ANALYSIS OF SUSTAINABLE HVAC SYSTEM IN TOURISM FACILITIES ON THE ADRIATIC COAST

by

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The world and Mediterranean trends in tourism growth are followed by energy consumption growth. Since heating and air conditioning accounts for an almost half of the energy consumption of many hotels, necessary infrastructure to meet growing demands with minimal impact on natural resources and environment should be provided. This paper deals with sustainable solutions for cooling and heating tourist accommodation facilities on the Adriatic coast. The analysis of the two systems for an apartment complex, the first utilizing sea-water as "free source" of cold energy, and the second as an absorption system utilizing solar thermal energy are compared with conventional vapour compression system. It was shown that significant savings in energy consumption and CO_2 emissions could be achieved. At the same time, the systems are environmentally friendly and ensure water conservation with negligible visual and noise pollution.

Key words: *hotels, sustainable systems, sea-water cooling, absorption cooling, energy savings*

Introduction

The Mediterranean region is one of the most visited regions in Europe and worldwide. It is expected that tourist visit will grow by 3% per year. The hotel trade is one of the most dynamic areas within the service sector. The countries of the European Union (EU), along with those of Northern and Eastern Europe, account for around 35% of the total world hotel capacity. Hotel occupancy in Europe varies considerably according to geographic situation and season [1]. In total, the EU hotels annually use 39 TWh of energy, half of which is electricity [2].

As a part of the Mediterranean, the Adriatic coast has all conditions for tourism development and growth. Due to the recent recovery of the Croatian tourism, it is expected that tourist visits will grow at an even faster rate (approx. 8.4% per year according to World Tourist Organization), which will consequently result in the increase in energy consumption. It is predicted that energy consumption in seven Croatian coastal counties could grow by 7.5% per year, which means that energy demand in the region will be doubled by 2010 [3]. Since 95% of the Croatian tourist accommodation facilities [4] are located in the mentioned seven counties, it is obvious that tourism facilities will considerably increase the pressure on nature resources, as well as CO_2 emission and pollution.

Factors that affect energy consumption patterns in hotels are the following: hotel category, guest's nights, location, climate conditions, local environment and architecture of the building. The main energy end-users within a hotel/motel can be divided into:
– heating, ventilation, air conditioning (HVAC),
– domestic hot water (DHW) production,
– lighting,
– catering, cooking, and
– other (lifts, *etc.*) .

Figure 1 shows different energy consumptions by end-users. Due to significant energy consumption in HVAC systems (approx. 48%), additional changes in system design, such as implementation of energy efficiency measures and renewable energy sources should be done. However, prior to HVAC system design, improvement of building envelope design should be carried out.

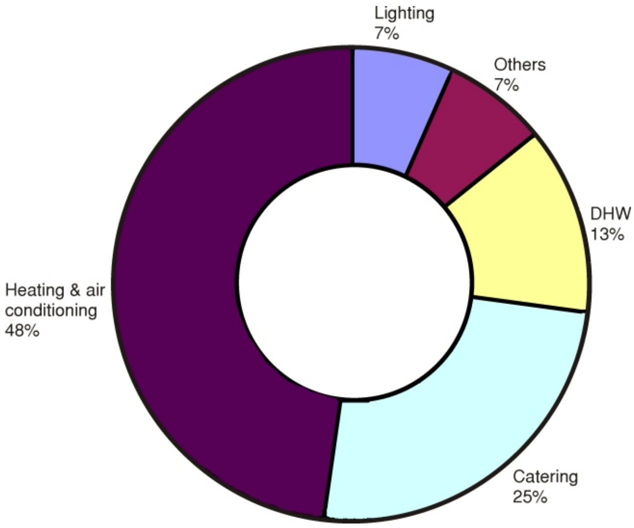

Figure 1. Energy end-users in a hotel [5]

Climate and geographical conditions

The geographical position, the Adriatic sea, weather conditions and mild climate make all seven coastal counties in Croatia suitable for the use of solar and wind energy. In particular the Adriatic islands have the highest insolation level of 2300-2800 sunshine hours per year [3]. The coastal areas and islands, outside the urban areas along the coast, are rather sparsely populated. This area with its mostly rural characteristics, Mediterranean climate, intact nature and clean martime zone is unique in Europe. This coastal region is the best place for holidays, leisure, recreation, sport, medical treatment and many other activities.

Average depth of the Adriatic sea is 252 m; it is shallow in the northwest (maximum 23 m in the Bay of Trieste) [6], and is much deeper in the south (1200 m in the South Adriatic basin). The lowest temperature during the warmest months is around 12 ºC, which is an important data for the analysis of possible utilization of sea-water for cooling purposes.

Sustainability in the HVAC systems

Sustainable measures in HVAC system design are the strategies that cover energy and building systems synthesis and sustainable energy supply and utilization. The strategies for sustainable energy development are the introduction of renewable energy technologies, energy savings, energy efficiency, energy conservation measures and energy management. Therefore, these strategies are expected to result in energy consumption and CO_2 emissions decrease, as well as increased environmental awareness in tourism and building industry.

