Possibilities for High Temperature Cooling in Tourism Accommodation Facilities

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Considering that energy consumption in hotels, depending on energy system efficiency is between 250 – 550 kWh/m^2 per year, tourism accommodation sector is undoubtedly responsible for a large ratio of CO_2 emissions. Although approximately half of that amount is utilized by HVAC systems that provide thermal comfort for guests, utilization of energy efficiency technologies and renewable energy sources is not even approaching the satisfactory level.

This paper analyses different renewable energy sources for high temperature cooling in Mediterranean region. Taking into account climate and geographical conditions it is possible to design centralized cooling system that would provide cold water temperature of 17^{o}C to the radiant cooling system in the guest rooms. Significant energy and environmental savings can be achieved using both seawater cooling system where seawater can be consider as unlimited renewable source and solar absorption refrigeration system. Therefore, sustainable approach in building and energy system in tourism accommodation facilities is necessary in order to achieve sustainable development of tourism that is one of the world's most rapidly growing industry.

1. Introduction

Mediterranean region is the biggest tourism region in the world, accounting for 30% of international arrivals. The number of tourists in Mediterranean countries is expected to increase from 260 million in 1990 to 440 - 655 million in 2025. It represents an annual growth rate about 3%, [1]. Tourism in Croatia, as in other Mediterranean country is primarily oriented on swimming and sunbathing, recreation activities that directly use the seashore. Therefore, the immediate coast, its relief, climate and the quality of land and sea are of prime importance to Mediterranean tourism. It can be expected even faster annual growth rate in Croatia than in other Mediterranean countries, since trust of the tourists regarding to the security in the country is growing.

Growth in tourism industry is welcomed, but it is question what did tourists really bring and what did they leave behind. Tourism accommodation facilities belong to the building sector that accounts for about 40% of the energy consumption worldwide. Hotels are high energy density consumers and depending of system energy efficiency consumes between 250 – 550 kWh/m^2 energy per year, [2]. Energy costs in hotels account for 3-6% of total running costs and represent one of few items that can be decreased and therefore contribute to the hotels higher profit.

Bearing in mind trends in tourism growth, energy and water consumption, climate change and environmental impacts of energy and water use and waste production, sustainable approach should be implemented in all sectors connected to tourism industry in planning and design phase as well as in operational phase in order to put tourism on sustainable path.

2. Cooling systems

Introduction of energy conservation and savings measures and environmentally sustainable technologies as renewable technologies and passive technologies into tourism accommodation facilities is of primary interest for tourism existence and sustainable development.

Having in mind climate and geographical conditions for chosen site for this analysis (Croatian Adriatic coast), as well as absence of commercial district cooling network, three environmentally friendly centralized cooling systems for tourist complex of 100 apartments were designed. Each system is designed as institutional centralized district cooling system. First system utilize free “cold energy” from seawater, second system is absorption unit with low temperature heat source from the solar panels, and the third one is vapour compression unit with condenser utilizing seawater as a heat sink. None of these three systems utilize refrigerant with ozone depleting potential. Focus will be on seawater system as high temperature cooling system.

Centralized system, besides possible energy and emission savings has more advantages as a prevention of visual and noise pollution that would be present installing separate cooling units (split cooling unit) in each apartment. However, the main reason for centralized system is possibility to utilize renewable energy sources and to implement advanced environmentally friendly technologies and systems.

Since tourist eco complex is planed to operate during whole year, heating system should be designed as well. Therefore, cooling and heating system are planed as a one, implementing principles of system thinking and taking advantages of majority of system’s components during the whole year.

Regular large-scale chillers for the production of cold water are still the most common production technology used both in commercial and institutional DC, [3]. Very often there is a huge amount of water needed like a heat sink for condensers. In that case utilization of cooling towers is needed, but that causes additional electricity and water consumption. Conceptual view of a chilled-water air conditioning can be presented in five loops of heat transfer, where thermal energy moves from left to right as it is extracted from the space and expelled into the outdoors, as it is showed in Figure 1, [4].

