Low temperature solar thermal domestic hot water potential of Croatia's Islands and Coastal Regions

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Abstract

This paper discusses solar thermal energy as a cost-effective alternative to conventional energy sources for the supply of domestic hot water for private housing and tourist accommodation along the Croatian Adriatic coast. The initial analysis concerns domestic hot water system designs and simulation. This includes a brief view on the following topics: simulation software, hourly climate data and simulation procedures. Daily, weekly and annual domestic hot water demand profiles reflect fluctuations in utilization of tourist accommodations. Potential solar yields along the coast significantly increase southwards. Simulation results for annual specific solar yield and solar coverage ratio are summarized for four different solar thermal systems, each with two collector orientations and using climate datasets from Rijeka, Zadar and Hvar. The number of inhabitants and tourist overnight stays are used to estimate current final energy consumption and potentially replaceable amounts, showing that only 10% of ST installations for the proposed applications would nearly double the current share of renewable energy in Croatia. Consequently, economic methods are used to show that investment payback times are significantly shorter than the expected system lifetime.

1. Introduction

The most widely used energy resources for preparing domestic hot water (DHW) in Croatia are fuel oil, gas and electricity. Diverse, ongoing and previous energy crises are signals that highlight existing European dependencies in the energy sector. A viable alternative would be the utilization of free and sustainable sources such as solar energy, which could help to lower this dependency and provide more than two thirds of the energy necessary for providing DHW within reasonable costs. Replacing a share of useful energy obtained from electrical or fuel sources, is expected to have positive side-effects of an ecological as well as logistical nature in regards to the summer peak electricity supply problems – especially on islands with poor grid connectivity. The percentage of international hotel managers (66%) considering solar thermal (ST) energy supports the relevance of this study [1].

An extensive analysis of low temperature ST systems by Pichler [2] has predicted significantly higher annual solar coverage ratios (*SCR*) along the Croatian Adriatic coast than those for middle and northern Europe. The analysis of a ST system for purely private demand (SFH f) and three systems of small (ACC S), medium (ACC M) and large (ACC L) size demand for tourist accommodation facilities show, that the southern part of the country is in the context of this paper nearly as favorable as the proponent Greece.

2. Methods

2.1. Simulation Software and Climate Data

Simulations presented here were performed using SHWwin [3] and synthetic hourly climate data provided by METEONORM [4], whose applicability has been investigated in [2].
SHWwin provides monthly and annual results in a table-like schematic [2, 3]. Thermal stratification of storage tanks is modeled using 10 layers and via the vertical heat conduction coefficient λ. System features from the collector field to the storage such as pipe length, the heat capacity of all parts and various thermal losses are taken into account. The step size of the algorithm is 6 minutes and it uses interpolation between two sequential hourly climate data inputs. Initial boundary condition problems for heat storages are avoided by using a two months overlap in the simulation period: i.e. it starts in August and ends in September of the following year.
This study required average hourly climate data for a base period of at least 10 years, namely global and diffuse solar radiation on a horizontal surface of 1 m², and ambient temperature. Climate data generation was based on measurements from 1996-2005 for temperature and from 1981-2000 for radiation data. Uncertainties were 1.5°C and 9% for monthly solar radiation, less than the natural variations of global radiation between consecutive years [4]. Climate datasets for Rijeka, Zadar and Hvar (designated *Ri* / *Zd* / *Hv*) were used to assess system performances in different latitudes and were assumed to provide representative samples of their surrounding coastal municipalities.

2.2. Control Parameters

All considered ST systems incorporate pumps for heat supply, for which typical parameters of on/off control units were a temperature difference of 5 K and a hysteresis of 1-2 K. Low, high and matched flow rate systems were analyzed. Low flow concepts (~10 ℓ / (m² h)) with stratification units as used in ACC S guarantee a high temperature rise in the collector field (40 K) and rapidly provide high exergy. By contrast, the temperature rise for high flow rate systems (~20 – 50 ℓ / (m² h)), as used in SFH f, should not exceed 10 K to assure high collector efficiencies. The systems ACC M and ACC L use the matched flow concept.

