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, to conform to fire safety regulations and be more energy efficient. This was achieved by renovation of the infrastructure of installations: central heating and cooling, water supply, and gas pipes, electrical power and control, fire detection, lighting and BMS integration.

Introduction

The concept shows 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. 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 (for 13 central air treatment units).

Data about the building complex

Location and landmark

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**).

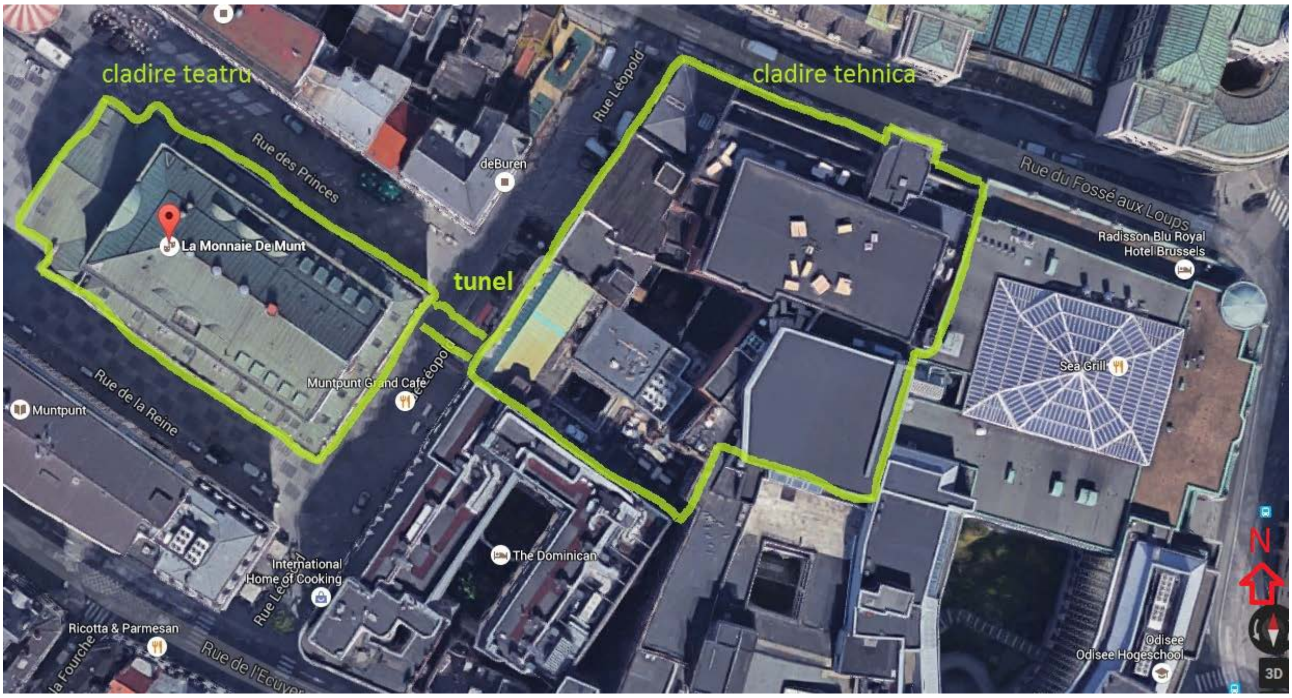

Figure 1. Location of theatre and technical building.

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

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

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. The new Theatre of the Mint reopened its doors in 1856.

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 campains one between 2003-2007 and the other between 2015 – 2017 to better conform to the new fire safety regulations.

Utilities

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 764 kW 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.

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
- Water softening station
- 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

Heating system

- 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].

Boiler room heat source

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 4** the capacity used is 83%.

From the BMS perspective, if 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.

Boiler room main manifolds
There are four main distribution circuits (**Figure 5**):

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

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, the BMS display works the same way.