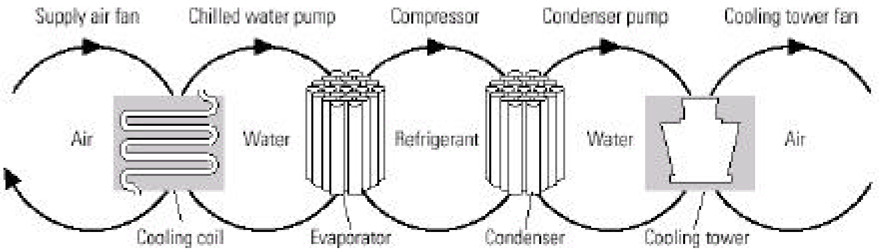

Figure 1. *Conceptual view of a chilled-water air-conditioning system [4]*

In order to minimize operational and environmental cost, energy efficiency of all loops should be increased; also influence of the refrigerant loop on the ozone depletion should be eliminated. Designing a new system with HFC (hydro fluorocarbons), refrigerant that has zero ODP value, one problem is eliminated but there is still significant global warming potential. If there is no possibility to design system with natural working fluid (NH_3), or maybe utilization of absorption cycle, measures for stopping refrigerant release to the atmosphere should be increased. Since higher portion of greenhouse gases is released into the atmosphere due to energy consumption for cooling than due to refrigerant discharge, energy efficiency is very important when analysing the global environmental impact of cooling that is mainly caused by CO_2 emissions. Efficiency of the each component should be improved.

If number of heat transfer loops can be decreased, energy efficiency of the whole system would be higher. This can be realized if local factors allow utilization of “free heat sink”, for example utilization of lake, river or seawater (Figure 2). Electricity for cooling towers funs and pumps is decreased just to electricity for seawater (lake, river or ground water) pump. At the same time water conservation measures are accomplished, and there is no need for chemical treatment of water. And finally, efficiency is improved since cooling water temperature is lower than temperature of the water from cooling tower, which is limited with the air temperature and humidity.

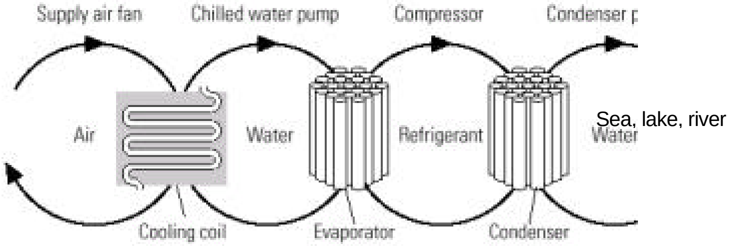

Figure 2. *Conceptual view of a chilled-water air-conditioning system with “free heat sink”*

Analysing heat transfer loops in the specific cooling systems one can see that intention is to have as less as possible heat transfer loops, with less electricity consumption providing the same cooling capacity. It is very obvious that each heat transfer loop has its own efficiency, and in order to increase efficiency of the whole system design should strive toward decreased number of heat transfer loops.

3. Seawater System - SWC

Seawater used in existing systems is deep cold sea or lake water with temperature in the range of 6-12 °C. These temperatures would correspond to chilled water temperatures produced in chillers for conventional air conditioning units. Adriatic sea, comparing to Oceans is shallow, with deepest spots of 200 m on the 20-50 km app. distance from the described site on the coast (Figure 3).

Figure 3. *The map of the Adriatic and depth profile [5]*

Average temperature on the 200 m depth during the summer months is 12,89 °C [5], that is not low enough for cooling application in fan coils. Any investment in that long pipeline would probably be too expensive.

Analysing how it is possible to apply free cooling in Mediterranean region of Adriatic Sea, where deep seawater is not available, higher level of cooling water was considered. High temperature cooling system might be applied if cooling system in the buildings is not conventional one with fan coil units. If radiant cooling system were considered with temperature level in the building 17/20°C, it would be possible to obtain the same cooling capacity and the necessary thermal comfort. To produce cold water of 17/20 °C, seawater should have temperature of at least 15°C that could be pumped form the depth of 50 m and offshore distance of a few hundred meters.

Having in mind heat transfer loops previously described (Figure 1, 2), this system has one more advantage. Since cold energy is transferred to the space with radiant mechanism, there is no need any more for air loop that maintains thermal comfort in the cooling space. Total electricity need for the system, compared with vapour compression system (Figure 2) is diminished with air fan electricity and electricity to drive compressor. Schematic view of the heat transfer loops for the SWC system can be seen on Figure 4. Literature survey showed that seawater for the high temperature cooling is not mentioned and applied yet.