2.3. Statistical Data, Facility Utilization and DHW Demand

Data for tourist overnight stays was obtained from [5] where it was compiled from regular monthly accommodation and agency services' reports. Accommodation facilities in this paper are divided into three categories named after the facility with the highest genuine share: Hotels etc. (later split into Hotels and Apartments), Camps and Private Accommodations.
The analyzed tourist traffic statistics showed that 91% of annual overnight stays in Primorje-Gorski kotar County (PGC) fall into the summer season between May and September. Different accommodation facilities vary with respect to facility utilization (FU), which is the total number of overnight stays in a year divided by bed capacity (n_{beds}) [2]. The average summer season FU , abbreviated $FU_{\mathrm{(S)}}$, is expressed in days as 143.5, 129.2, 63.3 and 37.7 for Hotels, Apartments, Camps and Private Accommodations, respectively. These numbers, divided by the number of summer days (153), lead to the facility utilization factors $FU_{\mathrm{F(S)}}$ which are 0.94, 0.84, 0.41 and 0.25, respectively. A nominal daily summer demand for DHW ($V_{\mathrm{dem(S)}}$) in tourist accommodations is given by [6, 7]:

$$V_{\mathrm{dem(S)}} = V_{\mathrm{G}} \cdot n_{\mathrm{beds}} \cdot FU_{\mathrm{F(S)}} \tag{1}$$

where V_G is the daily demand in ℓ at 60°C (over 45° for hygienic reasons) per guest, which was estimated to be 60 for Hotels, 40 for Apartments and Private Accommodations and 20 for Camps, [2]. $V_{dem(S)}$ is the key parameter in sizing of ST systems for summer tourism accommodations. All systems in use have been defined for certain standard accommodations [2]; $V_{dem(S)}$ was calculated at 320 ℓ / day for ACC S (Private Accommodation n_{beds}= 16), 1640 ℓ /day for ACC M (Camp n_{beds}= 200) and 5640 ℓ / day for ACC L (Hotel n_{beds}= 100). For a single family of 4 persons the assumed annual daily DHW demand (V_{dem}) is 200 ℓ at 45°C per day.

The actual daily DHW consumption results from folding $V_{dem(S)}$ or V_{dem} with respective demand profiles, see Fig. 1. Anticipated hourly demand for each day has been deduced in [2] from demand profiles for the IEA solar heating and cooling Task32. Daily demand for private housing was set to 90% during the week, 100% on Fridays, and 120% over the weekend but was assumed constant at 100% for tourist accommodations. Annual demand reflects variations of ground water temperature (set 10°C), demand variations for private housing, and the annual distribution of overnight stays for the respective accommodation facilities combined with minimum demand for the off-season months [2].

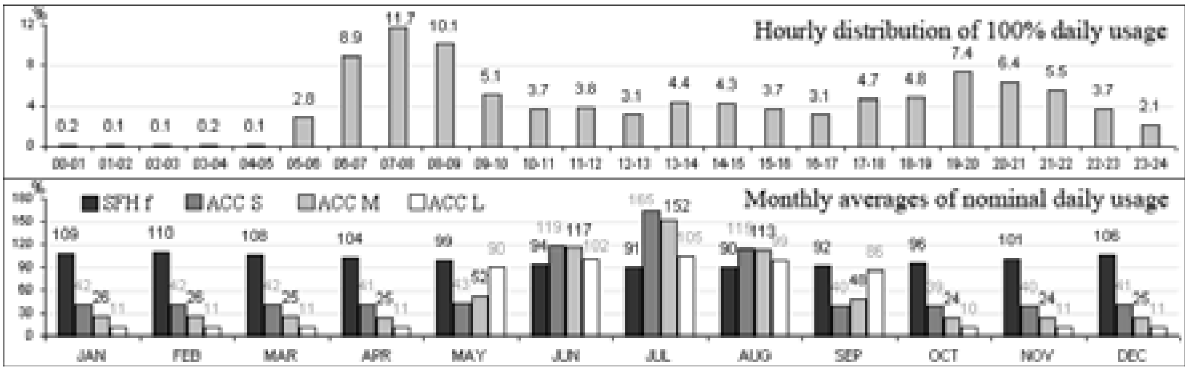

Fig. 1. Daily (above) and annual (below) DHW demand profiles relative to the nominal daily demand [2]. Monthly averages have been derived from data for PGC in 2008.