In the process of planning and design of tourist apartments, number of issues regarding architecture elements and thermal behaviour of building, depending on local climate and geographical conditions, should be taken into consideration. Passive architecture is one of the issues that will decrease cooling or heating needs, and, therefore, affect the increase of the whole system efficiency.

Since late 80s, there has been a growing concern about ozone depletion caused by the release of ozone depletion substances used as refrigerants in HVAC systems. Alternative refrigerants, as well as alternative cycles, can contribute to sustainability of the cooling systems. These systems should be both energy efficient and environmentally friendly. By maximizing utilization of renewable energy sources, and by minimizing refrigerant charge (CFC, HCFC, and HFC), three environmentally friendly cooling systems have been designed.

Sea-water cooling system – SWC

Sea-water can be considered as an unlimited source of energy, *i. e*. a renewable energy source. This paper analyses possibilities of sea-water utilization in building cooling systems. SWC is basically very simple and primarily consists of three components: the sea-water transfer pipeline, shore pumping station and heat exchanger unit, and cold water distribution network.

Sea-water of constant temperature of 15 ºC is pumped from the depth of 50 m to the shore and is circulated through heat exchanger. The warmed sea-water is then returned back to the sea. The second water loop carries cold fresh water through buildings.

Heat exchanger unit is titanium plate heat exchanger resistant to sea-water aggressive properties (fig. 2).

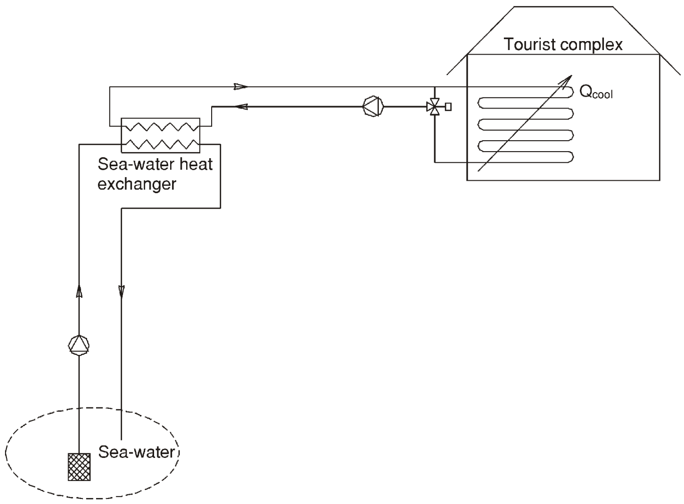

Figure 2. Sea-water cooling system – SWC

World experience in deep source water cooling (DSWC) systems shows that approx. 80-90% savings of the energy required to operate the centrifugal chillers, cooling towers and pumps can be achieved by replacing equipment in a conventional chilled water plant. DSWC systems use deep water with temperature of 4-6 ºC, also used in conventional fan coil cooling systems. The sea-water cooling system stated above is unique, due to the fact that water temperatures low enough for utilization are not commonly found in reasonable depth and distance from the coast. In the Adriatic, cold sea-water is also hard to reach. The average depth in the middle part of the Dalmatian coast is 50-100 m, where the lowest temperature is 12-15 ºC. In order to take full advantage of cold sea-water of 15 ºC for cooling purposes, a different energy transfer system in the building should be applied. To achieve the same thermal comfort, bigger heat transfer surfaces should be used, which will be possible with installation of radiant cooling system. Taking into account necessary temperature difference on the heat exchanger, local district cooling network would operate in the temperature range of 17,5/20 ºC.

When naturally chilled water is utilized, there is no need for refrigerants causing ozone depletion or global warming. At the same time, significant energy as well as CO_2 emission savings can be achieved. In addition, this also eliminates the need for cooling towers and the use of chemically treated cooling water. Therefore, use of fresh water is reduced and noise caused by cooling tower fans is eliminated.

Since sea-water system operates as a high temperature cooling system radiant heat transfer system is assured in the building. During wintertime, the same heat transfer area could be used for the heating system. Due to extended heat transfer area, inlet temperature into the system will be lower (approx. 25-28 ºC) that defines system as a low temperature heating system. Solar collectors would be the best alternative solution for the hot water production.

Solar cooling system – absorption cooling – ABSOL

Solar cooling system would take full advantage of solar energy as a renewable source of energy for cooling. It is one of the most attractive applications of solar energy since the biggest cooling demand is during the highest insolation.

This system designed for tourist apartments consists of LiBr-H_2O absorption unit. Absorption generator is powered by hot water from the solar collector field, while the absorber and condenser are cooled with sea-water. Therefore, the cooling tower is avoided and consequently fresh water consumption and treatment. Back up system for hot water production is electric heater. Since the Dalmatian coast is not supplied with gas pipeline, absorption chiller could optionally be powered by oil or LPG, which are not cost effective and environmentally friendly. Scheme of the solar cooling system is given in fig. 3.

