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BIOMASS TRIGENERATION WITH DECENTRAL COOLING BY DISTRIC HEATING NETWORKS

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The paper presents results from the implementation of energy efficient buildings and renewable energy supply systems in the German POLYCITY project in the Scharnhauser Park. About 80% of the heating energy demand and 50% of the electricity consumption of the whole area is supplied by a wood fired co-generation plant with 1 MW electrical power and 6.3 MW thermal power. In summer the heat from the network is used for decentral absorption cooling in one of the office buildings.

The city scale monitoring showed that low energy building standards can be reached on a city scale. The user behaviour leads to a large fluctuation of consumption values, although building age and standard are rather comparable. The monitored multi-family houses had about 10-20% lower energy consumption values than the standard constructions in the area.

The own electricity consumption of the ORC power plant is rather high, as full load conditions are rarely reached. The situation will be improved with increasing population and with additional heat use in summer, for example from thermal cooling plants in office buildings. A first project was implemented and monitored in one of the offices of the commercial district. The heating energy required for cooling was comparable to the winter heating energy of the building and extends the power plant full load operation during summer during 50 hours approximately. The performance of the absorption chiller and the influence of the chiller on the network hydraulics will be shown.

Optimisation of the biomass combustion control was done to stabilize the temperatures in the combustion chamber. Humidity control of the biomass material and an optimized flue gas recirculation rate enable considerable reductions of the temperature exceedance in the combustion zone. The optimization of the furnace performance results in a decrease of about 18% (274 kWh/day) of the CHP plants auxiliary power consumption.

1. INTRODUCTION

The European Commission proposed a climate and energy package, which became law in June 2009 after adoption by the European Parliament. The legal framework supports the implementation of the 20-20-20 targets, which are a reduction in EU greenhouse gas emissions of at least 20% below 1990 levels, a supply of 20% of EU energy consumption from renewable resources and a 20% reduction in primary energy use to be achieved by improving energy efficiency.

Most countries have significantly and measurably increased their renewable energy fraction of electricity, but less so in the heat sector; however, the urban energy demand has not gone down significantly. Furthermore, benchmarks are usually not available against which to measure the achieved CO_2 reduction. Energy consumption data are mostly available on a macroscopic scale (national or international) or on a microscopic scale (individual households), but rarely on a city scale.

Detailed monitoring data from entire cities or neighbourhoods are rarely available, making it difficult to separate the effects of building energy standards, user influence on energy consumption and other climate related issues. Furthermore, there is little knowledge on performance of local renewable energy supply systems such as biomass cogeneration plants, which creates barriers to a more wide spread use of the technology.

The paper discusses performance monitoring results of buildings constructed during the last decade and analyses the influence of building standard versus user behaviour. Furthermore, it reports on ORC (Organic-Rankine-Cycle) biomass technology which provides the main heating and electricity supply to the district.

1.2 *The case study*

The case study area analysed is located in the German town of Ostfildern at the southern perimeter of the city of Stuttgart and the neighbourhood investigated is the Scharnhauser Park. The area is a former military ground and has been developed since 1992. The area has 150 hectares and includes public spaces, 90.000 m² of commercial area and several housing types such as multifamily apartment blocks, row houses, public buildings and some single family homes. The project is part of a large European funding initiative named CONCERTO, which supports concepts for city neighbourhoods with high energy efficiency and renewable integration in 58 communities in Europe. The project discussed here is part of the POLYCITY project.

Fig. 1 shows the area of study with a general view of Scharnhauser Park and identifies buildings under consideration in this analysis: commercial buildings, detached houses, multi-family houses, renovated multi-family houses, tower blocks, town hall, school and biomass power plant. The heating and cooling load as well as electric energy consumption of these buildings were continuously monitored from 2005 to 2010; new buildings were constructed taking into account low energy standards, and the generation system that provides electric energy and district heating for the area is based on a cogeneration based on local biomass, an interesting alternative for reducing CO_2 emissions.

