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Improving Energy Efficiency of the Art School in Dubrovnik

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ABSTRACT

The paper deals with energy efficiency measures for music school "Luka Sorkočević" in Dubrovnik. The protected building situated in the old part of the city occupies the sites of two former nunneries. Up today electric resistance heating with radiators in heated space has been applied. Hourly simulations of all year round energy consumption of the building have been performed in order to define optimal replacement system. High temperature heat pump combined with existing electric boiler has been analyzed, as well as replacement of radiator heating system with variable refrigerant flow heat pump system. Variable refrigerant flow heat pump system which gives high level of the comfort has been chosen, giving lowest energy costs as well the lowest CO_2 emissions compared to other systems including conventional gas or oil heating as well. Other energy efficiency measures comprise window sealing, lighting improvements by introduction of CFL and introduction of saving mode for office equipment. Total effects of proposed measures result in CO_2 emission decrease of 75,8 tons annually compared to present state, and the investment payoff time of approximately 5,6 years.

KEYWORDS

heritage, renewal, heating, cooling, heat pump, carbon dioxide emissions, feasibility

INTRODUCTION

The building of "Luka Sorkočević" music school in Dubrovnik is protected as a cultural heritage. It is situated in the southern, oldest part of the city and occupies the sites of two former nunneries, first one of the Holy Apostles with the church of St. Peter (later nunnery of St. Catherine of Siena) in the east and another of St. Simon in the west. Traces of a building date from late antiquity and were built in pre Romanesque style late in the 9th or early in the 10th century. In 1808 the French dissolved the nunnery, and the building first housed a boarding school and later a grammar school (until 1920). The adaptation to the new function entailed a fairly substantial reconstruction of the church and nunnery where a storey was added to the church building. Until the earthquake in 1979 the building housed the "Luka Sorkočević" music school. During the earthquake in 1979 the building suffered damage which endangered the very existence of the facility and pointed out the need for emergency reconstruction of the building. The process of reconstruction finished in 1984 included the removal of all extensions to historic structure of the building, restoration of the original appearance of the building facades as well as the adjustment inside the building for teaching requirements. In present state the building has five floors with total usable area about 1.730 m^2. Design and construction of the heating system have also been completed during the renovation works in that time.

Figure 1. Music school building

The building is heated by hydronic system, using radiators and electric resistance boilers although oil boilers were planned to be used in the original project of central heating system. Oil heating was avoided for reasons of lack of storage space and environmental protection.

Figure 2. Boilers and central heating distributors

SIMULATION OF ENERGY CONSUMPTION

Total heating load of the building is 128 kW. Average annual electricity consumption according to receipts for electric energy in last three years is 211.973 kWh and average annual water consumption is 640,5 m^3.
All year round energy consumption of the building has been calculated in a study [1] using norm EN 13790 (for monthly values of heating energy demand) as well as

using software developed by the authors of this study (for evaluation of hourly values of heating energy demand). Annual energy consumption calculated according to EN 13790 is 134.281 kWh. Annual energy consumption calculated with software developed by authors of this study is 138.209 kWh. Slight differences appear in monthly distribution achieved using these two methods, as presented in figure 3.

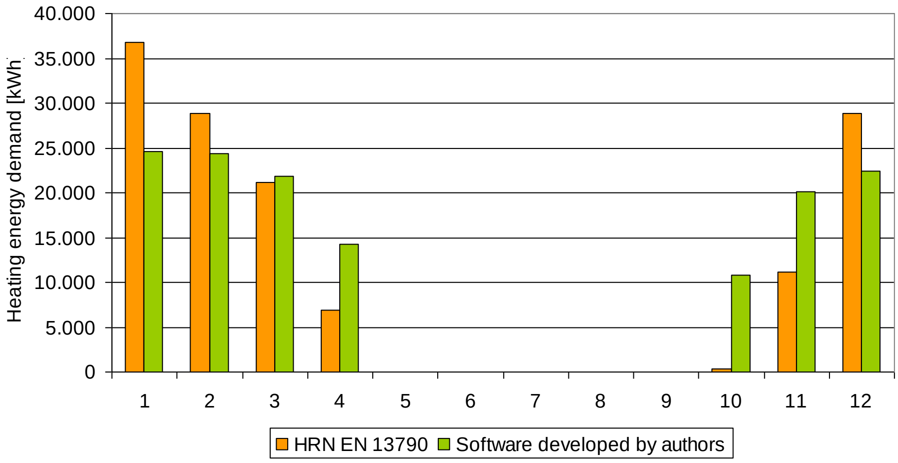

Figure 3. Monthly values of heating energy demand

HEATING AND COOLING SYSTEM

Heat pumps represent energy efficient systems for heating and cooling, especially concerning the fact that by heat pump application renewable energy from ambient is used for the purpose of space heating. European directive on renewable energies [2] recognizes that share of energy as utilization of renewable energy.