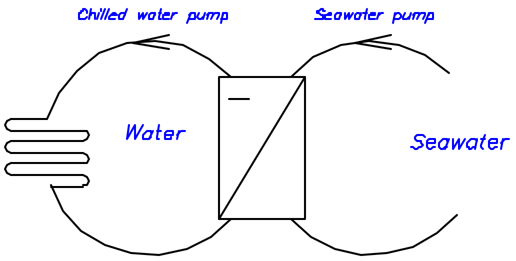

Figure 4. *Conceptual view of a seawater system*

Further simplification would be possible if the seawater is distributed directly to the objects. Utilizing seawater for the building's cooling system, only one heat transfer loop would exist. Therefore, efficiency of the system would be higher, but having in mind aggressiveness of seawater, installation and maintenance costs would be to high.

4. Radiant cooling and thermal comfort

Energy savings and emission reduction is both a matter of energy production, energy distribution and efficiency of these systems. A necessary prerequisite for the use of alternative energy sources is development of new heating and cooling systems within the building. Systems that can utilize low valued energy are low temperature heating and high temperature cooling system. In order to utilize energy from the "warm" seawater, high temperature cooling system has to be applied in the form of hydronic radiant cooling system.

Cooling and heating loads are function of the coefficient of convective and radiative heat transfer (k), conditioning area (A), and temperature difference between cooling/heating surfaces and the room air or the surfaces of unconditioned building components (DT).

$$Q = f\left(k, A, \Delta T\right) \tag{1}$$

Lowering the water temperature in the heating system, or rising the cooling temperature heat transfer surface should be increase in order to achieve the same heating or cooling capacity. Temperature of the water becomes close to the room temperature. Bigger heat transfer area, floor, ceiling or wall surfaces are used in the form of panels or embedded wall pipes.

Due to the high heat capacity and density of water, thermal energy can be transported by water in pipes with little pump power; saving approximately 70-80% of the fan power normally used to conditioning a building (in all air systems). This alone reduces the peak-power of the air conditioning system by about 30-45%. Besides power savings radiant cooling system has number of advantages as follows:

- Separation of the ventilation task from the thermal conditioning
- Space savings due to less space needed for air channels
- No drafts
- No noise
- The same installation for heating and cooling
- Free of maintenance and durability

On the other hand, minimum allowable temperature generally limits the cooling capacity of a radiant cooling system. Proper water temperature choice and control will help to avoid any condensation. Condensation on the surfaces of the panels occurs when the dew point temperature is reached.

Without radiant cooling system it would be impossible to utilize seawater in SWC system to obtain required thermal comfort. However, radiant cooling system that requires higher cooling operating temperature might be successfuly applied also in system where vapour compression or absorption chillers are used for cold-water production. Lowering the difference between condensing and evaporating temperature systems becomes more efficient.

5. Seawater cooling system operation

SWC system is calculated to cover total cooling demand of 210 kW in the tourist Eco Complex with 15°C seawater supply. If some changes in seawater temperature occur, or if cooling load couldn't be covered, as a back up cooling system vapour compression unit is predicted (Figure 5).

Seawater applied in SWC system in Eco complex can be used as an integral system only in summer cooling season. Energy supply for heating season should be separate. Bearing in mind principles of sustainable energy supply, heating system was chosen to be solar system. Solar collector field with thermal storage will provide necessary energy for heating. The same district network and the same house installation will be used. Heating system would operate as a low temperature heating system with temperature range 31/37 °C. When solar insolation is not sufficient for hot water production, the same vapour compression unit will be used in heat pump mode as a back up energy source. As a heat source for evaporator unit seawater is used.