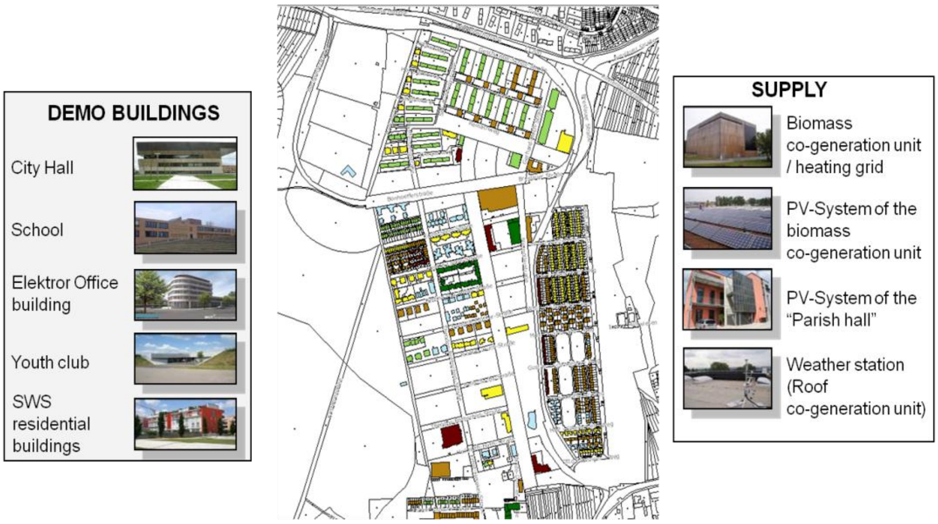

Fig. 1: Design, demonstration buildings and renewable supply of Scharnhauser Park

When the site was developed, energy standards for buildings were established by the town of Ostfildern in 1995, which demanded 25% lower end energy demand values than the existing national German standard at that time (WSVO 1995). The building standard WSVO 1995 required maximum heating end energy demand values of 70 - 100 kWh/m².a, depending on the ratio of surface to volume (from 0,5 up to 1,05 or higher). In the energy saving legislation EnEV 2002, the supply technology of the building with different conversion efficiencies and primary energy balances was included. From now on, there was only a primary energy demand limit so that buildings supplied by renewable (as in the Scharnhauser Park area) could be constructed with lower building standards. This standard was in place when the POLYCITY project was prepared. To obtain financial support for building investment measures, the POLYCITY project stated as objective to meet about 40% lower end energy values compared to the average EnEV 2002 value of about 90 kWh/m².a, i.e., 56 kWh/m².a for residential buildings and 50 kWh/m².a for office buildings.

In 2007 a certification system was introduced for buildings. In 2009 the dependence on surface to volume ratio was abandoned even for residential buildings. The calculated demand has now to be lower than for a reference building of the same geometry and is approximately between 50 – 80 kWh/m².a.

The targets set in the POLYCITY project for electricity consumption are 28 kWh/m²a in residential buildings and 35 kWh/m².a in office buildings. Under German climatic conditions residential buildings are not supposed to have active cooling systems, for office buildings the POLYCITY target was 30 kWh/m².a cooling end energy. In summary, the requirements set by the project in 2003 were sufficiently high to fulfil today's much more demanding legislation.

Only a small fraction of residential buildings in the Scharnhauser Park received additional funding (13.216 m² out of a total residential area of 178.000 m²). Three four-storey multi-family apartment buildings of 5.540 m² with a total of 42 apartments received 28 €/m² funding for energy measures, which corresponds to less than 3% of the total construction costs of 1.065 €/m². A total of

10 single family houses also received 3% funding with total construction costs of 896 €/m². All buildings were planned and constructed by the housing society Siedlungswerk Stuttgart GmbH during 2005 – 2010. The residential building measures supported include higher insulation standards (6 cm higher wall insulation and 4 cm more roof insulation and improved low e-coated double glazing with plastic spacers), low temperature heat distribution systems to reduce the district heating return temperatures (floor heating system) and mechanical exhaust ventilation for good indoor air quality control.

In the office building project of the company Electror GmbH, low temperature heat and cold distribution systems were chosen (concrete core activation) to improve the performance of the absorption chillers for cooling and to reduce peak power demand. The foundation piles were activated with plastic tubes to extract heat from the ground during winter and to reject heat loads from the ventilation system during summer. To reduce the electricity consumption for lighting, a centrally controlled corridor dimming strategy was chosen combined with highly efficient individual work space lamps, which are dimmed according to daylight availability.

A newly constructed public building of the municipality of Ostfildern was designed for near passive standard. Low-e coated double glazings were used instead of the more expensive triple glazings in passive standard buildings, as the building is used as a youth centre, with high risks of damage of such expensive material.

1.4 *Renewable supply systems*

In terms of covering the demand for both heating and electricity, an organic rankine cycle process (ORC) is the most suitable combined heat and power solution in the power range of 500 kW to 2000 kW.

Fig. 2 shows a 3D drawing of the biomass power plant. The storage and the furnace are shown in the front. The building in the background is the turbine house where the gas boilers are situated as well. The scheme shows delivery zone, furnace and exhaust treatment.