BIVALENT PARALLEL HEATING

The bivalent parallel heating using high temperature air to water heat pump in combination with existing electrical boilers has been proposed and analyzed as one of possible solutions. With such a system it is possible to avoid extensive installation works in the building as in that case the replacement of radiators and pipes is not necessary. High temperature heat pump can be added to existing electric boilers, supplying all the necessary heat whenever outdoor temperatures are lower than bivalent point temperature (in analyzed case 4^{o}C), and electric boilers are used only for additional heating during lower ambient temperatures (Figures 4, 6 and 7). The cooling of the building is not possible in that case. The choice of heating water temperatures in original heating system should be checked and heat pump control system which enables variable water temperature set point depending on outdoor temperatures according to Figure 6 should be provided in order to achieve maximum efficiency.
The high temperature heat pump can be either with two stage compression and refrigerant injection between two stages, or a cascade system as presented on figure 5 and analyzed in a study [1].

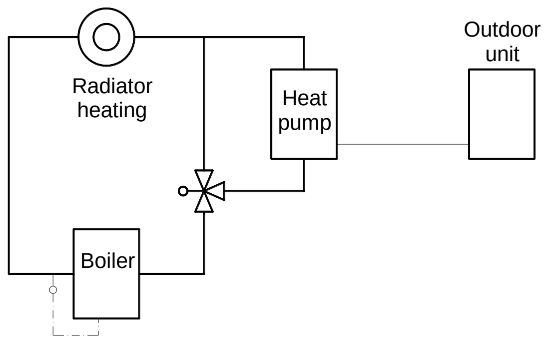

Figure 4. Functional diagram of bivalent parallel system with boiler and heat pump

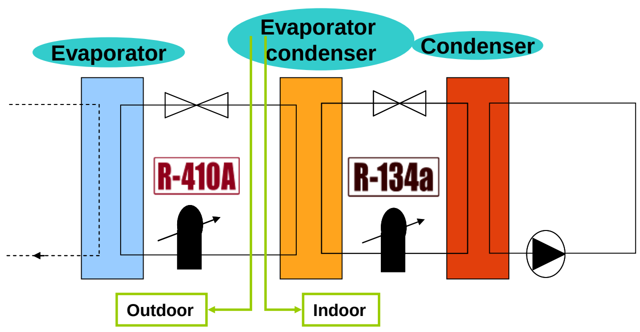

Figure 5. Functional diagram of applied high temperature heat pump

The curve of required heating capacity as a function of outside air temperature results in the bivalent point temperature of approximately 4°C and heating energy demand of 96 kW covered by using the heat pump. Six high temperature heat pump units with heating capacity of 16 kW each are necessary in order to achieve total capacity of 96 kW.

