THE IMPACT OF LOW ENERGY BUILDINGS ON THE OPTIMAL DESIGN OF DISTRIBUTED ENERGY SYSTEMS AND NETWORKS

Boran Morvaj\textsuperscript{1,2}, Ralph Evins\textsuperscript{1,2}, Jan Carmeliet\textsuperscript{1,3}
\textsuperscript{1}Chair of Building Physics, Swiss Federal Institute of Technology, ETH Zürich, Switzerland
\textsuperscript{2}Laboratory for Urban Energy Systems, Swiss Federal Laboratories for Materials Science and Technology, EMPA, Dübendorf, Switzerland
\textsuperscript{3}Laboratory for Multiscale Studies in Building Physics, Swiss Federal Laboratories for Materials Science and Technology, EMPA, Dübendorf, Switzerland

ABSTRACT

The aim of this paper is to analyse how low energy buildings influence the optimal design of distributed energy systems and district heating networks. Using EnergyPlus, heating, cooling and electricity consumption profiles are obtained for existing and new buildings. Multi-objective (cost versus carbon emissions) mixed integer linear programming is used to find the optimal system design and heating network layout for an urban neighbourhood. The model is applied to a reference scenario consisting of the existing buildings and different scenarios for the future inclusion of low energy buildings. The impact of low energy buildings on the optimal design of the distributed energy system is analysed as well as how the potential for district heating is affected.

INTRODUCTION

Reducing energy consumption, reducing carbon emissions and improving security of supply are the main energy goals of the European Union (EU). Therefore, the EU adopted two main legislations in order to prompt reduction of the energy consumption of the buildings - Energy Performance of Buildings Directive and the Energy Efficiency Directive. Two main key points of the directives are that all new buildings must be nearly zero energy buildings by 31 December 2020 and EU countries must make energy efficiency renovations to at least 3% of buildings owned by the government. Furthermore, climate policy finds reduction of the country’s greenhouse gas emissions as a key challenge for the overall energy sector, with goals of a 20-30% reduction of the carbon emissions from the 1990 level by the year 2020 and a possible 50-80% reduction by 2050.

Both goals cannot be met if the buildings do not become more energy efficient (by retrofitting and constructing new buildings as low energy buildings) and the remaining demand is not primarily met by renewable energy. This will have a big impact on the existing distributed energy systems (DES) which were designed for much larger consumption and no integration of renewables. The questions then arise how different are distributed energy systems that are designed for existing buildings compared to new low energy buildings, how should new low energy buildings be integrated within existing DES, and what is the impact of retrofit on the system. In addition, the impact of different carbon emissions limits on the optimal design of DES is of interest.

Various publications have reported the optimisation of the design and operation of distributed energy systems based on the mixed-integer linear programming (MILP) formulations (Mehleri et al. 2012) (Omu et al. 2013) (Weber & Shah 2011) (Casisi et al. 2009). However, they do not analyse the optimal design with low energy buildings and many do not consider district heating at all. In addition, they mostly deal with a single objective minimisation of the total cost with carbon emissions being included as a carbon tax even though they represent conflicting objectives.

On the other hand, a number of papers address the optimal design of low energy building (Chlela et al. 2009) (Fesanghary et al. 2012) (Hamdy et al. 2011) (Evins et al. 2012). However, they look only at the optimal design of a single low energy building and do not take into account interactions between multiple buildings. Additionally, (Dalla Rosa & Christensen 2011) and (Lund et al. 2010) looked at the impact of low energy buildings on the design of the district heating but taking energy system configurations as predefined.

In conclusion, previous publications did not look at the multi-objective optimal design of DES with district heating, for low energy buildings at neighbourhood level. In this paper, a multi-objective MILP model of DES with a decentralised district heating network, so called 4th generation ( see (Lund et al. 2014)) is used. The impact of low energy buildings on the optimal design of DES is examined and compared to a reference scenario. Also, inclusion of future low energy buildings in the vicinity of existing, already optimised DES is analysed for scenarios with and without retrofit of the existing buildings.

OPTIMISATION MODEL

Overview

The model can determine the optimal design and operation of a distributed energy system and district heating network layout. MILP formulation guarantees global optima unlike heuristics and other non-linear formulations. The drawback is that
equations have to be linear. However, advanced linearization methods can be applied in order to increase accuracy of the formulation such as piecewise linearization. This increases solving time so there is a trade-off between accuracy and computational time.

The considered technologies in all buildings are: gas boiler, combined heat and power (CHP), and solar thermal collectors (ST) for heat demand; photovoltaic panels (PV) and CHP for electrical demand; absorption (AC) and electrical chiller (EC) for cooling demand. The technologies are represented by efficiency of transforming one energy type to another and defined by additional operational constraints. Additionally, buildings can import/export electricity to the grid, store heat energy in a local, daily water heat storage, and form a decentralised district heating network.

The model is used for multi-objective optimisation of cost (investment plus operational) and carbon emissions using the ε-constraint formulation (Laumanns et al. 2006). In this formulation, the primary objective is minimised while the secondary objective is defined as an additional inequality constraints for which the limit (ε) is varied. The limits are set between the minimum and maximum value of the second objective. The model formulation builds upon the model described in (Morvaj et al. 2014).