In 1993 the local supply company Stadtwerke Esslingen (SWE) took over the energy systems of Nellingen Barracks from the US Forces, at that time the network was supplied with steam. The former infrastructure has been taken out of operation and was replaced by a new hot water network. The structure of the heating network was coordinated with the development plan of the road system in this area.

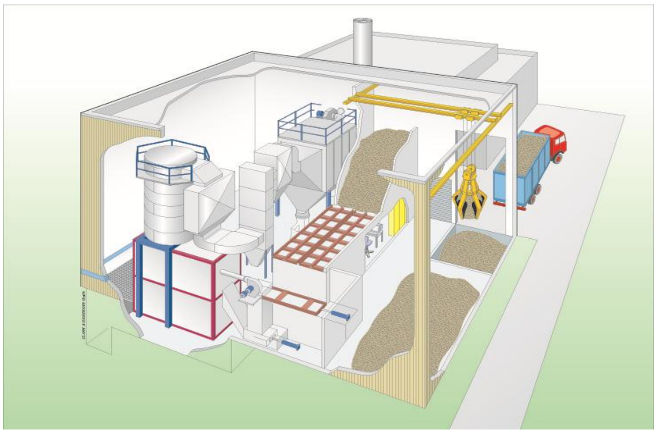

Fig. 2: Section through biomass plant Scharnhauser Park

2. RESULTS BUILDING ENERGY EFFICIENCY

The district heating network supplied by the ORC cogeneration plant provides heating for row houses, public buildings and multi-family houses; the heat distribution can be seen in the Sankey diagram presented in Fig. 3. 16% of all the energy delivered by the cogeneration plant is lost through distribution.; 63% of total heating energy is delivered to residential buildings, mainly multi-family buildings and row houses. Other buildings withcommercial, educational and administrative functions account for 21% of all the heating energy delivered.

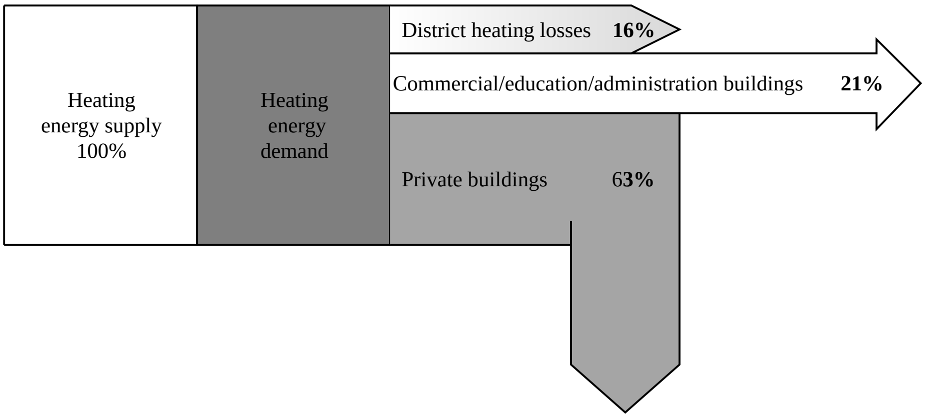

Fig. 3: Distribution of heating energy delivered by the biomass co-generation plant (2009)

The measured consumption of all multi-family houses is in general slightly lower than for the average row houses (between 56 and 68 kWh/m²a for the years 2005 and 2009 for multi-family houses, compared to 62 to 69 kWh/m².a for the row houses). All measured annual consumption values were normalized to the gross surface area, which creates some errors, as the gross surface areas were determined using basic geo-information system data (ground floor area and number of floors). Also some consumption metering information included several buildings and the value was equally distributed to the building surfaces. Fig. 4 illustrates the heating energy consumption for all multi-family houses from 2005 to 2009; the extreme ranges (0 to 20 and 100 to 120 kWh/m^{2}a) include a low number of buildings; the majority of buildings are in the ranges 40-60 and 60-80 kWh/m^{2}a, and this last range grew from 2005 to 2009.