Installation of solar collectors with the same back up system could be used in the wintertime for heating purposes.

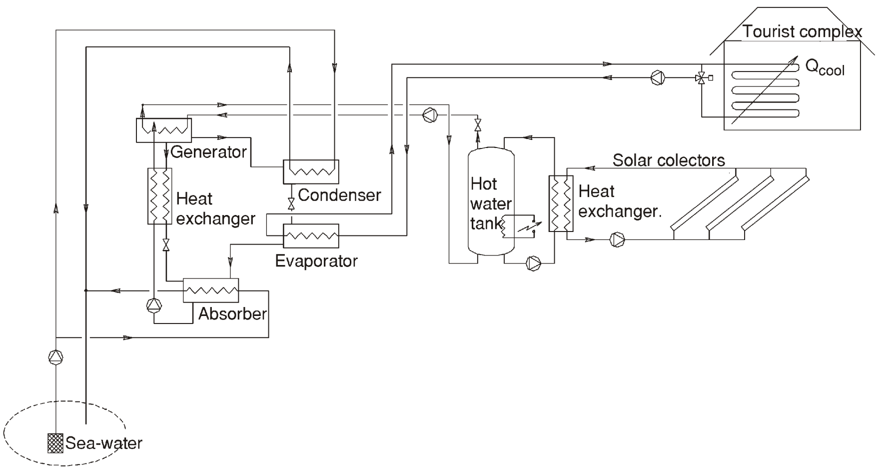

Figure 3. Solar cooling system – ABSOL

Vapour compression cooling system – VC

Vapour compression system is the most common cooling system on the Adriatic coast and worldwide. Since there is still no commercial district cooling network on the coast, cooling systems in tourist facilities are made as institutional district cooling network or as individual cooling split units. The average coefficient of performance (COP) of refrigeration unit with air-cooled condenser is 3. For evaporation temperature of 3 ºC and condensing temperature of 43 ºC, theoretical Carnot COP [7] would be 6.6. COP increases as temperature difference between evaporation and condensing temperature decreases. Assuming constant evaporation temperature, COP might be improved by lowering condensing temperature, which can be achieved by changing the cooling media. For the same evaporating temperature, water-cooled condensers would have COP_c = 8.6 at condensing temperature of 35 ºC. In order to avoid cooling towers and to improve the water conservation, it would be reasonable to use sea-water for the condenser cooling on the Adriatic coast (fig. 4). This system would achieve COP_c = 11, at condensing temperature of 28 ºC.

During the winter season when heating is needed vapour compression system could be operated in the heat pump mode. Therefore, there is no need for additional equipment. The heat pump operates in constant temperature range, since sea-water temperature is constant during the year at the depth below 10 m.

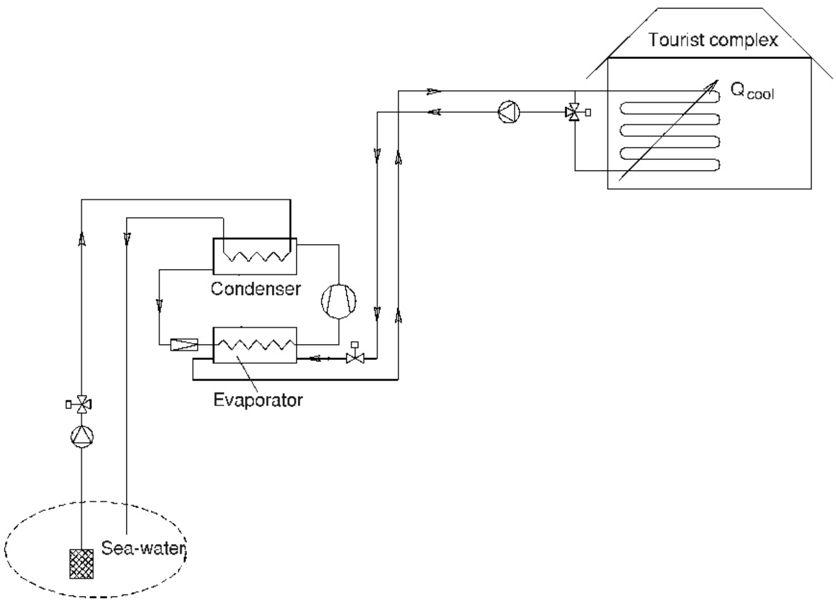

Figure 4. Vapour compression cooling system – VC

System analysis

Designed systems were modelled and analysed in TRNSYS computer program. TRNSYS is a transient system simulation program with a modular structure. It is well suited for detailed analyses of systems whose behaviour is dependent on the passage of time. Prior to an analysis of the three systems described above, optimisation of the system concerning number of solar collectors, inlet and outlet temperatures to the building and area of the heat transfer surfaces has been made [9]. This analysis applies for one cooling season, June 1st – September 15th, and for the warmest week, with the time step of one hour. TRNSYS program require definition of inputs, outputs and parameters for each component of the system. TRNSYS component Data reader allowing system's connection with input data file is supplied with weather data for the city of Split. Data file contains hourly measured values of temperature and solar radiation.