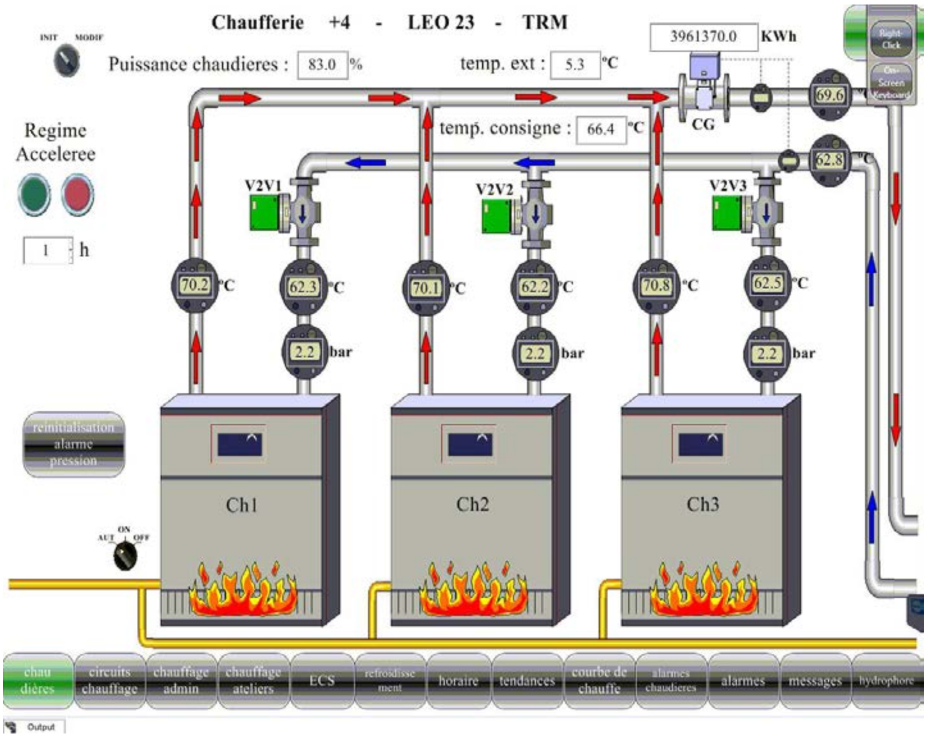

Figure 4. Heating system diagram – boilers.