2.4. Solar Thermal System Analysis and Optimization

The system description includes the collector field, storage, pipe, insulation and flow related parameters and along with the DHW demand profile constitutes the main part of the model in Fig. 2.

Fig. 2. System analysis procedure, with most relevant parameters and available results.

The solar coverage ratio is an important simulation result characterizing the performance of a system, and is generally used to compare different system designs for the same application. It is given by:

$$SCR = 1- [\Sigma_i (Q_{aux(i)}) / Q_{demand}], \qquad (2)$$

where Q_{demand} is the total heat demand and $Q_{aux(i)}$ the auxiliary heat demand of the i-th auxiliary source. For the optimization, it was assumed that systems with a *SCR* of approximately 70% for tilt β= 45° and azimuth γ= 0° represent a good balance of performance, ecological and economical optima [6] . This was applied to the climate datasets for Rijeka, Zadar and Hvar.

3. Solar Thermal Systems

Hydraulic designs of the investigated systems are illustrated in Fig.3 and their defining parameters are given in Table 1. Certain adjustments were needed in aiming for a *SCR* of 70% for templates previously defined in [2, 7] – mainly smaller collector fields and storages appropriate for the climate.

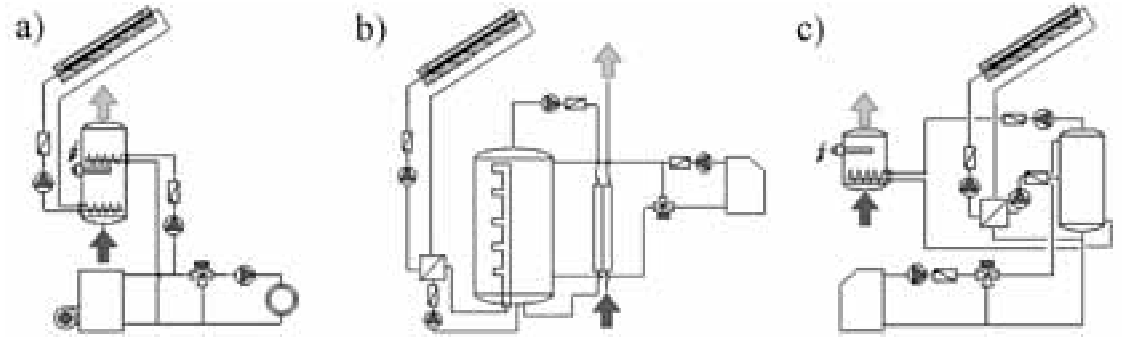

Fig. 3. Hydraulic design of three ST systems for DHW provision **a)** SFH f **b)** ACC S and **c)** ACC M / ACC L. Auxiliary heating for all designs is either electrical, via a boiler or both. Light and dark arrows indicate hot water draw-off and cold water inlet, respectively [3].

Table 1: Technical parameters for simulated systems; varying collector field and storage sizes separated with a slash refer to climate data *Rijeka* / *Zadar* / *Hvar*. All simulations were performed using a flat-plate collector.