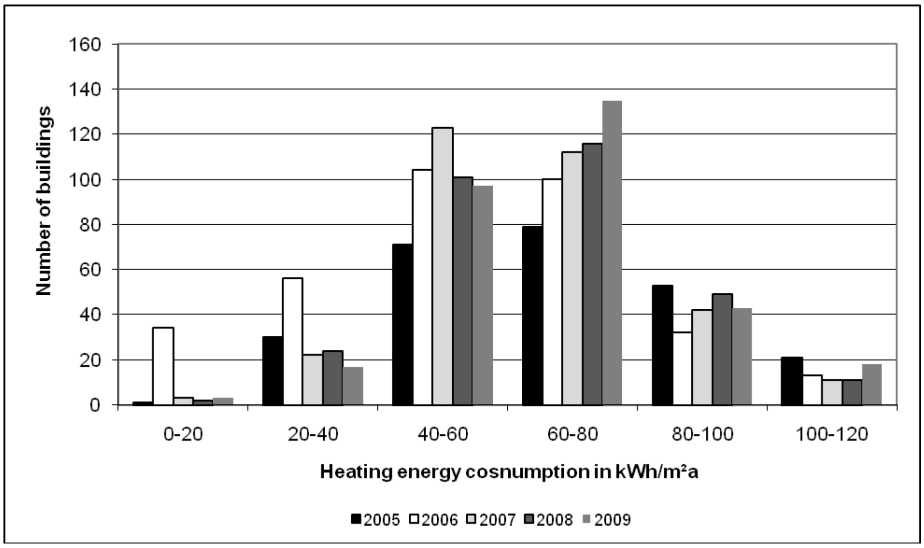

Fig. 4: Distribution of heating energy consumption measured for all multi-family houses

Fig. 5 presents the measured heating and electricity energy consumption per gross surface area of the demonstration project multi-family apartment building of the Siedlungswerk GmbH (SWG). The Siedlungswerk apartment building fulfils the set requirements for heating energy demand well. As can be seen, only in the first year of occupation the measured consumption was higher than specified. Regarding the electricity consumption only the value for the year 2010 is available, which fulfils the set requirement for electricity demand of 28 kWh/m²a.

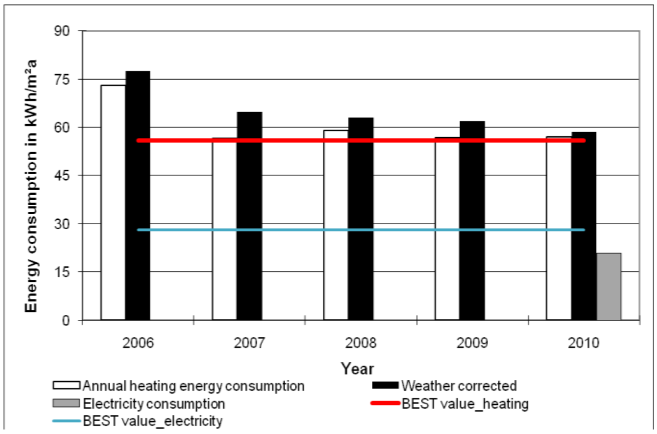

Fig. 5: Measured heating and electricity consumption per gross surface area of the multi-family apartment building of SWG.

Fig. 6 shows that the consumption of individual apartments fluctuates very strongly, showing the high user influence. Large variation in both heating and electrical energy consumption even in nominally similar dwellings have also been observed under UK climatic conditions [Lomas, 2009].

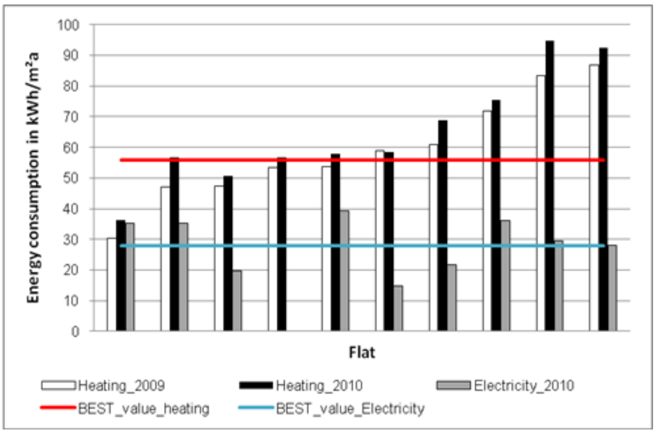

Fig. 6: Annual heating and electricity consumption for individual apartments

Not only the annual heating energy consumption differs a lot between the separate apartments, but there is also a strong variation in the annual electricity consumption. Factors such as number of occupants, number and type of appliances, and occupancy patterns are more relevant than the built form [Firth, 2008].

The analysis of the distribution of the monthly values for heating and electricity consumption for the year 2010 shows the influence of higher lighting electricity consumption in winter with otherwise rather constant electricity consumption over the year. The heating energy consumption strongly depends on the ambient temperature.