Since 35% of the hotels on the Adriatic coast in Croatia are seasonal which require only cooling system installation, this papers analyses only energy requirements for three cooling options described in previous chapters. In addition to that, building type chosen for modelling and simulation are bungalows with apartment units that are recently occupied only during the summer time. Contribution to the sustainability of HVAC systems during the whole year round operation would be utilization of the installed equipment for heating purposes *e. g.* utilization of solar collectors installed in ABSOL system, or operation of the vapour compression unit in heat pump mode.

Cooling load of 210 kW is calculated for tourist apartment facilities consisting of 50 bungalows with two apartments each (total area 6300 m^2.). In addition to transmission losses, hourly influence of the insolation [8], infiltration and ventilation losses on the building structure are taken into account as well. Buildings have been modelled with passive architecture elements such as shadings that prevent direct solar insolation through windows. Thermal characteristic of building material is $k = 0.4$ W/m^{2}K, while estimated and calculated cooling load per square meter is 33 W/m^2. The intention was to decrease cooling demand by making improvements in the building itself prior to cooling system design. In order to decrease cooling demand due to the ventilation system, ventilation rate was decreased by 25% during the warmest hours in cooling season.

Simulation results for the three described systems are given for the period August 1st – August 7th, which represents the warmest week in the cooling season. In figs. 5, 7, and 9, characteristic component flows and system powers are given. One can see that building heat gain (Q_{load} – curve 4) is covered by cooling load ($Q_{cooling}$ – curve 3), except for some peaks that hasn't influenced thermal comfort. Room temperature was maintained in comfort temperature range, *i. e.* room temperature was by 7 ºC lower than outside temperature. Design room temperature was 25 ºC, while the achieved room temperature didn't exceed 26 ºC.

Curves 1 and 2 on figs. 5, 7, and 9 represent electricity consumption by pumps and auxiliary heater or compressor respectively. From plotted diagrams one can easily see that sea-water cooling system consumes less electricity to cover the same cooling demand, compared to absorption and vapour compression system. Simulation was made with on-off regulation, according to the room temperature, which explains why curves

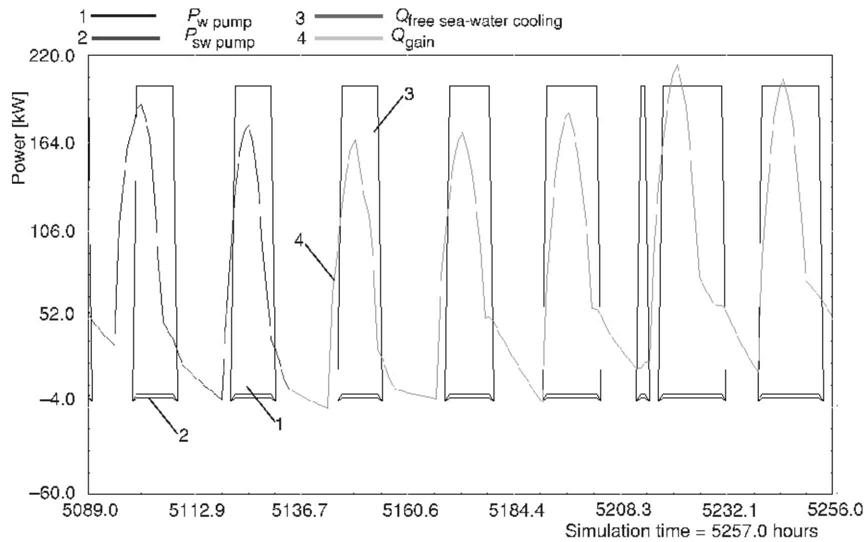

Figure 5. Flow of characteristic components and SWC system powers; period August 1st – August 7th