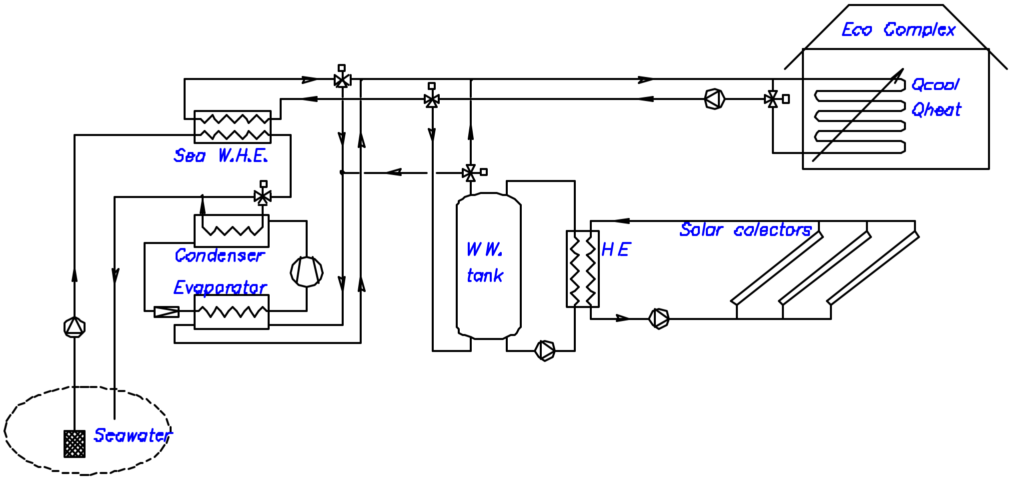

Figure 5. *SWC system - cooling and heating*

Seawater cooling system is very simple and is consisting of three primary components: the central seafront screening, pumping and treatment plant, the central transfer line and the end-user distribution network.

The SWC cooling system consists of two main loops. In the first loop, centrifugal pumps draw cold seawater from the bottom of the sea, and then circulate the seawater through heat exchangers that are located in the machine room of the Eco Complex. The warmed seawater is then returned back to the sea. In the heat exchanger, this water is chilled while heat is transferred to the seawater. The second pump then circulates the chilled water throughout the complex. If cold-water temperature of 17°C cannot be achieved, back up chillier is turned on and water is cooled to desired temperature and pumped to the buildings. As a heat sink on condenser, "warm" seawater at discharge line is used, that gives further savings in pumping costs.

Heat exchangers are plate and frame type heat exchangers that generally provide superior thermal performance. They are more economical and have smaller dimensions. Plates fabricated from titanium are used in seawater applications while stainless steel provides good performance in fresh water applications. Aluminium plates are now being developed as a cost effective alternative to titanium. Plate heat exchanger allows 0.5-1.7 °C temperature differences within exchanger, [6].

To minimize pumping costs, the seawater pumps are located as close to the seawater level. Concerning more expensive installation and maintenance of seawater pipelines and equipment, distance from the shore should be as less as possible. The use of VSDs (variable speed drivers) provides the ability to follow the cooling load. Since system is usually designed to follow load, the use of VSD pumps is generally economically justified.

Second designed system was solar absorption refrigeration (ABSOL) unit that is powered by hot water from the solar collectors. When solar radiation is not sufficient and when hot water cannot reach 88 °C, electrical heater is used in the storage tank to preheat water. During winter time solar collectors with storage tank system are used for low temperature heating.

To be able to compare efficiency of the environmental friendly systems SWC and ABSOL that utilize renewable energy sources, third system with the vapour compression principle was designed. The most appropriate vapour compression system that would be applied for the required cooling load of 210 kW would be chillier with air-cooled condenser. Water cooled condenser with cooling tower would be second option, that would allow heat pump mode in winter time, but it is not so common to design cooling towers for such "small" cooling capacity. Since seawater is available during the whole year vapour compression system utilizing seawater for the heat sink on the condensers unit is designed. During the winter time system will work as a heat pump, where seawater will be used as a heat source on the evaporator. As a working media R 410A refrigerant is taken which has no ozone depletion potential and low global warming potential. Schematic view of VC system is given on the Figure 6.

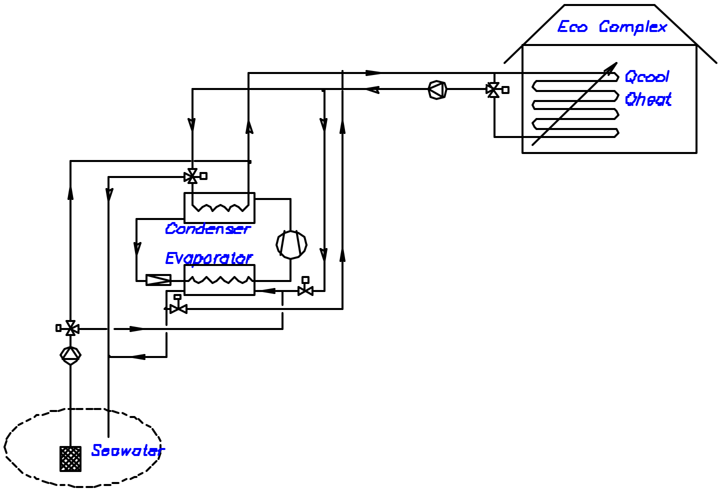

Figure 6. *VC system – cooling and heating*

6. System analysis

Designed systems were modelled and analysed in Trnsys. TRNSYS is a transient system simulation program with a modular structure. For three above described systems analysis is made for one cooling season, June 1st – September 15th, and for the warmest week, with the time step of one hour. Data reader Trnsys component that allows system's connection with input data file is supplied with weather data for Split. Data file contains hourly measured temperatures and solar radiation.

