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Heiselberg, Per Kvols

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Renewable Urban Heat Supply for Domestic Housing in the City of Vienna

Peter Holzer[#1], Renate Hammer[#1], Michael Cerveny[*]

[#] *Institute of Building Research & Innovation, Vienna, Austria*

[1] peter.holzer@building-research.at

[2] renate.hammer@building-research.at

* *Energy Center, TINA Vienna*

michael.cerveny@tinavienna.at

Abstract

Vienna is a rapidly growing city with a yearly need for clearly more than 10.000 new flats. Simultaneously the Viennese municipality passed the Smart City Vienna Framework Strategy in 2014, fixing reduction targets for CO2-emissions and primary energy consumption for 2050. Against this context, joint research is currently carried out to develop options of renewable heat supply of newly built urban residential settlements. [1]

The Smart City Vienna Framework Strategy targets max. 1 ton CO_2 emissions per year and capita respectively max. 2.000 Watt primary energy demand per capita in 2050, for all kinds of services and needs, related to energy use. These targets have been broken down specifically to the energy use in the sector of domestic housing, from which 0,46 tons CO_2 and 500 Watt primary energy demand per capita resulted as future benchmark for sustainable habitats.
Four parameters have been identified which form the CO2-emissions and primary energy demand per person: (a) the treated floor-area per person, (b) the net energy demand per treated floor area, (c) efficiency of heat-production from end-energy, (d) the end-energy-based emission factor. [2]

These findings lead to integrated research efforts towards decarbonized urban heat supply technologies based on renewable resources. Since Vienna is lucky having a wired spread district heating system, the challenge is changing the feeding of the district heating system from gas fuelled CHP to renewable sources plus making as much as possible use of on-site renewable resources.

The authors are involved in the energy designs of two actual urban site-developments of 300.000 resp. 750.000 sqm net floor area. The following concept turned out promising:
(a) Nearly-Zero-Energy-Buildings (NZEB), (b) Low-Temperature-Floorheating (optionally with cooling), (c) heat supply from large brine-to-water heat pumps, fed from fields of earth-tube-heat-exchanger, (d) the earth-tube-heat-exchanges being thermally recharged from renewable all-year-heat-sources, possibly even recharged from urban district heat supply, which then can be used most efficiently from the return flow only and with significantly better balanced peak loads. Basic concepts are now ready for detailed design.

Ventilative Cooling; IEA ECB Annex 62; Hybrid Ventilation

1. Building Related CO2-Emission and PE-Use Targets

The Smart City Vienna Framework Strategy targets ecological Key-Performance-Indicators, such as CO_2-emissions and Primary Energy need, not against treated floor area but per capita, including all kinds of services and needs, related to energy use. This is an important step forward, combining not only the measures of efficiency with those of consistency, but including sufficiency, too. Those factors being coupled by simple linear correlation:

$$CO2/Pers.a = m^2_{GTFA}/pers \text{ x } kWh_{EE}/m^2_{GTFA}.a \text{ x } CO_2/kWh_{EE} \quad (1)$$

$$PE/Pers = m^2_{GTFA}/pers \text{ x } kWh_{EE}/m^2_{GTFA}.a \text{ x } PE/kWh_{EE} \text{ / } 8.760 \text{ h/a} \quad (2)$$

The targets are max. 1 ton CO2 emissions per year and capita respectively max. 2.000 Watt primary energy demand per capita in 2050, for all kinds of services and needs, related to energy use. These targets have been broken down specifically to the energy use in the sector of domestic housing, from which 0,46 tons CO2 and 500 Watt primary energy demand per capita resulted as future benchmark for sustainable habitats.

m²/pers: Specific Treated floor area TFA_{pers}, has been rising significantly, today having reached an average value of 34 m^2_{TFA}/pers, within single family households already at 63 m^2_{TFA}/pers. Vienna's municipality has reacted and obligatorily defines that one third of all flats with subsidies have to offer "smart-homes" which indicates specific Treated Floor areas which are 10% to 30% below average. [3], [4]

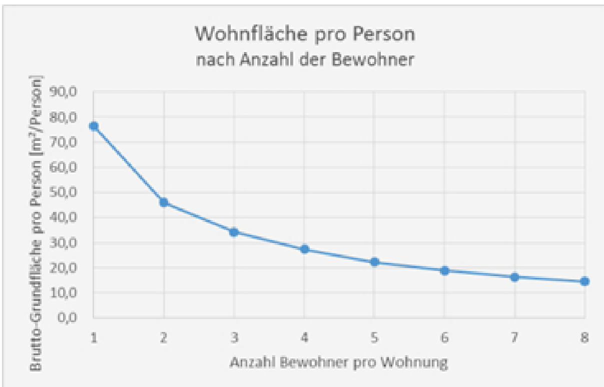

Fig. 1 Statistics of treated gross floor area per capita of the city of Vienna, 2014

kWh/m^2.a: Specific Net Energy Demand related to treated gross floor area, E_{TFT}, has been decreasing significantly, an still is, targeting values around 20 kWh/m²a for heating and 13 kWh/m²a for domestic hot water. Specific End Energy Demand for heating plus domestic hot water ranges between thus 40 and 55 kWh/m²a. Further improvements are expected both from further efforts in reducing heat losses as well as from increasing the efficiency factor,η, of building service units.

