ENERGY EFFICIENT HVAC SYSTEM FOR THE REGISTERED ARCHITECTURAL CULTURAL HERITAGE BUILDING

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Abstract: *The Rijeka's national theatre Ivan pl. Zajc, built in 1885 in the neo-renaissance and partially in the late baroque style, is registered as a cultural heritage monument. During the renovation period in 1970/82 the new HVAC system was not completed. During that period it was provisionally connected to the boiler-station of the nearby factory. The complete HVAC system design was started in 2003 and the construction of the new cooling station was placed in the ex-factory next to the boiler station. The design includes the cooling system powered by natural gas. Absorption cooling units function all year round, connected by the existing pipeline. The applied system of gas absorption devices represents a simple, modern, energy-efficient technical solution, financially supported by the national Environmental Protection and Energy Efficiency Fund. The newly constructed cube, with cooling tower built in place of the old oil reservoir, is a simple architectonic solution, appropriate for the future new urban area.*

Key words: theatre building, architectural cultural heritage, energy efficiency, HVAC system, air-conditioning, absorption cooling unit

1. INTRODUCTION

The building of the Croatian national theatre *Ivan p. Zajc* in Rijeka was built in 1885 as the first of the three European theatres designed by the renowned team of two Austrian architects, F. Fellner and H. G. Helmer. The second building was the Zagreb theatre and the third one was the Vienna theatre. The Rijeka building was built in the neo-renaissance style and the interiors in the late baroque style were decorated by G. Klimt and others and can accommodate about 677 visitors. The system for heating and ventilation had been solved at the time with the most innovative solutions for the period. It is worth mentioning that at the opening ceremony, the building had an autonomous system of electrical lighting, which, unfortunately, due to a short circuit, spoiled the ceremony of this event. The system of the electrical supply was powered by water. It is well known that the right bank of Rječina River has many underground water sources so that even in that period this natural resource of renewable energy was used. Today, after 125 years, we can say that the theatre building belongs to the Rijeka's rich history along with a great number of excellent performances where world-renowned musicians, composers and artists performed: Sarah Bernhardt, Giacomo Puccini, Enrico Caruso, Pietro Mascagni, Beniamino Gigli, Arturo Toscanini, Eleonora Duse and many others. In the theatre, a few politicians and presidents were seen and liked to deliver their speeches there: Gabriele D'Annunzio, Mussolini, Tito and Tuđman [1].

Figure 1: Photography of the theatre building in Rijeka/Croatia [2]

During the seventies the theatre building was closed for 12 years due to renovation and restoration of the interiors, facade and art pieces. In that period several structural details were solved [3]; the building lies on the embanked part of the town – at less than one meter deep are underground waters (sea water). The project solution of the engineering thermo-technical system included the system of insuring higher microclimatic conditions for the pleasant stay of visitors as well as actors and technical staff. Special care was given to the auditorium and to the stage. The previous solutions of heating and ventilation system with the new project were raised to a different comfort level with HVAC. Unfortunately, due to restricted financial resources for the renovation and reconstruction of the building, at that period the system of air-conditioning was not completed with the cooling of the building. Originally, the boiler room, see Figure 2, in the theatre building was on the ground level and it was not suitable for the location of heating and cooling devices. This space does not meet the minimal conditions for the location of a built-in chimney.

2. PRECONDITIONS FOR APPLICATION OF ACU ON THE THEATRE BUILDING

The project solution of the new heating, ventilating and air-conditioning (HVAC) system was reduced by minimal intervention or, better said, nonexistent building interventions on a building which is a registered cultural heritage monument. These new solutions, after the first projects which were advanced for the period, were not adequate from today's technical point of view. Primarily, it refers to the adequate space for the building of the main energy equipment and to the openings on the building to intake and to expel the air for ventilation. Today we have an additional condition: the system must also be energy efficient and it is clear that it is very difficult to obtain this stipulation in such architectonically complex buildings. It is very good