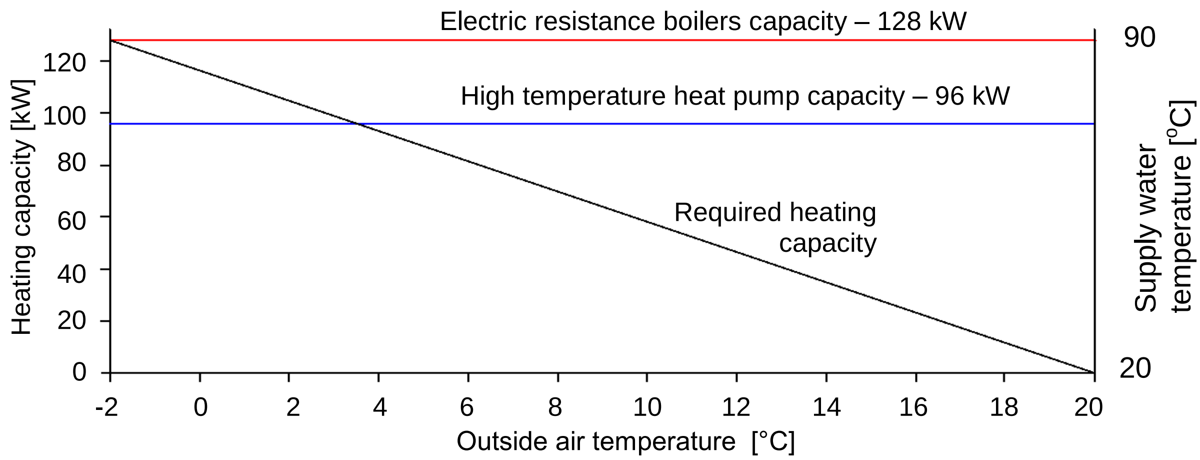

Figure 6. The correlation between required heating capacity and outside air temperature

The annual electricity consumption for heat pump is 43.713 kWh and for electric boiler operation 5.402 kWh, total 49.415 kWh. Share of boiler heating in total energy consumption is thus 9,8%. Figure 7 represents similar results using degree-day curve for considered location. Slight differences between results presented in figure 7 and calculated values are result of the fact that simulations take in consideration operation time, while it can not be taken into consideration using the degree day curve. With total energy (including losses) necessary for the building heating equal to 145.119 kWh, average annual system COP is 2,93. The annual cost for such a heating is 9.330 Euros.

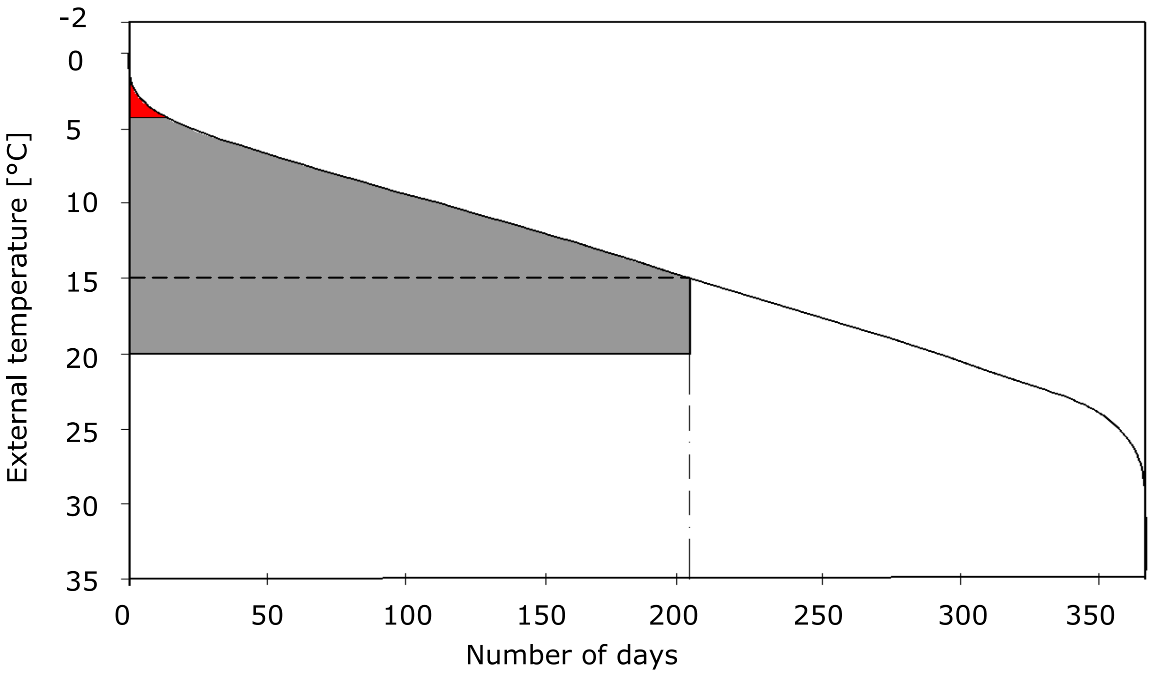

Figure 7. Degree day curve for the considered location with energy consumption for electric resistance hating (red) and heat pump heating (grey)

Effects of analyzed case results in annual saving of 9.317 Euros compared to present state With investment of 36.000 Euros the payback period is 3,9 years. CO_2 emission decrease is 50,72 tons.

Analyzed application of high temperature heat pump results in a short payback period. Nevertheless, it has not been recommended for implementation because cooling of the building is required, and it is not possible without replacement of existing radiators. Also, life cycle cost analysis gives the advantage to VRF heat pump system analyzed in the following chapter.