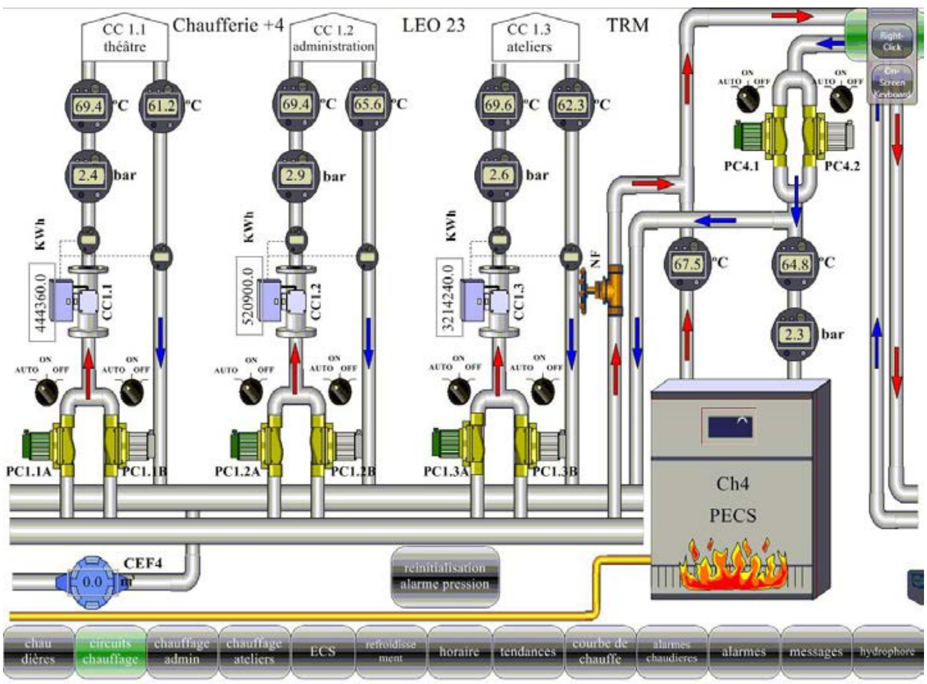

Figure 5. Heating system diagram – main manifolds.

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 6**):

- 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.

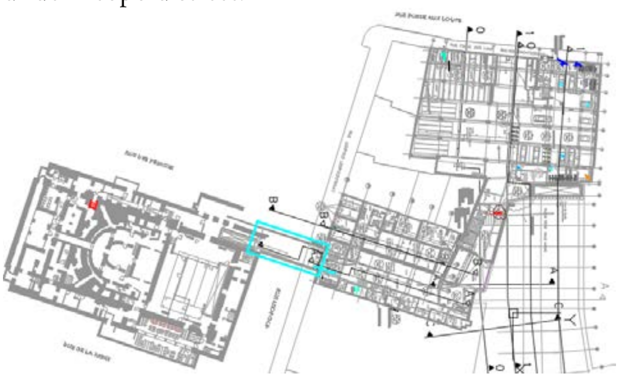

Figure 6. Underground tunnel for CC1.1.

Site works consist 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.

Administrative offices Substation 1 – CC1.2

Substation 1 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, and the water softening station.

Workshops Substation 2 – CC1.3

Substation 2 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.

Hot water production station – CC1.4

The reservoir VT1 (**Figure 7**) 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. The temperature in the reservoir must be at least 60°C. This inhibits

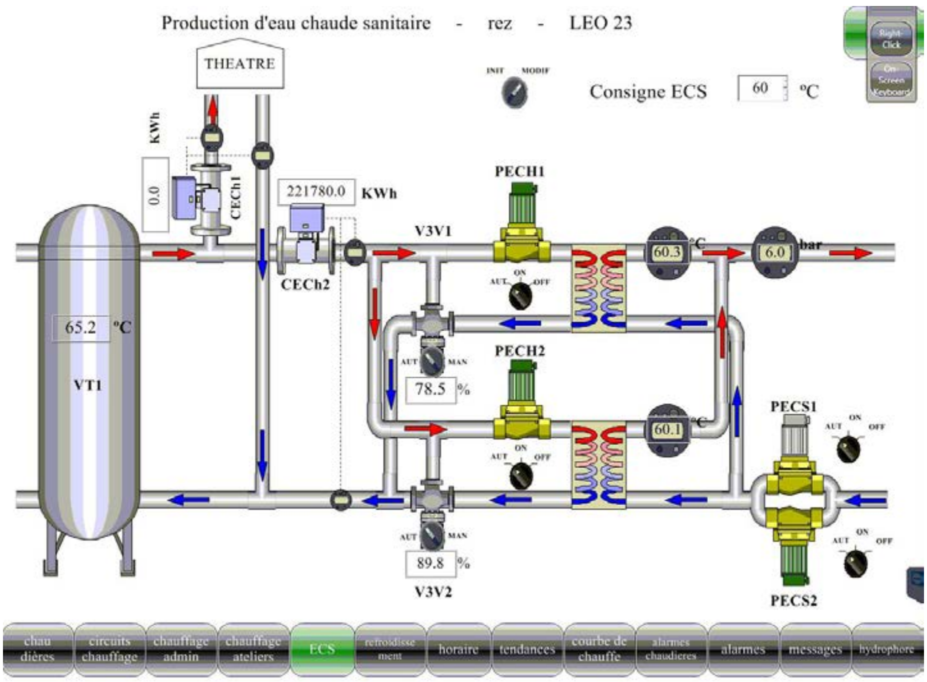

Figure 7. Heating system diagram – domestic hot water.