Cooling load of 210 kW is calculated for tourist apartment complex consisting of 50 bungalows with two apartment each, total area of 6300 m^2. Besides transmission losses, hourly influence of the solar insolation, infiltration and ventilation losses on the building structure are taken into account as well. Buildings are designed according to principles of passive architecture, preventing direct solar insolation through windows, and with thermal characteristics of building material of k=0.4 W/m^2K. Estimated cooling load per square meter is 33 W/m^2.

Simulation results of three described systems are given for period August 1st – August 7th, what represents warmest week in the cooling season. On the Figure 7. flows of characteristic component 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 some picks which haven't influenced thermal comfort since room temperature have been maintained in comfort temperature range e.g. room temperature have been 7°C lower than outside temperature. Room temperature is maintained under 26°C.

Curves 1 and 2 on Figures 7 represent electricity consumption by pumps and auxiliary heater or compressor respectively. From plotted diagrams one can easily see that seawater-cooling system needs the lowest rate of electricity to cover the same cooling demand. Simulation was made with on-off regulation, according to room temperature, that is the reason why curves doesn't have gradually increase and decrease according to the demand.

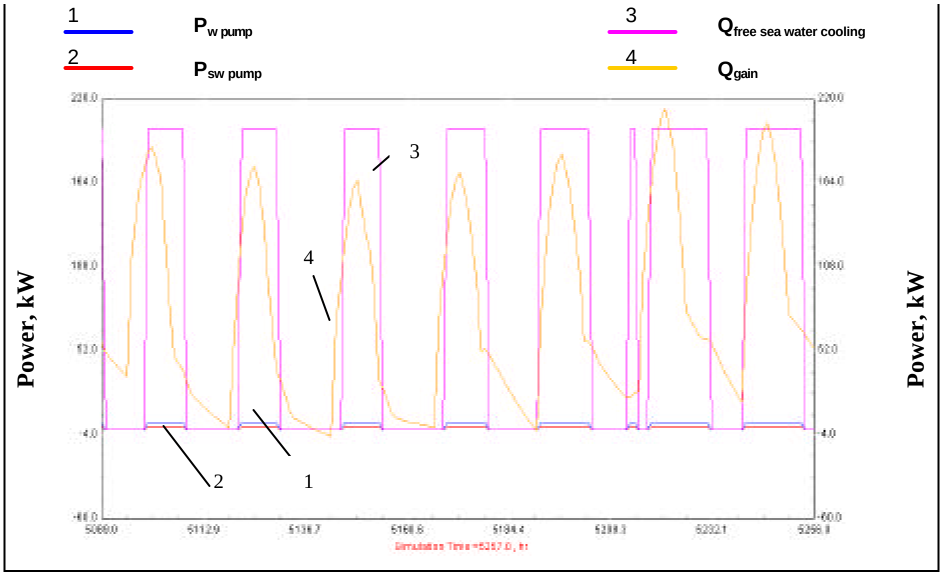

Figure 7. *Flow of characteristic components and SWC system powers, period August 1st – August 7th , [7]*