Description	Parameters and respective values
Collectors (at 1.92 m²):	Conversion factors: c_0=0.759, c_1=3.768, c_2=0.0 — Incidence angle modifier = 0.9
SFH f: 200 (liter 45°C)/ day,	**Collector field**: net. surface 5.75 m² / 3.83 m² / 3.83 m²
Collector loop, pipes	1.5 mm Cu, *d* =15 mm, *L* = 20 m; insul.: 30 mm, 0.04 W/(m^2 K), mass flow = 0.045 kg / s
DHW Storage	300 ℓ / 300 ℓ / 250 ℓ , λ = 1.46 W/(m K); $T_{max\ solar}$ = 67°C, $T_{max\ aux}$ = 50°C
ACC S: $FU_{F(S)}$ = 0.25, 320 (ℓ 60°C) / day;	**Collector field**: net. surface 7.66 m²/ 5.75 m^2/ 5.75 m^2
Collector loop, pipes	1.5 mm Cu, *d* = 15 mm, *L* = 40 m, insul.: 30 mm, 0.04 W/(m^2 K), mass flow = 0.04 kg / s
Heat Storage (stratif.)	500 ℓ / 500 ℓ / 350 ℓ , λ = 1.5 W/(m K); $T_{max\ solar}$ = 80°C, $T_{max\ aux}$ = 65°C
ACC M: $FU_{F(S)}$ = 0.41, 1640 (ℓ 60°C) / day;	**Collector field**: net. surface 36.39 m²/ 28.75 m^2/ 26.83 m^2
Collector loop, pipes	2 mm Cu, *d* = 42 mm, *L* = 40 m; insul.: 30 mm, 0.04 W/(m^2 K), mass flow = 0.6-0.85 kg / s
DHW Storage	500 ℓ, λ = 1.8 W/(m K), $T_{max\ heat\ storage}$ = 65°C, $T_{max\ aux\ elect}$ = 60°C
Heat Storage	1500 ℓ / 1000 ℓ / 1000 ℓ , λ = 1.2 W/(m K); $T_{max\ solar}$ = 93°C, $T_{max\ aux\ boiler}$ = 67°C
ACC L: $FU_{F(S)}$ = 0.94, 5640 (ℓ 60°C) / day;	**Collector field:** net surface 130.22 m²/ 99.58 m^2/ 95.74 m^2
Collector loop, pipes	2 mm Cu, *d* = 66 mm, *L* = 100 m; insul.: 30 mm, 0.04 W/(m^2 K), mass flow=1.1-2.2 kg / s
DHW Storage	1000 ℓ , λ = 1.4 W/(m K); $T_{max\ heat\ storage}$ =62°C, $T_{max\ aux\ elect}$ = 60°C
Heat Storage (stratif.)	7000 ℓ / 5000 ℓ / 5000 ℓ , λ = 1.0 W/(m K), $T_{max\ solar}$ =88°C, $T_{max\ aux\ boiler}$ = 67°C

3.1. Simulation Results

Unless explicitly stated otherwise, all results refer to annual values. Hourly DHW consumption for SFH f and ACC S was taken at the first simulation step of each hour while ACC M and ACC L distribute consumption continuously within the hour. Results for each system and the three different climate datasets are provided in Table 2. Annual useful energy demand for DHW preparation in kWh equals to 2964, 4353, 19099 and 55995 for SFH f, ACC S, ACC M and ACC L, respectively. System size decreases significantly towards south for the same DHW demand, and parallel the operation time increases. Q_{losses} incorporates all losses connected to the ST equipment installed.

Table 2: Result overview of three climate datasets for all systems, $\gamma = 0°$ and $\beta = 45°$. System names are given in the leftmost column along with the net collector field size and total volume of storages involved. Columns with the suffix ***Sample*** refer to $\gamma = 45°$ and $\beta = 30°$ for SFH f and ACC S or $\beta = 15°$ for ACC M and ACC L.

