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ECONOMICAL ASPECT AND ENVIRONMENTAL IMPACT OF RENEWABLE TRIGENERATION IN URBAN AREAS

SCHARNHAUSER PARK CASE STUDY

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ABSTRACT

In this study, a biomass powered tri-generation system integrated in an urban area is described and both its economical aspect and environmental impact are assessed.

Scharnhauser Park (Germany) is a modern urban settlement in which low-consumption buildings and renewable technologies are demonstrated. Through EU-funded research projects CITYNET and POLYCITY [1, 2], a significant part of on-site energy flows is measured and monitored. The core of the energy supply system is an 8 MW_{th} wood-fired ORC co-generation plant. The residual heat from the electricity generation process amounts to 30 GWh/a and is fed into a 13 km long district heating network. The plant is operated in heat-driven mode and its power can be adapted flexibly to the demand of the urban quarter. Additionally, more than 40 kWp of photovoltaic equipment have been installed in the area.

Finally, a decentral 105 kW absorption chiller has been connected to the district heating in order to provide cooling to a 3 500 m² office building.

ENERGY SYSTEM DESCRIPTION

Urban area

Scharnhauser Park (Germany, 48.72°N - 9.27°E) is a modern urban settlement in which low-consumption buildings and renewable technologies are demonstrated. The site offers opportunities of public spaces, 40 000 m² of industrial area, 90 000 m² of mixed commercial area as well as a wide range of housing types for more than 7 000 inhabitants.

Biomass ORC power plant

The core of the energy supply system is an 8 MW_{th} wood-fired ORC co-generation plant.

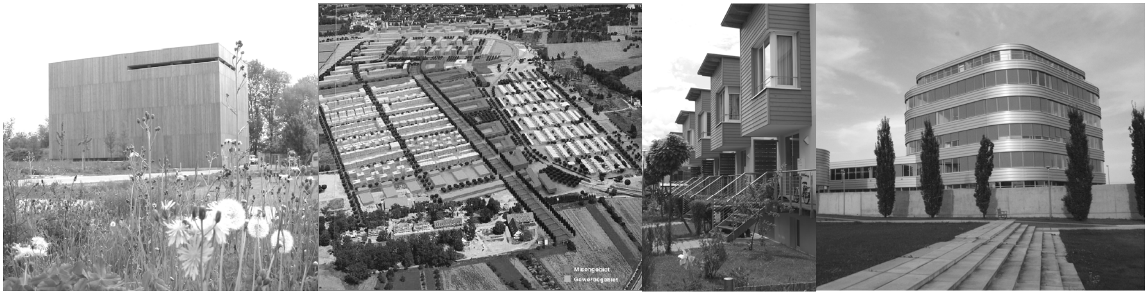

Figure 1- Scharnhauser Park – CHP / Aerial view / dwellings / Elektror office building

Component	Physical quantity	Value	Unit
Biomass furnace	heat transfer rate	8 000	[kW]
Wood storage	capacity	1 400	[m³]
Fuel consumption	design point volume flow	200	[m³/d]
Power ORC	heat transfer rate (input)	6 356	[kW]
	heat transfer rate (output)	5 300	[kW]
	electric output	1 000	[kVA]
Feed pump	electric input	61	[kW]
Vacuum pump	electric input	5	[kW]
Auxiliary power furnace	electric input	25	[kWh(el)/MWh(th)]
Annual wood comsumption	annual mass flow	43 000	[tonnes/a]
Fossil fuel saving		38 000	[MWh/a]
CO2 reduction		7 000	[tonnes/a]

Table 1 - Biomass cogeneration plant specifications [2]