VARIABLE REFRIGERANT FLOW (VRF) HEAT PUMP SYSTEM

The installation of variable refrigerant flow air to air heat pump for heating and cooling has been analyzed as well. Refrigerant (R410A) is distributed between the outdoor and indoor units by copper pipelines for refrigerant vapour and liquid. Due to phase change between refrigerant liquid and vapour which takes place in the evaporator as well as phase change between vapour and liquid in the condenser, pipelines between internal units and external unit can be of much smaller diameter for the same cooling or heating load than in the case when the water is used as a heat transfer fluid. That is particularly suitable for cultural heritage buildings because such pipes demand low space and low extent of installation work.

System has been designed for the school building, consisting of five separate VRF systems, one for each floor in separate parts of the school [3].

The simulation of VRF system operation, which has taken into consideration partial load system efficiencies has resulted in annual electricity consumption for heating of 28.858 kWh. Seasonal heating coefficient of performance is 5,02. The annual cost for heating is 4.200 Euros.

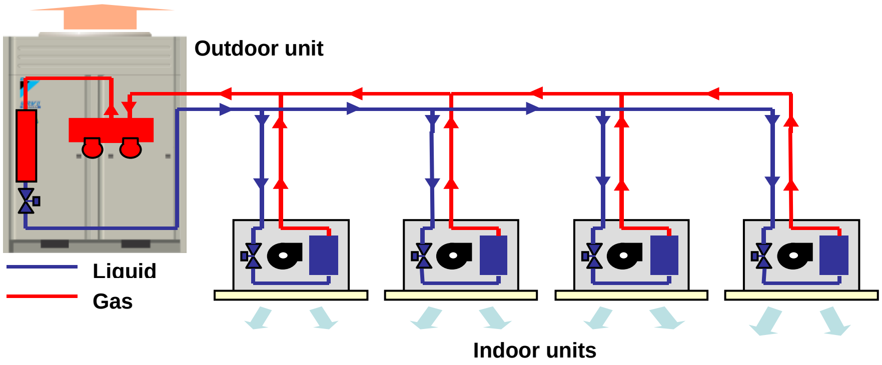

Figure 6. VRF system layout

Effects of analyzed case result in and annual saving concerning present state with 14.500 Euros Investment into the system building has been achieved using equipment lists from [3] to get real prices from an offer for system building. With investment of 94.000 Euros the payback period for this case is 6,5 years. CO_2 emission decrease is 61,6 tons.
VRF system enables cooling of the facility as well. The calculated annual energy demand for cooling (68.444 kWh) and the electricity consumption for cooling have been calculated using the simulation software. Electric energy consumption for cooling is 9.426 kWh. Seasonal energy efficiency ratio is 7,2. The annual cost of electric energy for cooling is 1.200 Euros.
When two analyzed cases of heat pump applications are compared, addition of the heat pump into a bivalent parallel heating is more feasible on the first sight. It demands relatively small investment cost and has short payback period. On other side, variable refrigerant flow heat pump system is much more expensive, but has the possibility for summer cooling and thus enables much higher level of the comfort.
Initial price of installation for the first case is 36.000 Euros. When that price is divided with lifetime of such heat pumps (at least 12 years) it gives annual cost of 3.000 Euros per year. Annual energy savings are expressed with price of 9.317 Euros, and net savings are 6.317 Euros, or 75.804 Euros in 12 years.
Initial price of installation for the second case is 94.000 Euros, and divided with lifetime of such heat pumps (at least 15 years) it gives annual cost of 6.267 Euros per year. Annual energy savings are expressed with price of 14.500 Euros, and net savings are 8.233 Euros, or 98.796 Euros in 12 years. In the same time (12 years) the second system is more feasible, and as pointed out earlier it provides higher level of comfort.
VRF system is also far more superior in energy costs and CO_2 emission compared to condensing gas boiler or oil fuel boiler. The annual heating energy consumption simulation was carried out for the analyzed building object and cases of boiler heating (electric, gas condensing and oil fueled boiler). Table 1 represents comparative energy consumption and CO_2 emission, compared to performance of VRF system.