CO_2/kWhEE and PE/kWh/EE: Emission factors of CO2-Equivalents per kWh End-Energy and of kWh Primary Energy per kWh End-Energy. Vienna's district heating system is powered by natural gas, dominantly in CHP (63%), waste treatment and heat recovery (35%) and others. The CO_2 emission factor results to 20 g_{CO2} / kWh_{EE}. The Primary Energy factor results to 0,33 kWh_{PE} / kWh_{EE}. In districts without district heating gas boilers are dominating, with in emission factors of 236 g_{CO2} / kWh_{EE} and 1,17 kWh_{PE} / kWh_{EE}. Coal and electric heating play a substantially minor role in Vienna. Though the emission factor and the Primary Energy Factor of Vienna's district heating is excellent, it still comes from mostly non-renewable natural gas. Thus, efforts are undertaken to make additive use of on-site renewable resources.

2. Urban heat supply concept based on boehole heat exchangers

2.1 General System Layout

Amongst others, urban heat supply concepts based on borehole heat exchangers together with large heat pump units are object of intensive research in the town of Vienna.

Exemplary for other new residential developments, chances and challenges have been investigated in detail against a 300.000 sqm net floor area urban site-developments for 8.800 inhabitants.

The basic idea is to

- firstly erect houses consequently in NZEB – standard,
- secondly install low temperature floor heating systems,
- thirdly utilize utmost levels of onsite renewable resources

Fields of Borehole Heat Exchangers offer constant brine temperatures to run large scale heat-pumps, but have to be fully recharged during summer.

One crucial challenge is to find useful, robust and cheap ways of recharging the Borehole Heat Exchangers.

Another field of optimization is the question, if an additional peak-load boiler should be installed, in order to support the het-pumps during those 5% of operating hours where the last 25% of heat-capacity are needed.

In the test-case of the Vienna urban site-development “Hausfeld” a basic constellation of heat supply system has been investigated, both technically and economically.

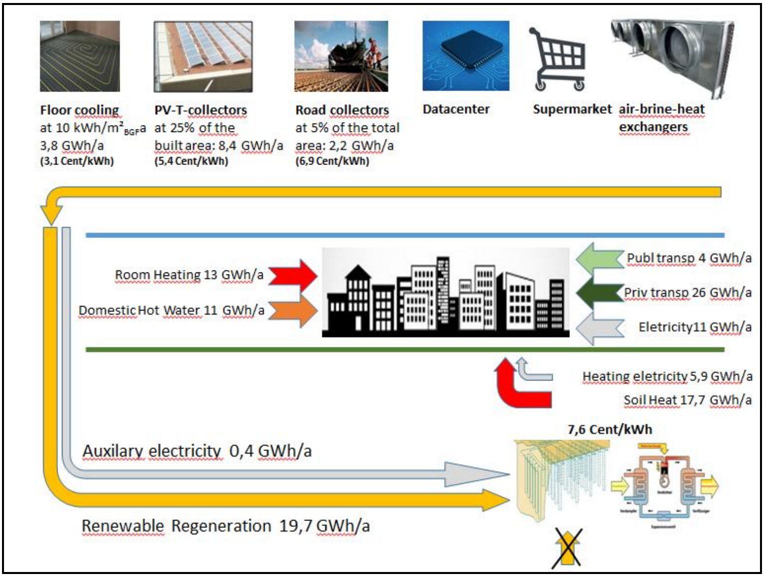

Fig. 2 Flow scheme of borehole based urban heat supply system

2.1 Borehole Heat Exchanger Field

The system’s heart is the borehole heat exchanger field. To cover the full heat supply of the 300.000 sqm net treated floor area, there’s need for more than 250.000 m of total borehole length. The limiting factor is the maximum abstraction capacity. Over a calculatory depreciation period of 40 years, the total heat supply costs from boreholes result in 2,8 Eurocents per kWh, which is still reasonable.

See table 1 for calculation results, both technically and economically.

Table 1. key design parameters of the borehole heat exchanger field

Heat Supply from Borehole Heat Exchangers				Key Design Parameters		
thermal capacity	10,6	MW		depth	150	m
heat supply	17.719	MWh/a		specific abstraction capacity	40	W/m
total length	265.270	m		specific abstraction load	67	kWh/m.a
numbers of boreholes	1.768	#		distance of borholes	7,1	m
land demand	88.423	m²		area per borehole	50	m²
land demand relative to built-up area	43%			specific production costs	45	EUR/m
production costs	11.937.145	EUR		specific mainainance costs, relatice tp production costs	0,5%	p.a.
cost of production relative to treated floor area	40	EUR/m²TFA		depritiation period	40	a
maintainance costs	59.686	EUR/a		real interest rate	2%	p.a.
total heat supply costs	2,8	Cent/kWh		anuuity factor	0,04	1/a

2.1 Heat Pumps

There's a growing market for large scale heat pumps. Units up to 600 kW are available at good quality and reasonable price. Within the specific test-case a number of 24 heat pumps with a nominal capacity of 600 kW each have been chosen.