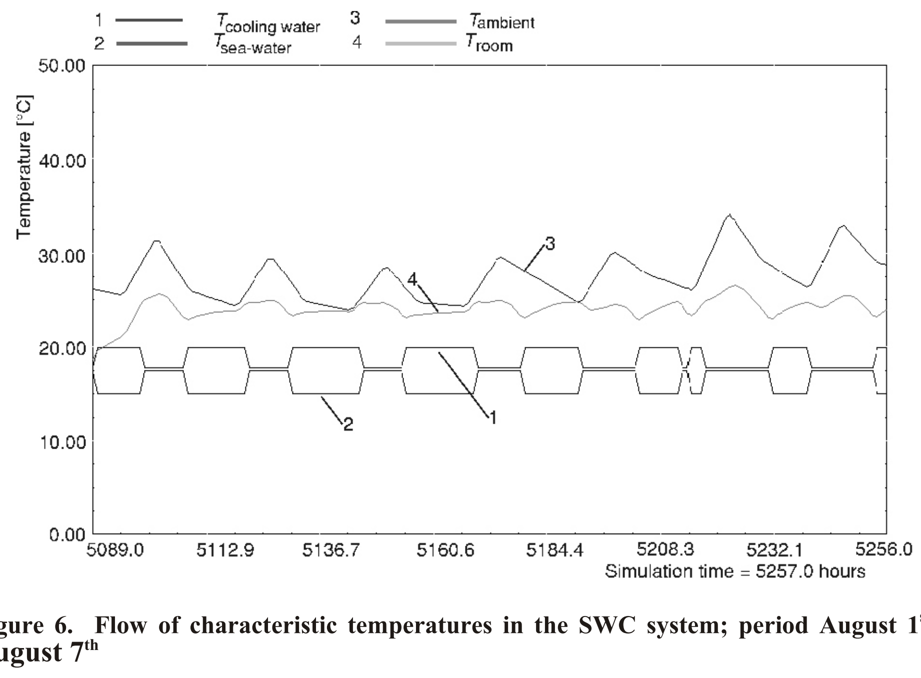

Figure 6. Flow of characteristic temperatures in the SWC system; period August 1st – August 7th

don't gradually increase and decrease according to the demand. In fig. 7 one can see that electrical back up heater (curve 3) is operating even in the warmest week, since solar storage is not sufficient to cover cooling demand in the late afternoon hours.

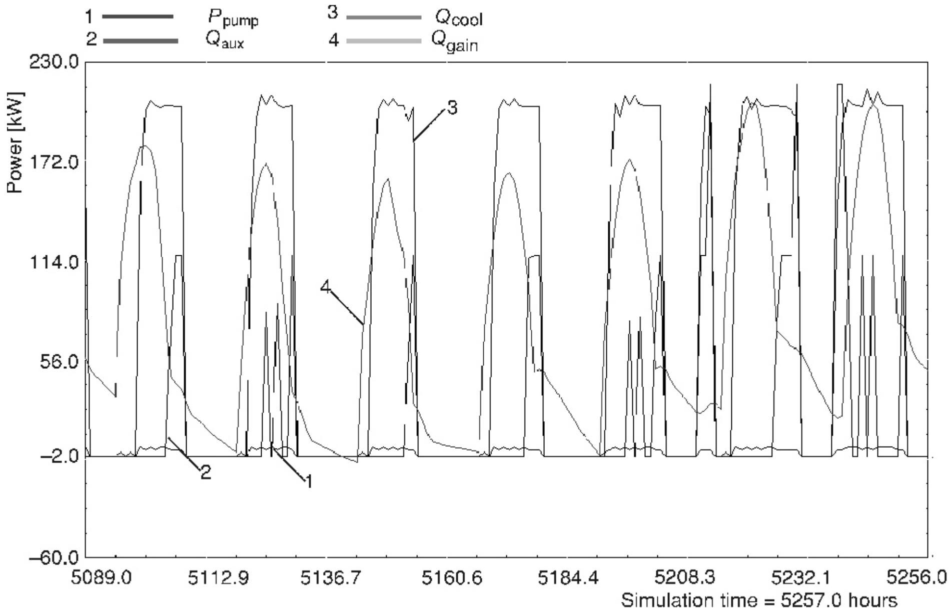

Figure 7. Flow of characteristic components and ABSOL system powers; period August 1st – August 7th

Figures 6, 8, and 10 show flow of characteristic temperatures in the systems. Due to delayed responding of the building system and due to on-off regulation, room temperature (curve 4) has small variations. However, room temperature is always maintained in thermal comfort level. Curve 3 in figs. 6, 8, and 10 represents ambient temperatures obtained from the test referent year (TRY) for the city of Split. In fig. 6, curves 1 and 2 represent temperatures of the cooled water and sea-water respectively. Mean temperature difference between sea-water and cooled water is 2.5 ^{o}C.

Curves 1 and 2 (fig. 8) are hot water inlet and outlet temperatures at the generator of absorption (ABSOL) system. Hot water from the solar collectors is stored in the tank and supplied to the generator when needed. When hot water temperature drops bellow 87 °C, electrical heater is turned on and water is heated. Electrical heater behaviour is represented by curve 2 in fig. 7.

To meet cooling demands in the vapour compression cooling system (VC), electricity is used to power compressor and sea-water pump. Curves 2 and 1 in fig. 9 show the compressor power and sea-water pump power during the simulated period of time.