Annual mean values **System: [m²], [ℓ]**	***Rijeka/ Zadar/ Hvar***	**Global radiation [MWh]**	***SCR* [%]**	***SCR Sample* [%]**	**Operation time [h]**	**Q_{useful} Coll. [kWh]**	**Q_{losses} sol. loop & Storage [kWh]**	**Specific solar yield in storage [kWh/ m²]**	**Specific solar yield in storage *Sample* [kWh/ m²]**	**System Efficiency [%]**	**Coll. Efficiency [%]**
SFH f: 5.75, 300	*Ri*	8.1	68.3	63.3	2214	2655	631	**434**	**407**	32.8	47.5
SFH f: 3.83, 300	*Zd*	6.7	72.5	65.6	2491	2803	655	**685**	**628**	42.1	53.1
SFH f: 3.83, 250	*Hv*	6.8	72.1	67.4	2510	2758	620	**673**	**633**	40.3	52.6
ACC S: 7.66, 500	*Ri*	10.8	74.1	72.1	1722	3775	737	**462**	**448**	35.1	53.5
ACC S: 5.75, 500	*Zd*	10.0	72.0	70.7	1797	3681	760	**597**	**583**	36.8	56.8
ACC S: 5.75, 350	*Hv*	10.3	76.0	75.6	1939	3718	695	**602**	**595**	36.2	56.0
ACC M: 36.39, 2000	*Ri*	51.1	71.7	69.2	1652	15421	1828	**404**	**388**	30.2	43.9
ACC M: 28.75, 1500	*Zd*	50.0	72.2	69.3	1842	15835	2182	**521**	**497**	31.7	46.3
ACC M: 26.83, 1500	*Hv*	47.9	71.9	69.6	1923	15806	2207	**557**	**535**	33.0	46.9
ACC L: 130.22, 8000	*Ri*	183.0	71.2	70.0	1533	47945	5330	**347**	**339**	26.2	40.3
ACC L: 99.58, 6000	*Zd*	173.3	69.6	68.3	1766	46942	5367	**439**	**429**	27.1	41.9
ACC L: 95.74, 6000	*Hv*	170.9	69.8	69.8	1820	47198	5463	**458**	**456**	27.6	42.1

3.2. Result Analysis

A specific storage volume of 60 ℓ / m² is suggested for Austria [6], while a study focusing on economical viability of DHW systems proposes 55 ℓ / m² for Greece [8], however, it ranges from 52 ℓ / m² to 78 ℓ / m² in this paper. System efficiencies are between 26.2% and 42.1%.

Increasing the storage volume for **SFH f** to 350 ℓ for climate data *Ri* would increase *SCR* to 70.2%, while a 200 ℓ storage for *Zd* would decrease *SCR* to 59.6%. For *Hv,* a storage of 200 ℓ leads to *SCR* = 63.1%, while for 250 ℓ the *SCR* rises to 72.1%. The maximum *SCR* for *Ri* is achieved with $\gamma = 0°$, $\beta = 45°$ (Fig. 4); for *Zd* and *Hv* the angle β changes marginally. Actual specific outputs of a slightly smaller system in Greece were found to range from 350 to 800 kWh/m² [9].
For **ACC S** and climate data *Ri,* a storage smaller than 500 ℓ sometimes cannot maintain a set DHW temperature value. A similar problem occurs for *Hv* even though a storage of 300 ℓ would lead to a *SCR* of 77.5%. Reducing the collector field for *Hv* by one panel to 3.83 m² leads to a *SCR* of 52.1%. For systems like **ACC M**, with off-season demand equal or less than one quarter of the nominal demand, $\gamma = 0°$, $\beta = 30°$ lead to maximum annual performance, see Fig. 4. The average *SCR* over the summer period for **ACC L** is surprisingly ~3.3% lower than the annual values. This can be explained by the high *SCR*s off-season because of low demand, which is approximately only 11% of the nominal demand. The parametrized DHW circulation for this system, with three circulation periods per day, resulted in 4323 kWh losses in the draw-off loop per year.

By contrast to the wide range of specific annual yields of the four systems, average specific yields from May to September vary only between 342 and 360 kWh/m² (given for *Zd*). Another investigation in [2] showed an average drop in *SCR* of 3.6 ± 1.6% for atypical years with 9% lower global radiation. These numbers increase for larger systems, while *SCR* proportionally decreases.