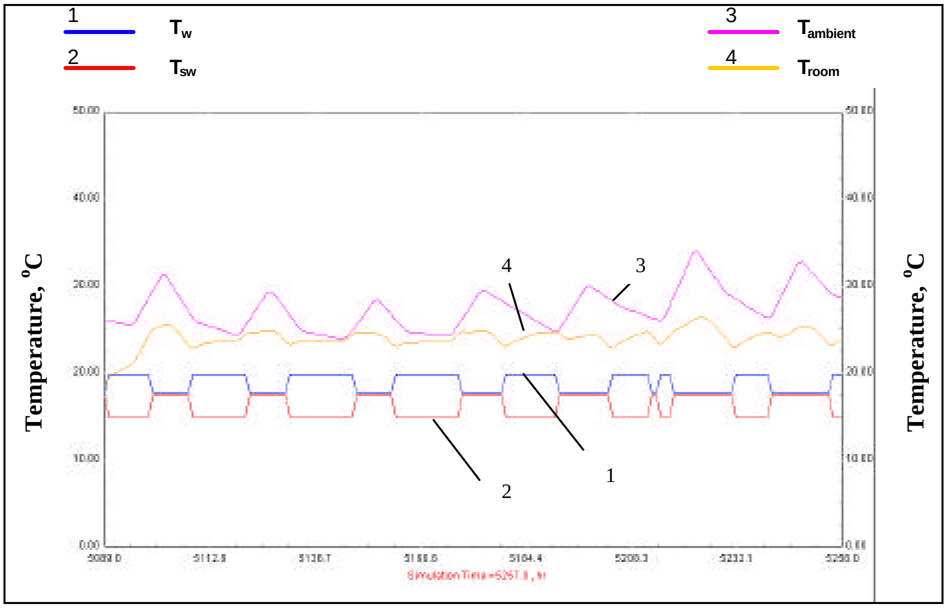

Figure 8. *Flow of characteristic temperatures in the SWC system, period August 1st – August 7th, [7]*

On the Figure 8 flow of characteristic temperatures in the systems is showed. Since building system delays in response and due to on-off regulation, room temperature (curve 4) has slightly variations, but it is always maintained in thermal comfort level. On the Fig.8 curves 1 and 2 represent temperatures of the cooled water and seawater respectively.

Simulations were made for all three systems and results were integrated through cooling season. Comparing these systems (Figure 9.) one can see that SWC systems gives the best results, consuming less electrical energy for the same cooling energy supplied to buildings. SWC system is consuming 80% less electricity than second best VC system, and 83% less electricity that worst cooling system.

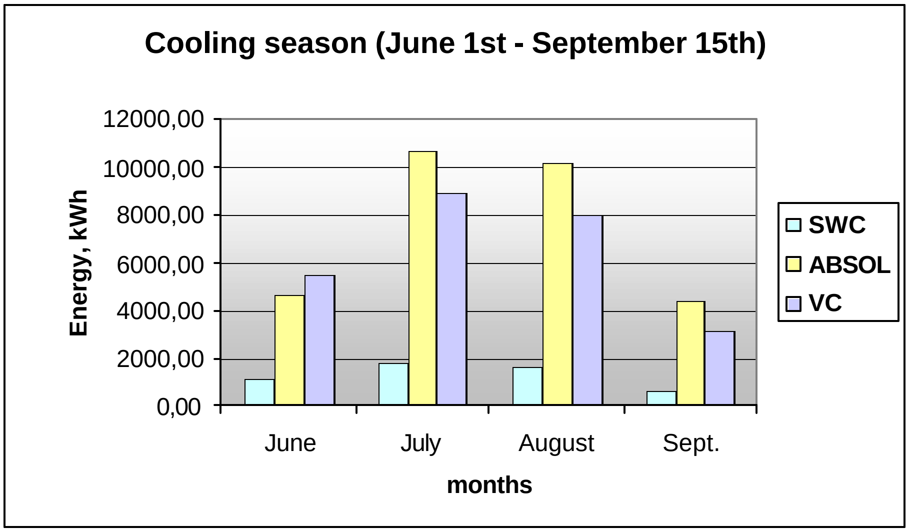

Figure 9. *Electricity consumption in cooling systems*

Although expected, ABSOL system utilizing solar energy for cooling is not second best, due to collector's type and back up system. Exception was only in June, when due to the lower cooling demand and high insolation ABSOL system gives better results than VC system. Results would be better if instead flat plate collectors, evacuated tubes or concentrated collectors were used. The back up system for hot water production is electricity what makes big ratio of electricity consumption in ABSOL system especially during the pick hours.

7. Conclusions

Tourism facilities belonging to tertiary sector, as well as residential buildings have an impact on long-term energy consumption and new buildings should therefore meet minimum energy performance standards tailored to the local climate. Therefore, current process of renovation of Croatian hotels should be regarded as an opportunity to take cost effective measures to enhance energy performance.

With the example of tourist Eco complex it was showed that assuming sustainable building design it is possible to implement system with high temperature cooling and to reduce electricity consumption up to 80% during the cooling season. High temperature cooling system gives opportunity for seawater utilization that might be considered as renewable energy source.

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