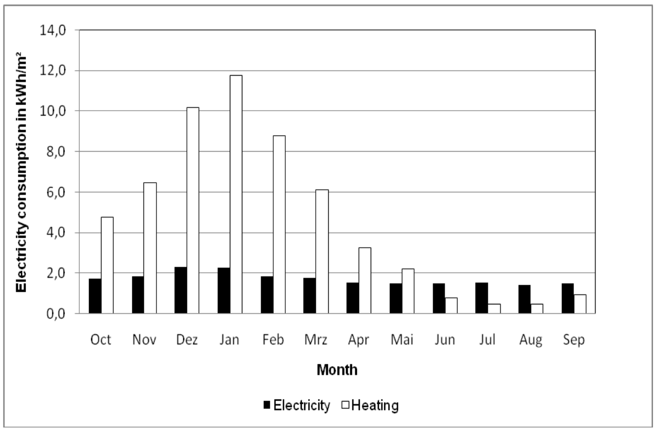

Fig. 7 Monthly heating and electricity consumption for the whole multi-family houses SWG

Fig. 8 illustrates the distribution of heating energy consumption for all row houses. The row houses analysed did not receive funding from the POLYCITY project and were constructed by different housing societies or investors. Despite rather similar building type and construction age, the consumption fluctuates strongly.

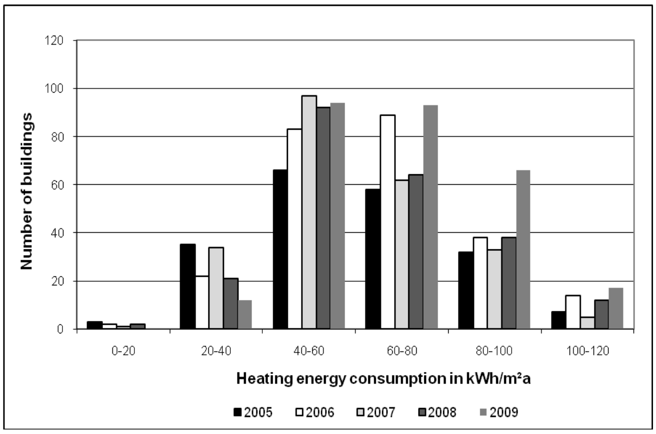

Fig. 8: Distribution of heating energy consumption for all row houses.

For interpreting the high variability and to evaluate the influence of user behaviour, row houses with a very similar construction type were compared. As can be seen in Fig. 9 the calculated demand is very similar for the analysed group of row houses (shown as “Calculation 1”); however, monitoring results showed strong fluctuations of consumption within the same building type, demonstrating again the rather high user influence.

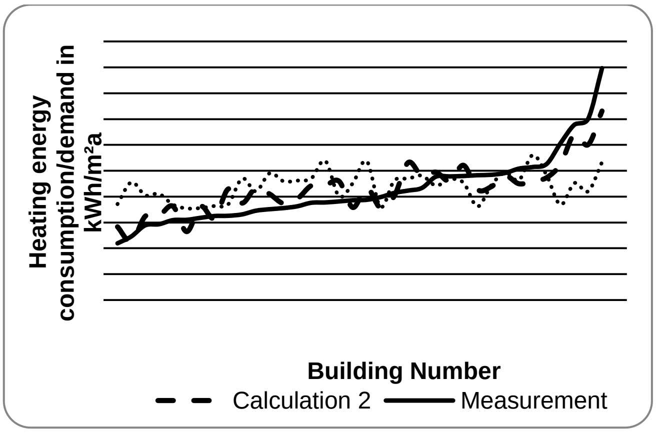

Fig. 9: Measured heating energy consumption compared to calculated demand for similar row house types.

From the 35 houses considered in this analysis, 14 (40%) presented heat energy consumption higher than the calculated demand, and the remaining 21 (60%) had measured values less or equal to the calculated demand; however, just 47% of all heating energy was consumed by the buildings for which the demand was higher than consumption. If user related building parameters (air change rates, heating set-point temperatures, night shut-off times of heating system) are statistically varied (shown as “Calculation 2”), the measured consumption curves can be approximated quite well.

A more detailed hourly analysis of the electricity consumption of individual apartments of the monitored multi-family houses SWG was done.

Fig. 10: Average hourly profiles for electricity consumption (Jan-April 2010)

It can be observed that in the night hours, both heating and electricity consumption is reduced, comparing to the daily hours. In case of electricity consumption a peak occurs in the evening hours.