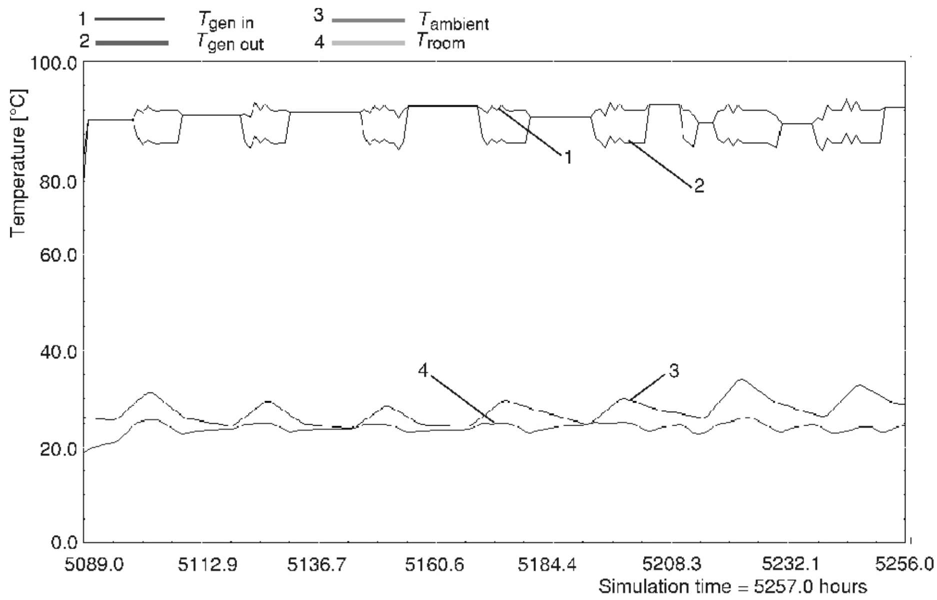

Figure 8. Flow of characteristic temperatures in the ABSOL system; period August 1st – August 7th

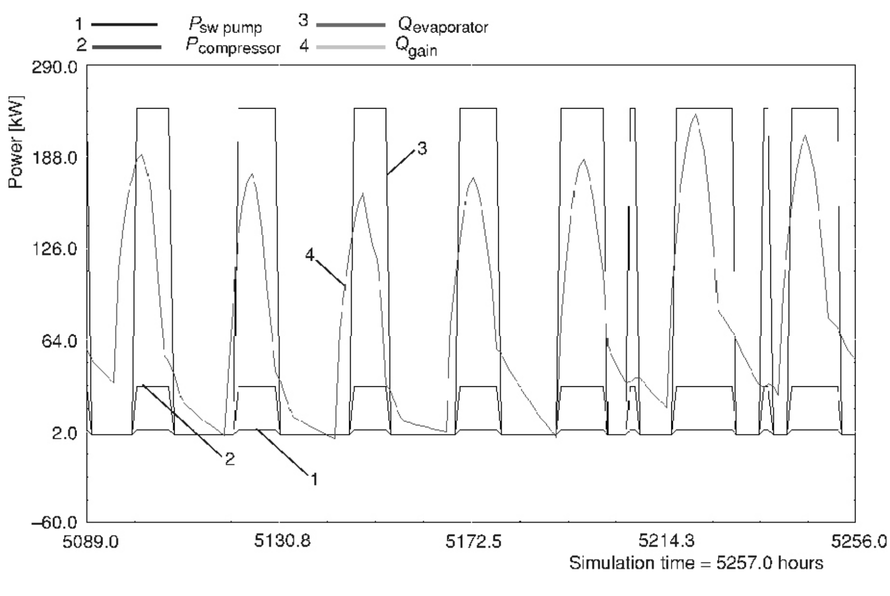

Figure 9. Flow of characteristic components and VC system powers; period August 1st – August 7th

Curve 1 in fig. 10 shows sea-water temperature changes at condenser outlet, while chilled water temperatures are shown by curve 2. The evaporator inlet and outlet temperatures are fixed (7/12 °C) and the chiller operates when chilled water is needed.