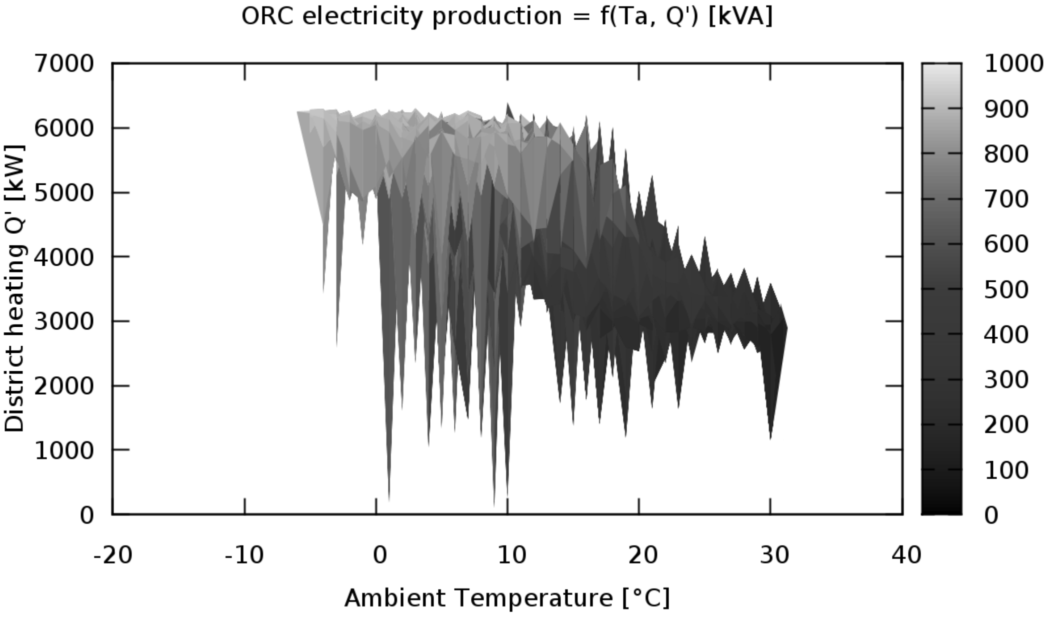

Figure 2- ORC electricity production vs ambient temperature T_a and district heating heat transfer rate $\dot{Q}$ – 8760 hourly values of 2008

The carpet plot is ill-shaped because T_a and $\dot{Q}$ are not independent variables: the heat-driven power plant only delivers its full power when requested, i.e. when outside temperatures are low and heat demand is sufficient. This graph clearly shows that the ORC process only reaches its maximal power in winter cases, when more than 5 MW heat are delivered to the district heating network.

One suggested way to improve electricity production in summer cases is to connect decentral absorption chillers to the district heating system.

District heating network

The residual heat from the electricity generation process amounts to 30 GWh/a and is fed to the 13 km long district heating network.

District heating network	Physical quantity	Value	Unit
Annual heat transfer	heat transfer	29.5	[GWh/a]
Maximum heat transfer rate	heat transfer rate	16	[MW]
Design supply temperature	water temperature	85	[°C]
Design return temperature	water temperature	55	[°C]
Average mass flow	mass flow	103	[m³/h]
Maximum mass flow	mass flow	460	[m³/h]
Supply pipes total length	length	13	[km]

Table 2 – Design parameters of district heating network

The plant is operated in heat-driven mode and its power can be adapted flexibly to the demand of the urban quarter.

Photovoltaic modules

More than 40 kW_p of crystalline silicon photovoltaic modules has been installed in the area.

Generator type	Energy yield [kWh/kWp.a]	Method	Reference
Facade	639	(measured)	[internal]
Horizontal	810	(simulated)	[4] [5]
Tilted (30°)	910	(simulated)	[4] [5]

Table 3 – PV-generator energy yield

Absorption cooling machine (ACM)

A decentral 105 kW absorption chiller has been connected to the district heating in order to provide cooling to a 3 500 m^2 office building.

Yazaki WFC-SC 30	Physical quantity	Value	Unit
Nominal power	thermal power	105	[kW]
Coefficient of performance	ratio	0.65	[-]
Generator level	temperature	78.0→73.7	[°C]
Heat sink level	temperature	27.0→30.6	[°C]
Evaporator sink level	temperature	15.0→9.0	[°C]

Table 4 – Absorption chiller specifications

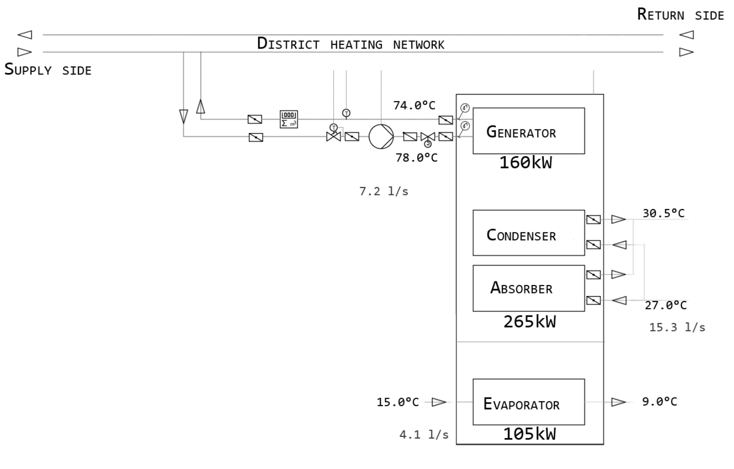

Figure 3 - Yazaki WFC-SC 30 connected to the district heating network

ANALYSES

Primary energy analysis

COP based comparisons of thermal-driven and vapour-compression chillers (CCM) are not satisfying, since they do not take into account that these systems use energy of different qualities. Studies should take either exergy or primary energy requirements under consideration in order to reflect the associated environmental impact.