Over a calculatory depreciation period of 20 years, the total heat supply costs from boreholes result in 4,8 Eurocents per kWh, already including electricity costs.

See table 1 for calculation results, both technically and economically.

Table 2. key design parameters of the borehole heat exchanger field

Heat Supply from Large Scale Heat Pumps				Key Design Parameters		
thermal capacity	14,1	MW		Annual COP	4	-
heat supply	23.625	MWh/a		electricity price	15	cent/kWh
electricity demand	5.906	MWh/a		production cost per 600kW unit	95.000	EUR
numbers of het pumps	24	#		surcharge for assembling and commisioning	25%	
specific capacity per heatpump	600	kW		specific mainainance costs, relative to production costs	2,5%	p.a.
production costs	2.800.071	EUR		depreciation period	20	a
production cost relative to treated floor area	9	EUR/m²TFA		real interest rate	2%	p.a.
maintainance costs	70.002	EUR/a		anuuity factor	0,06	1/a
electricity costs	885.938	EUR/a				
total heat supply costs	4,8	Cent/kWh				

2.1 Thermal Recharging

Large Scale Field of Borehole Heat Exchangers have to be fully recharged within one season. With only heat extraction the borehole temperature would constantly drop without time limits and would drop below reasonable points of operation.

Thermal recharging may be offered at low temperature levels starting from 20°C upwards. Specific technologies for recharging have been investigated:

Heat extraction from floor heating/cooling is a premium recharging technology with a strong additive benefit. Being run in free cooling mode only, a heat extraction capacity of 10 W/m² and an annual extraction load of 15 kW/m²a can be expected at reasonable total heat supply costs of recharging only of 4,8 Eurocents per kWh, already including electricity costs.

Solar Thermal system may be another option. Due to low temperature demands, cheap “swimming-pool-absorbers” may be applied. Another chance is the use of hybrid PV-Thermal-Systems. A somehow exotic option is the use of Solar Road Collectors, offering additional ambient space cooling, but already reaching total heat supply costs of recharging only of up to 7 Eurocents per kWh.

Hope is put upon waste heat usage from datacentres and from supermarkets, if available.

Another experimental and tempting option is the vice-verse use of simple external dry coolers. Being accompanied by the challenge of noise, they could offer a very cheap researching technology, with the additional benefit of ambient cooling, close to the effect of traditional wind towers.

2.1 Peak Load Coverage

Cost optimization by additional Peak Load coverage is still a point of research. For example a peak load boiler of 50% of the full heat capacity needed would cover only 10% of the total heat demand, while significantly reducing the investment costs.

Research additionally is guarded towards short time recharging via district heat, offering more regular demand patterns for the district heat supply.

3. Results

Results on the level of pre-dimensioning are available, being still objective of optimization.

As regards costs, total heat supply costs over depreciation periods of 40 years are expected in the range of 6,9 Eurocents for the heat supply from borehole heat exchangers together with the heat pumps. Additional costs in the range of 4,6 Eurocents are expected for a mixture of recharging technologies. Those costs result from a monovalent design with full investment in boreholes and heat pumps but without costs for peak load devices or for district heat supply. This price-level is competitive to district heat supply, but still is clearly above heat generation from fossil “natural” gas.

As regards ecological balance, the investigated system offer heat supply at a level of more than 80% of the primary energy coming from renewable sources. A level close to 100% renewable heat could be reached if switching to green electricity.

See table 4 for a comparison of key-indicators between heat supply from (a) borehole heat exchangers together with large scale heat pumps and full thermal recharging, (b) district heat supply (numbers from the city of Vienna) and (c) natural gas boilers.

Table 3. key design parameters of the borehole heat exchanger field

	Borehole Heat Exchanger + Heat Pump + Recharging	District Heat Supply	Natural Gas Boilers
Total Heat Supply Costs	8-15 Cent/kWh	8-10 Cent/kWh	4-6 Cent/kWh
Conversion Factor CO2	74 g/kWh	20 g/kWh	236 g/kWh
Conversion Factor Primary Energy	0,51	0,33	1,17
Renewable Proportion Final Energy	73%	18%	0%
Renewable Proportion Prim. Energy	82%		0%

4. Discussion and Perspective

The parameter studies carried out so far delivered promising results. Next level design is ongoing right now. Two smaller residential projects are realized right now, meant to deliver small scale learnings for later large applications.

Focus of research is optimization in economy, smart recharging technologies, peak load solutions, support of and from district heating.

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