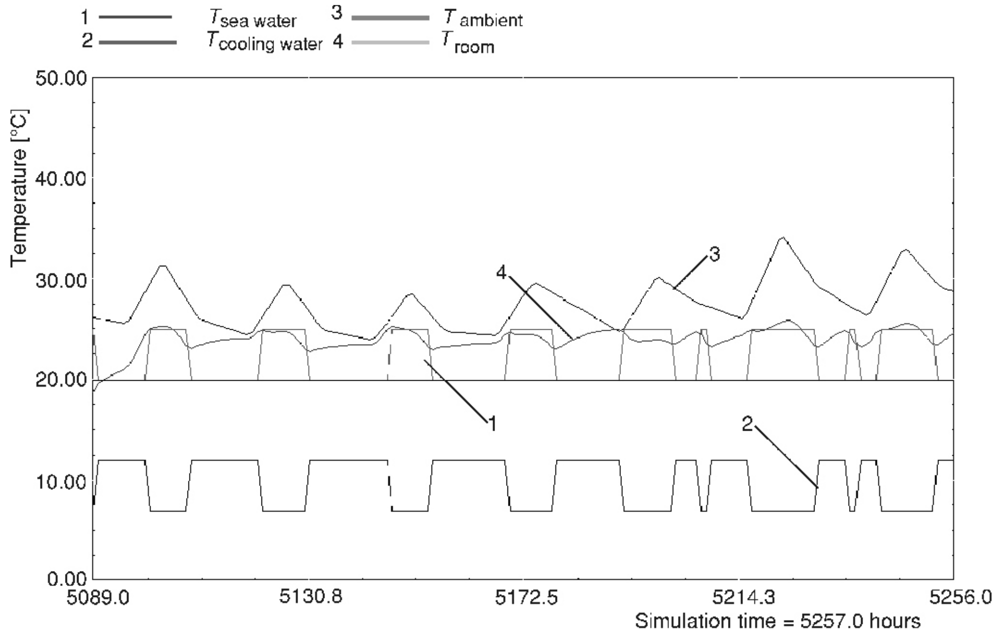

Figure 10. Flow of characteristic temperatures in the VC system; period August 1st – August 7th

Results

The analysis of energy flows has been shown that sea-water cooling system during the warmest week saves 79.5% of electricity compared to the vapour compression cooling system (with sea-water cooled condenser). At the same time, SWC system supplies necessary cooling energy with renewable energy sources up to 97%. It was expected that absorption cooling system powered by solar energy will be the second best, but analysis of the system has shown that this system utilizes 30% more electricity for the same cooling demand than VC system during the warmest week. This is due to the electrical back up heating system used for the hot water production. In addition, in the model of ABSOL system flat plate collectors were used. Evacuated tube or concentrating solar collectors would probably give better results, since outlet temperatures from these collec-

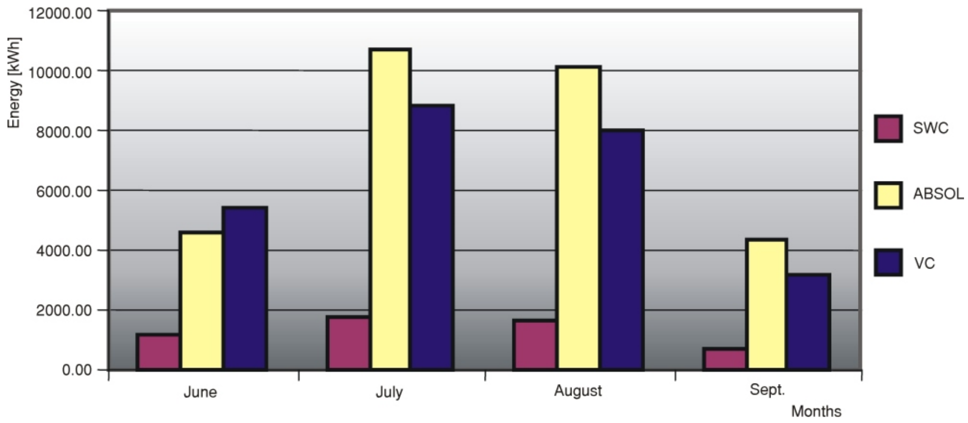

Figure 11. Electricity consumption for the designed cooling systems per month of the cooling season June 1st – September 15th

tors are higher than at flat plate collectors and requirements for additional preheating would be decreased. Comparing electricity consumption of systems for different months of the cooling season, one can see from fig. 11 that ABSOL system has achieved lower electricity consumption than VC system in June. This is due to lower cooling demand compared to the level of insolation. However, VC system is highly efficient with the theoretical COP being 66% bigger than vapour compression system with air-cooled condenser. Comparing ABSOL system with vapour compression system (air cooled condenser) leads to the conclusion that solar absorption cooling will achieve energy savings as it was initially expected (fig. 12). Vapour compression cooling system with air cooled condenser is the most common system on the Adriatic Coast and can be found in 90% of hotels that are equipped with cooling systems. Bearing in mind saving that proposed systems might achieve, possibilities for electricity savings in Croatian hotels are significant. Water-cooled condenser is also convenient if system is operating in wintertime, (*i. e.* if a hotel work during the winter season when vapour compression system works in heat pump mode), since seawater has constant temperature at the depth bellow 10-15 m throughout the year. In addition, during the coldest days in the heating season, the seawater causes higher evaporation temperature and thus increases COP of the heat pump. However, ABSOL system doesn't require any additional equipment for winter operation that contributes to the sustainability of the system. Hot water for heating is provided from existing solar collectors, while in case of insufficient insolation the same back up heater is used.

In fig. 13 the three systems during whole season (June 1st – September 15th) are compared. One can see that difference between ABSOL and VC systems is somewhat less than for the warmest week and it is calculated to be 15%. SWC system utilizes 20% of electricity compared to VC system.