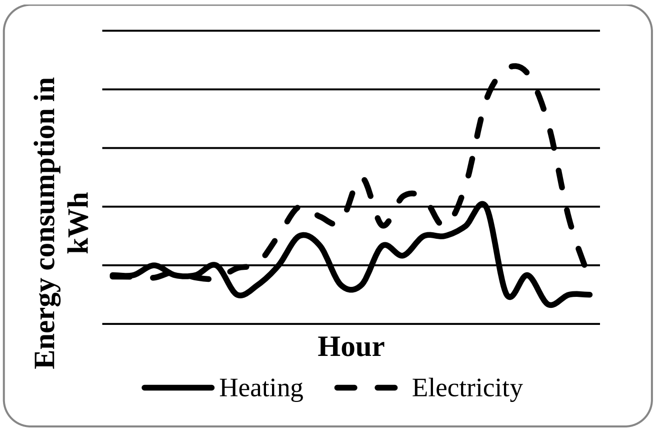

Fig. 11: Average heating and electricity hourly profiles for one example apartment (April 2010)

3. RESULTS FROM ENERGY SUPPLY SYSTEMS

The ORC cogeneration plant was constructed in Scharnhauser Park considering the adequateness of such systems to the sustainable city quarter’s demand profile. Cogeneration is a rational (and sustainable) way of using energy, since it reduces the use of electric energy from the national grid (often produced by burning fossil fuels). The ratio of waste heat from the OR-cycle’s condenser and the converted electric energy are suitable regarding climate conditions, building standard and user demand conditions. In this plant biomass harvested in the region (which saves energy for transportation) is burnt in a furnace. Table 1 presents the design specifications of the biomass furnace; Figure 7 illustrates the ORC cogeneration plant with district heating system; the maximum delivered network thermal power is of 6.3 MW and electric power delivered to the electric grid is 1 MW.

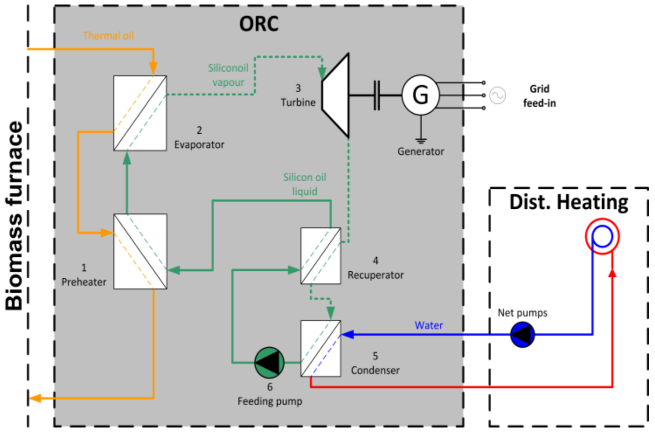

Fig. 12: ORC-scheme including district heating

During normal operation, the biomass supplies 80% of the total heating energy demand. Only in 2009 there was a long plant shutdown due to a fire incidence. Since then the plant is running at a reduced maximum power level; the auxiliary natural gas boilers were then started up for meeting the heating network demand.

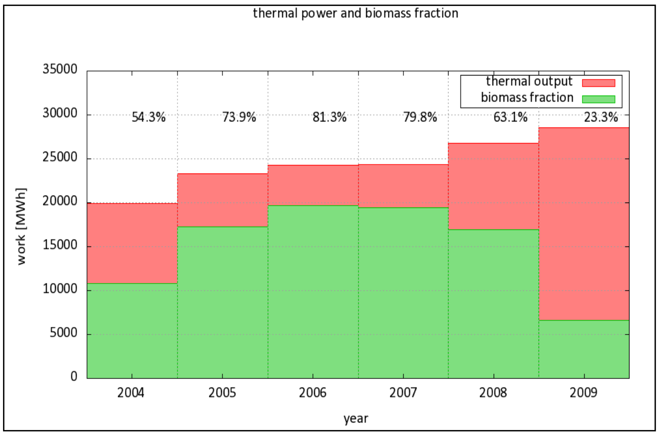

Fig. 13: Development of biomass fraction to total heat demand

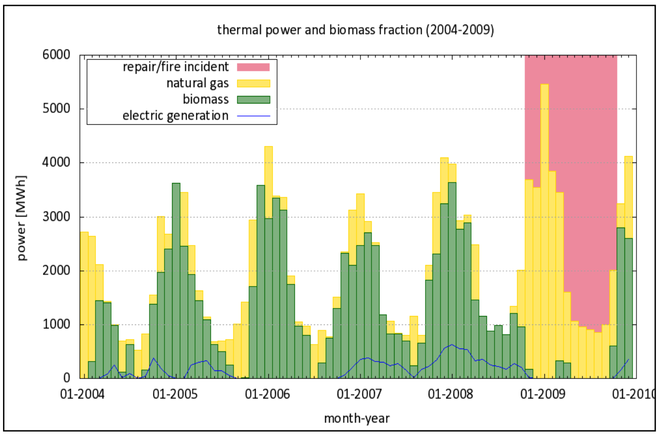

Fig. 14: Monthly demand and biomass coverage

Over a period of six years, all auxiliary supply of the biomass plant has been monitored. In addition to the thermal conversion efficiency, the auxiliary electric energy consumption for biomass ventilation fans, thermo-oil pumps etc. has been measured and related to the total thermal energy produced. For the conversion of biomass to district heat, 43 kWh electric energy for the combustion process per MWh of thermal energy are necessary. Including the heat from gas boilers, with lower auxiliary electricity demand, the specific value goes down to 26 kWh/MWh.