Table 1. Energy consumption and CO_2 emission

Heating system	**Annual consumption**	**Annual running costs (Euro)**	**Annual CO_2 emission (tons/year)**
VRF system	Electricity – 28.858 kWh	4.200	15,3
Gas condensing boiler	Gas – 14.952,9 m^3	6.600	28,4
Fuel oil boiler	Fuel oil – 14.818,1 liter	8.800	38,5
Electro resistive boiler	Electricity – 145.119 kWh	18.700	76,9

OTHER ENERGY EFFICIENCY MEASURES

After the decision on VRF system application was made, additional two measures have been analyzed: window replacement and additional sealing of existing windows. When considering the possibility of windows replacement two cases were analyzed.
The first case analyzes present windows replacement by new ones with U_w factor less or equal than 1,2 W/m^{2}K and glass with transmittance of thermal radiation equal to 0,3. In that case building heating demand decreases to 110.377 kWh and cooling demand to 67.713 kWh. The annual electricity consumption for VRF heating is 22.690 kWh. Investment is high, as those windows have to be specially made as the building is protected cultural heritage, and equals 96.800 Euros. The annual cost for electricity using VRF heating is 3.300 Euros in that case. That results in annual saving of only 930 Euros concerning state with VRF system installed. Therefore this energy efficiency measure can not be recommended.
Further analysis comprised window replacement by ones with other type of glazing. U_w factor is again equal to 1,2 W/m^{2}K, but glass has transmittance of thermal radiation equal to 0,8. Such a glass can be much cheaper than the first one. Investment for this type of windows is 88.000 Euro. In that case annual heating energy demand of the building is 95.380 kWh and annual cooling energy demand of the building is 89.800 kWh. The annual electricity consumption for heating is 19.666 kWh. The annual cost for heating is 3.000 Euros. Annual saving of electric energy in heating is 1.150 Euros for VRF system installed. As savings were low again, that measure was also not recommended.
Comparison of energy demands for heating and cooling of the building with low-e windows or case without them, points out that application of low-e windows should be carefully analyzed for single cases because it brings significant savings in energy consumption during summer period, but increases heating energy demand during winter period as it prevents useful winter solar heat gains.
Having in mind rather low quality of existing windows, the measure of additional window sealing has finally been proposed. It comprises installation of sealing tape on existing windows. Investment for this method is assumed with price of 300 Euros and annual savings concerning state with VRF system installed is 7.051 kWh or 900 Euros. This measure results in the investment payback time less than one year.
Other proposed energy efficiency measures comprise lighting improvements by introduction of CFL as well as introducing the standby mode of operation for office equipment. Calculated annual energy saving by replacing installed filament lights as well as fluorescent tubes with compact fluorescent lamps is 19.278 kWh in electricity and 7,711 kW in reduced electrical power and results in total annual saving of 2.300

Euros. With investment of 4.500 Euros the payback period for this case is 1,9 years therefore this measure is very recommendable. Annual CO_2 emission decrease is 10,22 tons. Annual energy saving by energy efficiency measure of introducing the standby mode of operation for office equipment is assumed with 553 kWh or 65 Euros. Because this measure comprises software adjustment of existing office equipment there is no investment in this measure. Annual CO_2 emission decrease is 0,29 tons.

FINAL PROPOSAL OF EE MEASURES

Finally proposed measures for music school "Luka Sorkočević" in Dubrovnik are listed in Table 2. Potential savings on electricity is 143.143 kWh annually or 67,5% of the consumption in the current state. Possible decrease in CO_2 emission after the implementation of proposed measures follow from the summary table and amounts 75,8 tons per year.

Table 2. Proposed energy efficiency measures for music school "Luka Sorkočević"

Energy efficiency measure	**Investment (Euro)**	**Annual savings**		**Payback period**	**CO_2 emission decrease**
		Electricity (kWh_e)	**Euro**	**Years**	**Tons/year**
VRF system	94.000	116.261	14.500	6,5	61,6
CFL introduction	4.500	19.278	2.300	1,9	10,22
Standby mode	0	553,2	65	0	0,29
windows sealing	300	7.051	900	0,3	3,73
TOTAL	**98.800**	**143.143**	**17.765**	**5,56**	**75,8**

CONCLUSION

Analyses performed in a present paper have pointed out that the application of heat pump systems is the most feasible EE measure concerning the renewal of thermal systems for cultural heritage buildings in mild Mediterranean climate. Application of heat pumps makes possible summer cooling, which is also important for achieving the proper comfort level. Other measures, such as lighting replacement and introduction of energy saving mode for office equipment are also welcome.

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