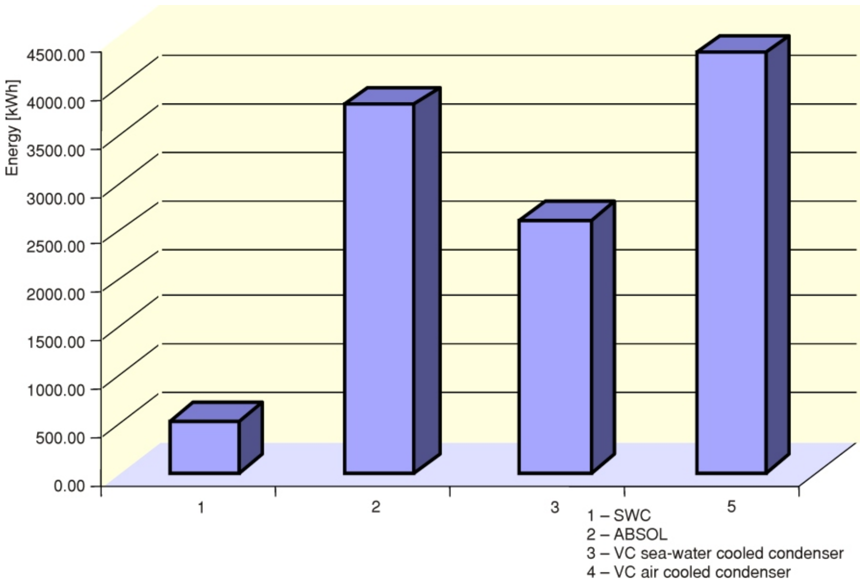

Figure 12. Electricity consumption for the designed cooling systems; period August 1st – August 7th

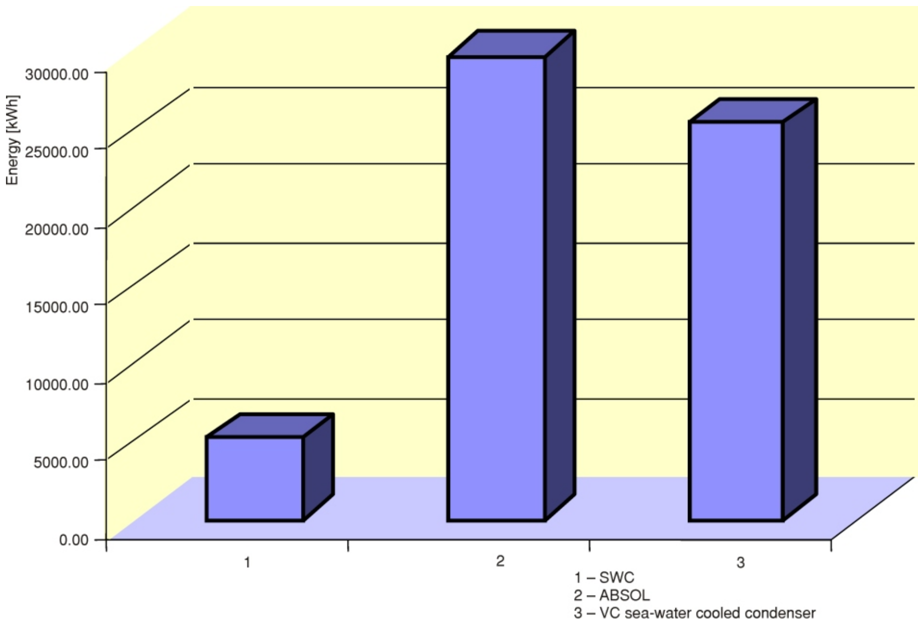

Figure 13. Electricity consumption for the designed cooling systems; period June 1st – September 15th

Conclusions

Sustainable development is a growing point of interest in majority of developed and developing countries and requires an integral approach at all levels. Energy within the sustainable tourism development is a very important issue, since tourism industry requires high energy consumption for its existence. New innovative systems with maximized use of renewable energy sources will achieve significant savings in electrical energy consumption and will proportionally reduce CO_2 emissions. Instead of constructing new thermal power plants, which is the most realistic option for the new electricity supply in Croatia, investment should be made in sustainable building design and sustainable energy systems in built environments. Measures that contribute to the sustainability of the systems and energy saving that are analysed in this paper are:

- utilization of the sea-water in SWC system as a reliable renewable source of energy for cooling,
- installation of high temperature radiant cooling system,
- utilization of the sea-water for vapour compression system for condenser cooling that decreases condensing temperature and increases COP, thus eliminating need for cooling towers,
- utilization of solar energy for cooling in absorption system,
- utilization of centralized system, that allows utilization of renewable energy sources that contributes to the conservation o natural resources, and
- non of the systems utilize ozone depleting substances as a working fluid, therefore, systems do not contribute to the ozone depletion.

This analysis of three designed systems shows that with good planning and sustainable system approach both improvements and energy and emission savings could be achieved.

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