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°C.

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 accessories.

The problem of water treatment

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

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 according to **VDI 2035**.

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

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

Cooling system

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 300 kW
- 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.

Table 1. Analyses were performed for conductivity, PH and salts.

No.	Analysis	UM	H_2O after treatment	H_2O Boiler plant	H_2O CC1.2	H_2O 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

Energy consumption

Figure 9 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.

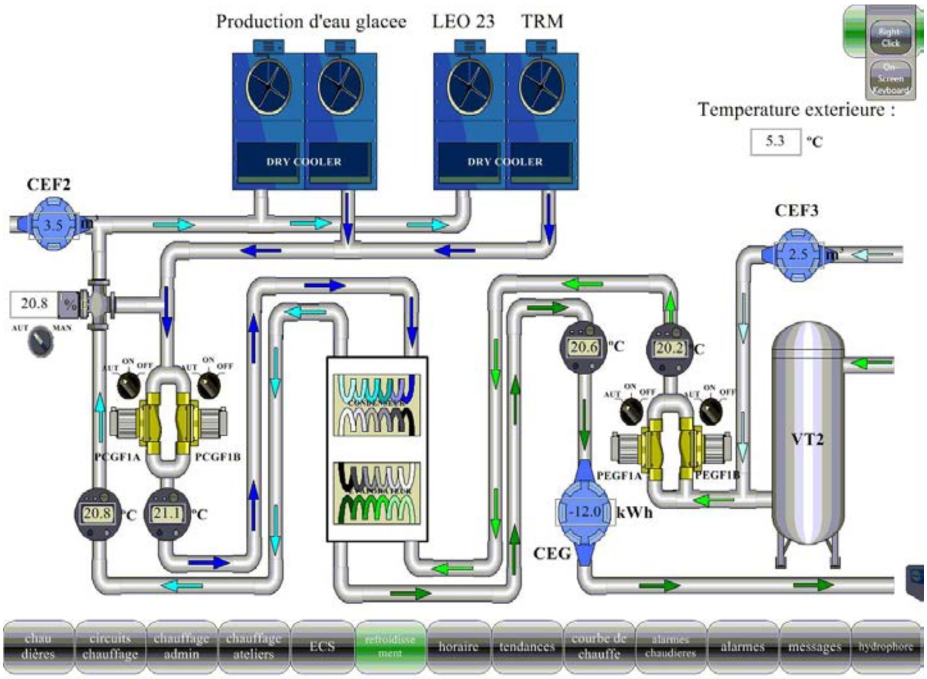

Figure 8. Cooling system diagram.

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.

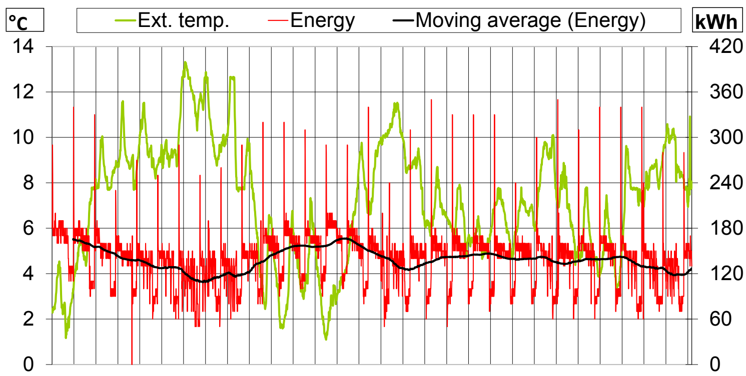

Figure 9. Thermal energy consumption graph.

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 equipment, the routes and the connection between the circulation of the thermal agents from different areas of the installation. ■

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