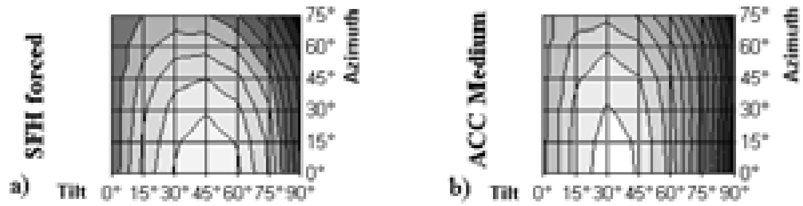

Fig. 4. Collector orientation contour plots of *SCR*, performed for the *Ri* climate. Azimuth refers towards the east and the grayscale map for category values is divided in 2.5% steps, with higher values shown brighter. **a)** SFH f, DHW demand: 200 ℓ 45°C /day, and **b)** ACC M, DHW demand: 1640 ℓ 60°C /day [2];

For evaluation of actual average values of ST systems for DHW purposes when installed, simulation results within the range of $\beta \in \{15°, \dots, 60°\}$ and $\gamma \in \{0°, \dots, 60°\}$ have been taken into account for each averaged variable [2]. Comparing the average values with individual results, the angle combinations $\gamma = 45°$ and $\beta = 30°$ (SFH f, ACC S) and $\gamma = 45°$ and $\beta = 15°$ (ACC M, ACC L) provide representative samples that were used as surrogates for the averaging procedure. Uncertainties of 3% and 15 kWh / m² can be attributed to the *SCR* and specific ST yield, respectively.

4. Potential Estimation and Economical Aspects along the Croatian Adriatic Coast

Seven coastal Croatian counties were considered for estimates of ST potential. Simulations using climate datasets of Rijeka (lat. 45.33°, long. 14.45°), Zadar (lat. 44.10°, long. 15.36°) and Hvar (lat. 43.16°, long. 16.45°) were assumed as representative for their surrounding coastal mainland and island municipalities. Municipalities were grouped across counties to form, with their respective datasets: the northern group (counties Istria, PGC and Lika-Senj); central group (counties Zadar and Šibenik-Knin); and southern group (counties Split-Dalmatia and Dubrovnik-Neretva) used in Table 3.

4.1. Annual Bed Capacities and Overnight Stays

Table 3. Total useful energy demand, and replaceable and auxiliary final energy demand for DHW preparation in SFHs and four accommodation categories. Data from Hotels (etc.) was split into Hotels (75%) and Apartments (25%), according to the PGC data distribution [2]. Total bed capacities for accomodations and the number of SFHs ±10% are given for each group of municipalities. *SCR Sample* is taken from Table 2.

Annual energy demand	**Hotels (etc.)**	**Apartments**	**Camps**	**Priv ACC**	**# of SFH**
Northern group (*Ri*): Bed capacity I #SFH	94311		148801	178869	81346
Central group (*Zd*): Bed capacity I #SFH	21869		32704	113973	36803
Southern group (*Hv*): Bed capacity I #SFH	51672		17818	143909	73396
$FU_{F(S)}$	0.94	0.84	0.41	0.25	-
Daily demand ℓ / unit	60	40	20	40	200
$Q_{specific}$ [Wh/ ℓ]	58	58	58	58	40.6
Demand for DHW, for seaside resorts of coastal counties and SFHs in [MWh]					
$Q_{useful\ total}$	**76303**	**15467**	**22261**	**63430**	**237968**
Demand for DHW, for seaside resorts of coastal counties and SFHs for 10% share; in [MWh]					
$Q_{useful\ for\ 10\%}$	**7630**	**1547**	**2226**	**6343**	**23797**
Conversion Efficiency	0.70 ± 0.08			0.79 ± 0.10	
SCR Sample [%] ± 3% for *Ri* / *Zd* / *Hv*	70/ 68/ 70	70/ 68/ 70	69/ 69/ 70	72/ 71/ 76	63/ 66/ 67
$Q_{final\ replaceable}$ [MWh]	**7630**±589	**1547**±119	**2201**±191	**5789**±449	**19068**±1934
$Q_{final\ auxiliary}$ [MWh]	3270±314	663±63	979±104	2240±216	11055±1206