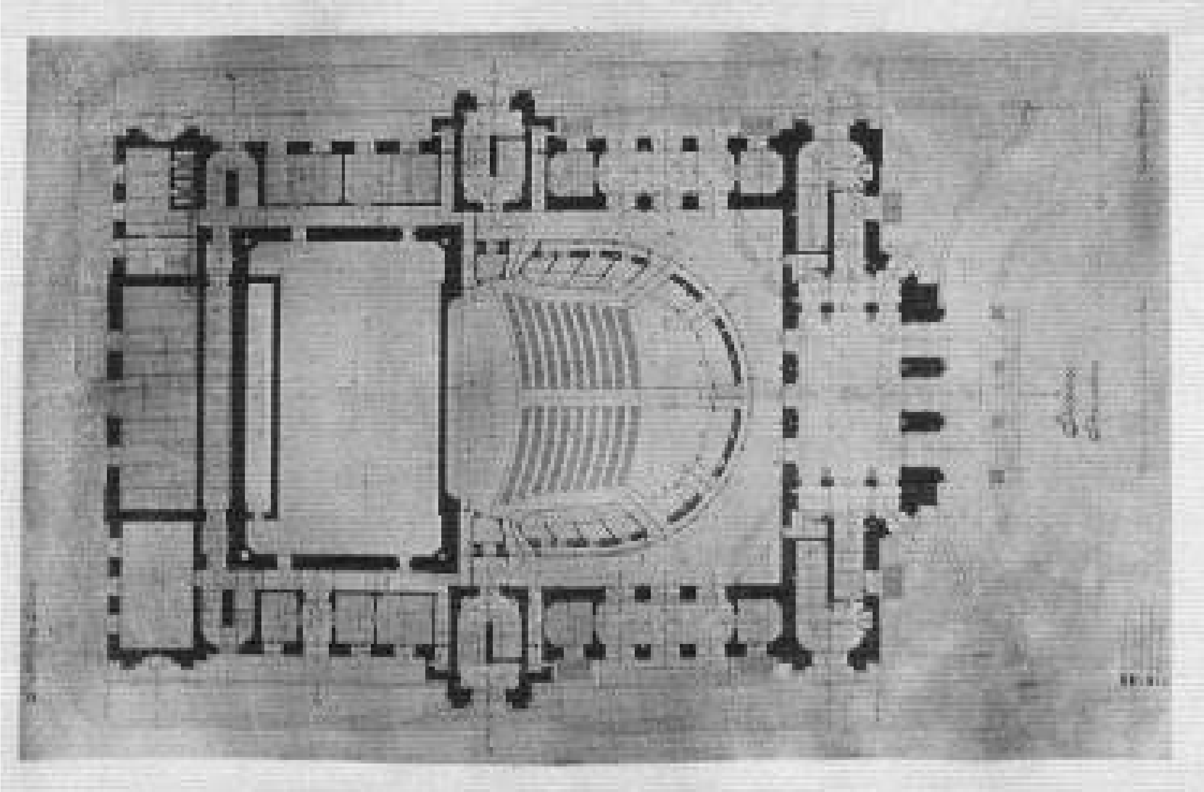

Figure 2: Lay out of the theatre building in Rijeka/Croatia [1]

that the project, done by professor Milan Viličić from the Faculty of Mechanical Engineering and Naval Architecture of the University of Zagreb during the seventies of the last century, has foreseen a very contemporary technical solution which at the time was only partially constructed. It included all the necessities for the performance of the HVAC system of the building. Even in that period it was clear that the heating and cooling supply must be done outside the building and the provisional solution was to connect the building to the boiler station of the nearby factory *Istravino*. The heat pipeline is 250 m long and it crosses the river's canal *Mrtvi kanal.*

After the introduction of natural gas in 2007, several projects have been completed in the Rijeka area with absorption cooling units (ACU) for the HVAC of public buildings: the Cultural centre, the building of Faculty of Civil Engineering and the Science Park, all at the new campus of the University of Rijeka. Similar systems have been adopted for buildings owned by the Municipality of Rijeka: the Croatian Cultural Centre in Sušak, the Museum of Modern and Contemporary Art and the HVAC system of the building of the Croatian national theatre, *Ivan pl. Zajc,* in Rijeka. These systems are supplied with two-step absorption cooling units. The working element in the unit is the mixture of lithium bromide ana water (LiBr-H_20). Such compounds during cooling reject waste heat through the cooling tower into the open space [4/11].