As the ORC module had low operation hours and often runs in part load conditions, the own auxiliary consumption of electricity of the whole plant including the combustion process is high. In total the own electricity consumption compared to the electric energy fed to the grid was 28% in

2007 (939 MWh out of 3327 MWh electricity feed in) and 30% in 2008 (1044 MWh out of 3527 MWh).

The electric gross efficiency of the ORC module was expected to be around 17%. So far, the annual efficiency did not exceed 12% and maximum values of 14.5% were reached. The large number of downtimes and the unexpectedly low demand for heating energy forced part-load operation.

Despite the enormous advantages concerning CO_2 and primary energy saving the success of biomass facilities is very much depending on the annual load distribution. High building standard housing such as in Scharnhauser Park reduce the demand for heat. Also in summer only very low loads for warm water have to be covered. This leads to several economical and technical challenges. To keep the ORC module operational a minimum heating power (2 MW to 3 MW) needs to be transferred. Additionally the cooling system of the generator is limited to 85°C in partial load. Low loads of 1 MW during summer are common. In these cases 1 to 2 MW of heating power are rejected to the environment by a re-cooler. An alternative to heat rejection is the useof thermal cooling systems during summer.

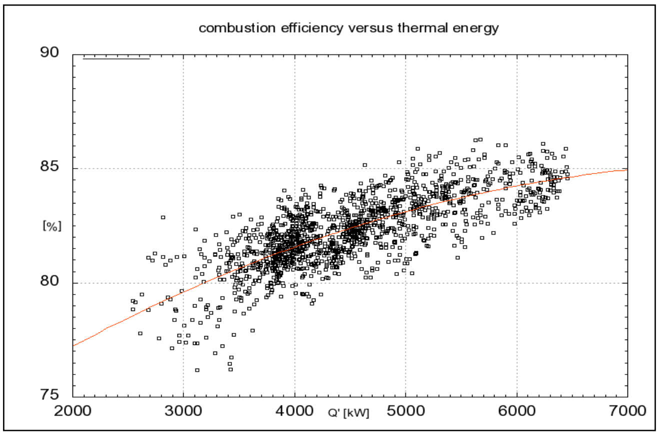

Fig. 15: Measured combustion efficiency as a function of network heat demand

A simulated characteristic of the ORC cycle efficiency is shown in ***Fig. 16***. With lower condenser temperatures the efficiency should rise. This curve has been derived from the technical specifications of the company of Turboden [2]. Organic-Rankine processes are expected to function at high efficiency over a wide load range [3]. In practical application both temperature levels and mass-flows alter with load conditions. In a part-load situation a heat guided cycle works with lower heat input and output, mainly regulated by lower mass flows, which decreases the heat transfer coefficients