Annual overnight stays in counties considered in this paper amount to 54.63 million – 52.66 million of which (~96.4%) refers to seaside resorts, including coastal mainland and islands, where the season from May to September accounts on average for 93.5% of the total seaside resort overnight stays. Official data was not available for the number of single-family houses (SFH) in relevant counties; it was estimated at 40% ± 10% of the total number of households [5].
Bed capacities listed in Table 3 reflect 89% of the total capacity, which includes other types of accommodation. Useful energy demand in Table 3 was calculated for an assumed share of ST system installations, namely 10% of the total bed capacity, for the summer (153 days) using $FU_{F(S)}$ and the off season (212 days) with a factor of 0.1 (low occupation, maintenance, cleaning etc.). Conversion efficiencies [2], together with *SCR Sample*, lead to the potential replaceable final energy of 17.2 GWh (62 TJ). For SFH and a share of 10% ST system installations it is 19.1 GWh (69 TJ).
Results in Table 3 can be extrapolated for other ST installation shares, due to linear dependencies.

4.2 Economical Viability

A net present value (PV) calculation [9] was applied to gauge the competitiveness of ST systems compared to conventional ones. Local suppliers were consulted for investment costs, which incorporate specific collector costs (€ 200±25 per m²), specific storage costs (between € 0.91 and 3.1 per ℓ) and costs for other components and installation [10]. Maintenance and operation costs were 1.5% for SFH f, ACC S and ACC M and 1.0% for ACC L, with respect to the total investments.
PV of savings was calculated using a current price of € 0.077 ± 0.01 per kWh (electricity for SFH f and ACC S) or € 0.060 ± 0.01 per kWh (light fuel oil for ACC M and ACC L).

Table 4: Overview of economic viability for all simulated systems. System names on the left are followed by replaced and auxiliary final energy. Together with *Ri, Zd* or *Hv,* they correlate to the systems in Table 2. Needed subsidies with respect to the total investment costs are given for three investment payback times (*IPBT*) in years (7 a, 10 a and 15 a); *IPBT* is also provided for 0% subsidies in the rightmost column.

System: *Q*final replaced *Q*final aux. [MWh]	***Rijeka/ Zadar/ Hvar***	**Specific costs** [€/m²]	**Subsidy** [%] for 3 *IPBT*			***IPBT*** [a]
			7 a	10 a	15 a	no subsidy
SFH f 2.6 ± 0.4 1.1 ± 0.2	*Ri*	570 ± 95	>50	45	10	16.5
	Zd	648 ± 95	50	23	0	12.5
	Hv	609 ± 95	45	17	0	12.0
ACC S 3.9 ± 0.5 1.7 ± 0.3	*Ri*	553 ± 100	>50	36	0	14.5
	Zd, Hv	598 ± 103	45	18	0	12.0
ACC M 19.1 ± 2.3 8.2 ± 1.2	*Ri*	457 ± 48	>50	47	13	16.5
	Zd, Hv	453 ± 48	45	17	0	11.5
ACC L 56.0 ± 6.8 24.0 ± 3.6	*Ri*	426 ± 48	>50	43	6	16.0
	Zd, Hv	425 ± 48	47	22	0	12.5

An inflation rate of 2.9% ± 1.0% was assumed (mean value of the Harmonized Indices of Consumer Prices for EU27 and Croatia for the last 10 years). Average interest rates for 10-year government bonds yielding 4.4% ± 0.4% were assumed for market capital costs. The energy price index is the most important and time sensitive parameter for this assessment. It was set at 7.1% ± 5.1% using the five-year average for Electricity, Gas and other Fuels for EU27. Results obtained for *IPBT* are slightly higher than those achieved in [1], but subsidies between 17% and 47% (depending on the system) could reduce the *IPBT* to 10 years. For comparison, state subsidies between 11% and 30% existed in Greece before 2004 [9] and different counties in Austria offer up to approximately 25% in subsidies.