The design of the complete HVAC system of the theatre building was started in 2003. Four possibilities to house the water chiller-room were considered: next to the existing energy room in the theatre, in two possible locations in the block of houses south of the theatre, in the underground cooling station in the park in front of the theatre, and the one in the area of the *Delta* on the east side of the river canal where the previous connection to the heat pipeline already existed. After analysing the potential locations, it was decided that it should be in the area of the *Delta* and that it should be the permanent solution for the energy supply of the theatre building. Because of the complexity of the *status quo* and real dynamic of the design execution, the design was divided into four phases: reconstruction of the natural gas supply system in the *Delta* area, reconstruction of the boiler-station of the old *Istravino* factory, adjustments and reconstruction of the existing thermo technical - HVAC system in the theatre building and construction of the new cooling station next to the boiler station.

Figure 3: Rijeka City plan – The estuary and Delta area

3. SURVEY OF ADOPTED HVAC SYSTEM

There are three necessary conditions for the heating and cooling of the theatre building: Heating capacity is 1050 kW, taking into consideration that the morning charges of the building (rehearsals, regular staff) compared to the maximal charge during the evening performances, and heating of the auditorium and the stage is 40 to 60%. Cooling capacity is 700 kW. According to thermal needs, the two-step absorption cooling unit with LiBr-H_2O (product York, model YMPC-F 10EX) has been chosen.

Table 1: Capacity of absorption cooling unites

	Cooling capacity kW	Heating capacity kW	Rejected heat kW	Fuel
ACU	2×352	2×286	2×637	Natural gas

Table 2: Technical characteristics of two-step absorption cooling unit with LiBr-H_2O (York YMPC-F 10EX)

Model	YMPC-F 10EX	
Working regime	Cooling	Heating
Capacity, kW	352	286
Heat rejection, kW	638	/
Temperature outlet/inlet, °C	7/12,5	60/55
Max inlet temperature, °C	12	60
Max outlet temperature, °C	18	/
Min inlet temperature, °C	7	/
Min outlet temperature, °C	10	40
Cooling water temperature, °C	29-32/35-38	/
Power supply 400 V, 50 Hz, kW	4,03	1,78
Fuel	Natural gas (H_d = 34,43 MJ/m^3)	
Nominal heating capacity, kW	310	318
COP	1,134	0,897
Range of capacity	30-100%	
Annual working hours	1500-2000	

The absorption cooling devices with continuous power perform with a binary mixture of lithium bromide and water (LiBr-H_2O). In this unit, water is the cooling medium and

