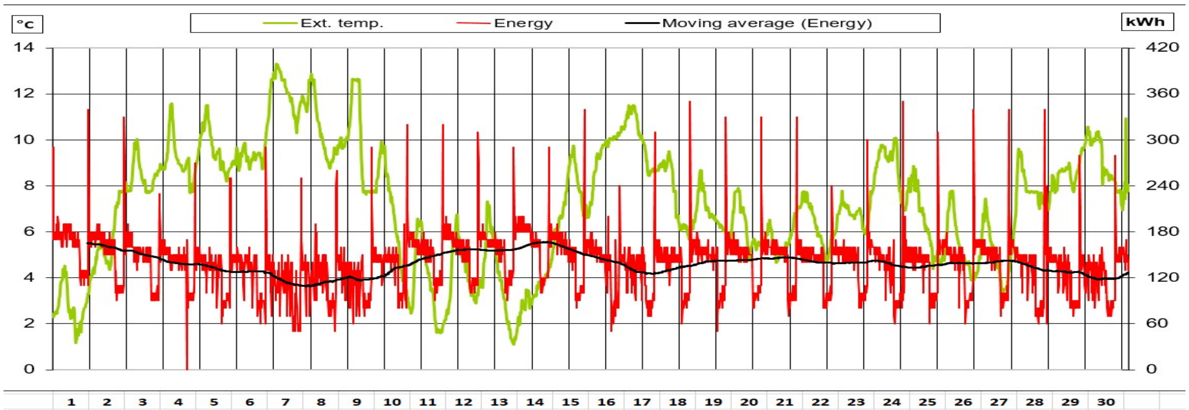

Fig. 14. Thermal energy consumption graph

The green graph is the variation of outside temperature. The red graph is the variation of thermal energy consumption. The high spikes are at the beginning of each day are the energy boosts when the boilers are turned on. Then the graph is pretty stable. The black graph is the calculated moving average for the thirty days.

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