In (1) and (2), the required amount of primary energy to provide 1 MWh of cooling with both systems is calculated.

$$\left.\begin{aligned} COP_{el} &= 3 \\ \eta_{el} &= 0.38 \\ PEF &= \frac{1}{\eta_{el} \cdot COP_{el}} \end{aligned}\right\} \Rightarrow PEF_{ccm} \approx 0.88 \frac{MW_{pe}}{MW_{cooling}} \qquad (1)$$

0.88 MWh of primary energy is required in order to provide 1 MWh of cooling with a vapour-compression chiller, when driven by German electricity grid [6].

$$\left.\begin{aligned} COP_{el} &= 7 \\ COP_{th} &= 0.65 \\ \eta_{tot}^{(CHP)} &= 0.88 \\ \eta_{el}^{(CHP)} &= 0.16 \\ \eta_{el}^{(PP)} &= 0.38 \\ PEF &= \frac{1}{\eta_{el} \cdot COP_{tot}} \\ \frac{1}{COP_{tot}} &= \frac{1}{COP_{th} \cdot x} + \frac{1}{COP_{el}} \\ x &= \frac{\eta_{tot}^{(CHP)} - \eta_{el}^{(CHP)}}{\eta_{el}^{(PP)} - \eta_{el}^{(CHP)}} \end{aligned}\right\} \Rightarrow PEF_{acm} \approx 1.61 \frac{MW_{pe}}{MW_{cooling}} \qquad (2)$$

These calculations are based on Directive 2004/8/EC [7], being slightly modified to take the electricity consumption of the auxiliary pumps and cooling tower into account.

In the case of Scharnhauser Park 1.61 MWh of primary energy are required in order to provide 1 MWh of cooling with an ACM connected to the district heating network. This represents approximately 84% more than shown in (1). The parameter that varies the most from one energy system to the other is $\eta_{el}^{(CHP)}$. All other parameters being equal, the same primary energy requirements for ACM and CCM will be achieved with an $\eta_{el}^{(CHP)}$ of 30%, while state of the art combined-cycle CHPs can reach 60%.

CO₂ savings

Even though the heat driven chiller requires more primary energy than the conventional one, its energy input derives from a biomass furnace with a much lower carbon footprint than the average German power plants: a life cycle analysis has shown that the biomass CHP releases 5 times less CO_2 (110 g/kWh vs 550 g/kWh) [8].

Therefore, producing one MWh of cooling will release approximately 60% less CO_2 with an ACM than with a CCM.

Cooling costs

Costs	Capital [€/kW]	Extra [€/kW]	Maintenance [€/kW.a]
Absorption	420	830	30
Compression	220	108	37

Table 5- Costs related to absorption and compression chillers

Energy costs		
electricity	150	€/MWh
heat	20	€/MWh
water	1.8	€/m³

Table 6 - Energy costs

This raw data sum up to cooling costs of 145 €/MWh for the ACM, and 92 €/MWh for the CCM. The European Union funded 35% of the capital costs, which led to cooling costs of 120 €/MWh for the heat-driven alternative.

Heat demand

After refurbishment, the specific heat demand of the area has been lowered by 30% in comparison to German standards [9].

U value [W/m².K]	Residential			Offices		
	Standard	SHP*	Savings [%]	Standard	SHP*	Savings [%]
Facade/Wall	0.45	0.3	33	0.45	0.17 - 0.26	53
Roof	0.25 - 0.3	0.23 - 0.31	2	0.3	0.1 - 0.21	48
Ground/Floor	0.4 - 0.5	0.26 - 0.36	29	0.45	0.16 - 0.38	50
Windows	1.6 - 2.3	1.2	25	1.6 - 2.3	1.2 - 1.24	24
*SHP Scharnhauser Park						

Table 7- Heat transfer coefficients of buildings envelopes [10]

CONCLUSIONS

More than 80% of the heat demand is delivered by renewable energy sources, while 50% of the electricity demand is covered by the combination of PV systems and ORC power plant.

The thermal driven chiller is planned to ensure CO_2 emissions savings of ~60% in comparison to conventional compression chillers, at a cost of 120 €/MWh (compared to 90 €/MWh with CCMs).

Under the following conditions, economic break-even can be achieved:

- Electricity price should be significantly higher than heat price (ratio>10)
- Auxiliary consumption must be kept at a minimum.

- System must be used its nominal power as often as possible. Additional thermal storage on the chilled side (either as a water tank or activated parts of the building) allows to shave the demand peak, therefore reducing the required design cooling power. A compromise must be achieved between increased capital costs due to thermal storage and reduced capital costs due to smaller design power.
- Most importantly, a low cost heat-sink should be available: the heat transfer rate ratio between heat rejection and cooling is approximately 2.5. The heat sink therefore has a significant influence on both cooling cost and primary energy requirements.

Biomass powered tri-generation in urban area is a promising technology and an efficient way to reduce primary energy requirements as well as CO_2 emissions. High electricity prices, the availability of a low cost heat-sink, very careful design and a good integration into the energy system are needed in order for this technology to achieve economic break-through without incentives.

ACRONYMS

ACM	: Absorption cooling machine, heat-driven chiller
$\eta_{el}^{(CHP)}$	: Electrical efficiency of a cogeneration plant
EU	: European Union
CCM	: Compression cooling machine, vapour-compression chiller
CHP	: Combined heat and power, cogeneration plant
COP	: Coefficient of performance
ORC	: Organic Rankine Cycle

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