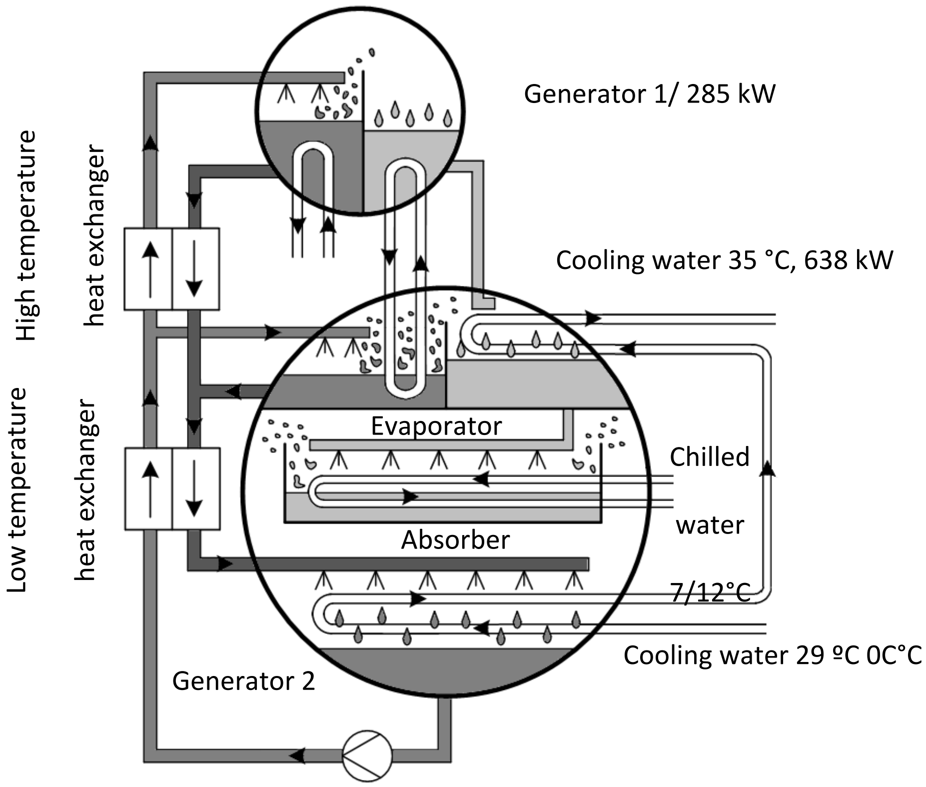

Figure 4: Two-step absorption cooling unit with LiBr-H_2O (York YMPC-F 10EX)

lithium bromide is the absorbent. ACU with LiBr-H_2O is constructed as two-step absorption cooling unit. In the two-step ACU with LiBr-H_2O, heat of vapour condensation from the first stage is used for additional evaporation of the water in the generator during the second stage.

High and low temperature heat exchangers use the temperature of rich (saturated) solutions, which are exhausted from the generators towards the absorber for the preheating of weak (low saturated) solutions which are oriented towards the generators. In such a way, the two-step ACU is almost 70% more efficient compared to the one-step ACU. The efficiency of the working conditions of the two-step ACU is about COP_h = 1,0 to 1,20, where the specific heat consumption in the generator is about 0,83 to 1,0 kWh/kWh. In the absorber and in the cold water condensator some 1,83 to 2,0kWh/kWh is carried away. The necessary flow of cooling water from the cooling tower is 180 to 270 kg/h/kW_0. The absorbed electrical energy in the one-step ACU is 0,002 to 0,008 kWe/kW. The two-step ACU-s are differentiated as parallel, serial and reverse, depending on the flow regime of solutions.

In the ACU with serial flow, the weak solution from the absorber passes through the LT and HT heat exchangers, after which it enters the generator of the 1st stage. At the ACU with parallel flow, the weak solution (from Figure 2) is divided and is directed into the HT heat exchanger of the 2nd stage after the LT heat exchanger. At the ACU with reverse flow the weak solution is preheated.

The ACU device, apart from being able to cool, can be designed to heat too. In the regime of heating, by opening of the valve between the generator of the 1st stage and the evaporator, the steam evades the condenser and goes directly into the evaporator where it heats water. Lithium bromide absorbs the water steam after which the wear solution is conducted into the generator and the cycle is repeated. The hot water in the ACU can be regulated for heating purposes up to 60 (80) °C. In the ACU device, while under the parallel regime of heating and cooling, the process is equivalent to the regime of cooling (Figure 2). In that case, the only exception is that one part of the steam from the 1st step generator is conducted before reaching the generator of the 2nd stage for heating necessities. In that case, the cooling capacity is diminished.