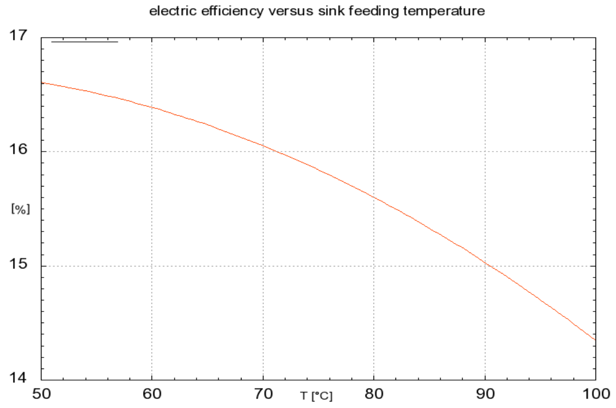

Fig. 16: Expected ORC part-load behaviour, calculated

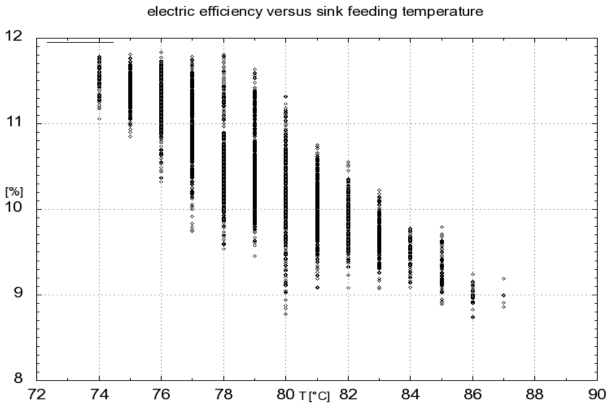

Fig. 17: ORC part-load behaviour, measured

2.1 *Decentralised absorption cooling*

The Elektror company office building, with an office surface area of 3.280 m², is heated and cooled using the heat from the biomass ORC cogeneration plant. Winter heating energy is supplied to thermally activated ceilings in addition to convectors at the air outlets. Cooling is only provided to the concrete core ceiling. The installed absorption chiller with 105 kW cooling power is directly connected to the district heating network and provides about 2/3 of the total cooling energy demand of the building (180 MWh annually); approximately 50% of the low summer district heating hot water flow is necessary for driving the absorption chiller. Fig. 18 illustrates the contribution of absorption and back up compression chillers in the building for the monitored period.

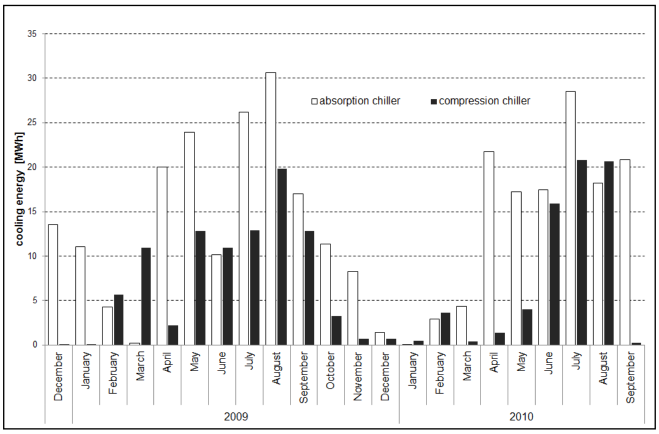

Fig. 18: Cooling energy provided to the office building by absorption and compression chillers.

The coefficient of performance of the chiller was between 0,6 and 0,7 during summer months and thus corresponds to expectations; its variation for the monitored period is presented in Fig. 19. The performance drop during autumn and winter months can be attributed to frequent switch-on and off under part load conditions and needs to be optimised during the next months. The annual heating energy required for the absorption chiller (371 MWh of heating in 2009) is similar to the winter heating energy demand (320 MWh heat for cooling in 2009) and this helps to increase operation hours of the ORC plant in summer.

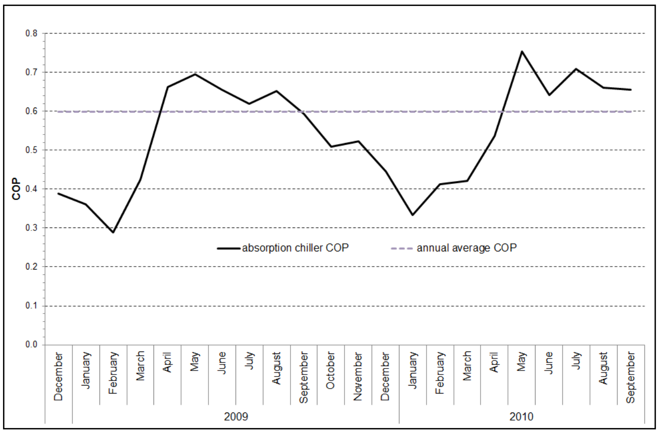

Fig. 19: Coefficient of performance of the absorption chiller in the Electror office building.

5. CONCLUSIONS

Monitoring of the city quarter Scharnhauser Park in the German city of Ostfildern showed that low energy building standards can be reached on a city neighbourhood scale. The user behaviour leads to a large fluctuation of consumption values, although building age and standard are rather comparable. The monitored multi-family houses had about 10-20% lower energy consumption values than the standard constructions in the area.

The area is supplied with a very high renewable energy fraction of 80% of the heat and 50% of the electricity consumption. The auxiliary electricity consumption of the ORC power plant is rather high, as full load conditions are rarely reached. The situation will be improved with increasing population and with additional heat use in summer, for example from thermal cooling plants in office buildings. A first project was implemented and monitored in one of the offices of the commercial district. The heating energy required for cooling was comparable to the winter heating energy of the building and extends the power plant full load operation during summer during 50 hours approximately.

Replication conditions are possible, as presented; technologically it is feasible to implement each of the considered technologies, adapting them to the climatic and behavioural conditions. The surpassing of several institutional and economic barriers is the major question to be taken into account in the near future.

ACKNOWLEDGMENTS

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