5. Conclusion

Four DHW ST systems, with net collector fields from 3.83 m² to 130.22 m² and specific annual solar yields between 347 and 685 kWh/m², were analyzed for applications in tourism accommodations and private housing, in three groups of Croatian municipalities on the Adriatic Coast.
System performance was shown to depend on geographical latitude, annual DHW consumption profiles and the heat storage volume. Oversized storages for small scale systems can significantly raise *SCR* and compensate for suboptimal collector field sizes. An alternative to the SFH f system would be a self-sufficient system employing natural circulation with an immersion heater (like 95% of the systems in Greece [9]). Maximum annual yields were achieved with 30° tilt angles for dominating heat demand in summer. Specific annual yields are higher than in Austria [2], where the ST market is well developed. ST systems showed high reliability, even for years with a 9% reduction in global solar radiation. Final energy savings in e.g. fuel oil for a scenario with a 10% share of ST installations for DHW systems in tourist accommodations and private housing would nearly double the current share of renewables in the total final energy consumption of Croatia and lead to CO_2 reductions of 12200 tons. The cost analysis indicated a significantly lower *IPBT* than the expected system lifetime of 20 years. It could drop to 10 years with subsidies but also increase for higher system costs at remote islands.
ST systems for DHW preparation represent a viable opportunity to save energy resources. Rising electricity prices and summer peak demands combined with poor grid connectivity further favor the use of ST systems. Finally, extensive market development would also create new jobs and Croatia's low temperature ST potential could further be extended to cooling and industrial purposes.

References

[1] M Karagiorgas, T. Tsoutsos, V. Drosou, et. al., HOTRES: renewable energies in the hotels. Renewable & Sustainable Energy Reviews 10 (2006) 198-224, Elsevier

[2] M. Pichler, (2010). Potentials and practical Proposals for the use of Solar Thermal Energy in a chosen Region in Croatia, Master thesis at the Karl Franzens University Graz, Graz – Rijeka 2009, London 2010

[3] W. Streicher, K. Schnedl, A. Thür, A. Vilics (1999). SHWwin V. 1, 2 Okt. 1999, Programmbeschreibung von SHWwin, Version 25. April 2000, Technical University Graz, http://lamp.tu-graz.ac.at/~iwt/

[4] J. Remund, S. Kunz, C. Schilter (2008). METEONORM Version 6.0 Handbook part I: Software; Software Version 6.1.0.12 METEOTEST, CH-3012 Bern, Switzerland

[5] I. Kovač, (2009). Statistical Reports 2009, ISSN 1332-0297, Editor-in-Chief: Jasna Crkvenčić-Bojić, Central Bureau of Statistics of the Republic of Croatia – Archive and Publications Division, stat.info@dzs.hr

[6] G. Tschernigg, Technical description, sizing and calculation methods of solar systems in tourism, arsenal research, Trans Solar Conference, Zagreb April 2009

[7] M. Pichler, S. Fućak, B. Franković (2009). Low temperature solar thermal potential for DHW purposes on the islands of Primorsko-goranska county, Third conference on marine technologies 2009, 176-194, Rijeka

[8] J.K. Kaldellis, K. El-Samani, P.Koronakis, Feasibility analysis of domestic solar water heating systems in Greece, Renewable Energy 30 (2005) 659-682, Elsevier

[9] J.K. Kaldellis, K. A. Kavadias, G. Spyropoulos, Investigating the real situation of Greek solar water heating market, Renewable & Sustainable Energy Reviews 9 (2005) 499-520, Elsevier

[10] M. Kaltschmitt, W. Streicher, A.Wiese (2007). Renewable Energy - Technology, Economics and Environment, Springer, Berlin Heidelberg New York