The ACU can be used as a heating device when it works as conventional boiler. It has primarily been used for cooling purposes and the recommended annual working hours are 2000. The waste heat of the ACU is conducted into the surrounding cooling towers. The temperature of the cooling water at the entrance of the cooling tower is 35 °C and at the exit it is 29 °C. One part of the waste heat of the CHW is possible to use rationally, i.e. for the preheating of the CHW. In that case, the condenser and the absorber of the ACU have to be connected to the container of the CHW and to the cooling tower. Depending on the needs of the building to be cooled, it can mostly be used for the preheating of the CHW. In the case of the complete cooling charge of a building of 700 kW, some 1 280 kW of waste water is produced and must be conducted to the ACU. In the future, this heat could be used to heat the existing building of the ex-factory when a new purpose would be found for it. The technical solution to use waste heat is rather easy to perform.

Figure 5: The cooling station

Figure 6: Smart architectonic solution of cooling tower next to the ex-factory [12]

Figure 7: The cooling tower in front of theatre

The absorption cooling devices, which are built into the cooling station, represent a simple technical solution [13, 14]. The primary energy is natural gas. The conventional hot water boiler station is exchanged for an adequate system and the conventional cooling station for a water chiller. It is a rather simple technical solution! The precondition of the realisation of this project was the reconstruction of the gas emergent of the existing boiler room of the ex-factory building. The result of this technical exercise is the realisation of the energy efficient HVAC system and reduction of the emission of toxic gases.

4. CONCLUSION

The design includes the cooling system by use of natural gas. An ACU and natural gas absorption plant have been built which in the summer period functions as cooling devices. In the wintertime these devices are used as a heating boiler station. The thermo-energetic connection with the theatre building is the existing pipeline system which is now a reversible energy connection in function all year around. The solution accepted has considered all the parameters of the protection of cultural heritage and the system of absorption cooling devices in the *Delta* area represents a simple, modern, and efficient technical solution. The newly built cube, in which the cooling tower is placed in place of the old oil reservoir, is a simple architectonic solution which is well adapted to the future of the new urban area. The applied system of gas absorption devices represents a simple, modern, energy efficient technical solution. The project has been financially supported by the *Croatian Environmental Protection and Energy Efficiency Fund.*

NOMENCLATURE

ACU	absorption cooling unit
COP	coefficient of performance
HT	high temperature
HVAC	heating, ventilating and air/conditioning system
LT	low temperature
CHW	consumption hot water

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ENERGETSKI UČINKOVIT TERMOTEHNIČKI SUSTAV ZA ZGRADU REGISTRIRANOG ARHITEKTONSKOG KULTURNOG NASLJEĐA

Sažetak: *Hrvatsko narodno kazalište Ivana pl. Zajca izgrađeno je 1885. u neorenesansnom i djelimično u baroknom stilu, registrirani je spomenik arhitektonske kulturne baštine. Tijekom obnove kazališta 1970./82. termotehnički sustav za klimatizaciju zgrade nije zaokružen, već je riješen na razini grijanja i ventilacije. Sustav grijanja bio je priključen na za tu namjenu izgrađenu kotlovnicu u tvornici u susjedstvu kazališta. Kompletiranje termotehničkog sustava započelo je 2003. izradom projekta hlađenja s rashladnom stanicom. Rashladni sustav koristi prirodni plin kao energent. Ugrađen je apsorpijski rashladni uređaj koji u zimskom razdoblju može raditi kao toplovodni kotao. Rashladni sustav predstavlja jednostavno i moderno rješenje kojim se učinkovito koristi energija, a realiziran je bez ijednog građevinsko-arhitektonskog zahvata na zgradi kazališta. Rashladna stanica je izgrađena u izdvojenom prostoru uz kotlovnicu, a arhitektonsko oblikovanje u prostoru slobodnostojećeg zaštitnog plašta rashladnog tornja predstavlja jednostavno arhitektonsko rješenje, prilagođeno urbanističkim planovima ovog gradskog područja. Projekt je sufinancirao Fond za zaštitu okoliša i učinkovito korištenje energije.*

Ključne riječi: zgrada kazališta, zaštićeno arhitektonsko kulturno nasljeđe, energetska učinkovitost, termotehnički sustav, klimatizacija, absorpcijski rashladni uređaj