Objective functions

Primary objective function for ε-constraint method is total cost that consists of investment and operational costs:

\[
\min \left[ Cost_{inv} + Cost_{op} \right] \tag{1}
\]

The investment cost consists of fixed installation costs \(Cost_{tech,fix}\), capacity-proportional costs \(Cost_{tech,lin}\), and the cost of laying pipes for the heating network \(Cost_{pipe}\). This is summed for every building \(i\) and every technology \(tech\). If there is a heating network connection between two buildings, the associated investment cost depends on the distance between buildings \(Dij\) (200 €/m).

\[
Cost_{inv} = \sum (\delta_{tech,i} \cdot Cost_{tech,fix} + Capacity_{max,tech,i} \cdot Cost_{tech,lin} + \sum (Cost_{pipe} \cdot Dij \cdot \delta_{ij}) \text{ for } tech \in \{PV, CHP, ST, boiler, storage, AC, EC\}) \tag{2}
\]

\(\delta_{tech,i}\) is a binary variable which defines if the equipment of technology tech is installed in building \(i\). \(Capacity_{max,tech,i}\) is the optimal installed capacity of the equipment and \(\delta_{ij}\) is binary variable that defines if buildings \(i\) and \(j\) are connected by the heating network.

The operational cost consists of the cost of purchasing electricity from the grid \(E_{grid}\) and the cost of purchasing gas for the CHP and natural gas boiler \(G\) minus the income from selling PV electricity \(E_{PV}\) and CHP electricity \(E_{CHP}\) to the grid summed for each timestep \(t\):

\[
Cost_{op} = \sum_{t} (E_{grid} \cdot p_{grid} + G \cdot p_{boiler} + E_{PV} \cdot p_{PV} - E_{CHP} \cdot p_{CHP} - E_{sell, t, i}) \cdot \text{NPV} \tag{3}
\]

The operating costs are calculated for period of 20 years which is the assumed average lifespan of equipment (Weber & Shah 2011). Net present value (NPV) is used to discount the future value of money to current values:

\[
NPV = \frac{(1 + i_{rate})^{years} - 1}{i_{rate} \cdot (1 + i_{rate})^{year}} \tag{4}
\]

where \(i_{rate}\) is discount rate of 3%.

The secondary objective is the minimization of the carbon emissions \(Carbon_{total}\) of the distributed energy system summed for each timestep over 20 years:

\[
Carbon_{total} = \sum_{t} \left( CF_{grid} \cdot (p_{grid} - p_{sell, t, i}) + CF_{gas} \cdot (p_{boiler} + p_{CHP} - p_{PV}) \right) \cdot 20 \text{ years} \tag{5}
\]

where \(CF_{grid}\) and \(CF_{gas}\) are the carbon factors (kg CO2/KWh) for electricity and natural gas. Only operating emissions are taken into account and not life cycle emissions. It is assumed that carbon is accounted for electricity exported to the grid with the same carbon factor of the grid import and it decreases the total carbon emissions of the buildings. This is in line with emissions metrics as discussed in (Marszal et al. 2011).

Energy demand constraints

The electricity demand of each building \(l_{load}^{i}\) and EC can be met by electricity imported from the grid \(p_{grid}^{i}\), generated by CHP \(p_{CHP}^{i}\) or by PV \(p_{PV}^{i}\). It is assumed that electricity required to pump fluid in ST is 8.5% of the generated heat.

\[
l_{load}^{i} + 0.085 \cdot p_{ST}^{i} + p_{EC}^{i} = p_{grid}^{i} + p_{CHP}^{i,building} + p_{PV}^{i,building} \forall i, t \tag{6}
\]

The heat demand of each building \(H_{load}^{i}\) and heat needed for AC can be met by energy from the heat network \(DH_{i}^{in}\), CHP, gas boiler, ST or heat storage \(Q_{i}^{in}\):

\[
H_{load}^{i} + p_{AC}^{i} = \sum \left( HeatLoss_{i}^{in} \cdot DH_{i}^{in} - DH_{i, t, i}^{out} \right) + p_{CHP}^{i,building} \cdot HER + p_{boiler}^{i} + p_{ST}^{i} + Q_{i}^{charge} \forall i, t \tag{7}
\]

where \(HER\) is heat to electricity ratio and \(HeatLoss_{i}^{in}\) is the heat loss of exchanging heat through the network between two buildings (4.3%/km).

Cooling demand of each building \(C_{cool}^{i}\) can be met by AC or EC cooling:

\[
c_{i}^{load} = p_{AC}^{i} \cdot \eta + p_{EC}^{i} \forall i, t \tag{8}
\]
Technology-specific constraints

All technology capacities have to be between appropriate lower (LB) and upper bounds (UB): $\delta_{tech,i}\cdot LB \leq \text{Capacity}_{tech,i}^{max} \leq \delta_{tech,i}\forall i,tech \in \{PV,CHP,ST,boiler,storage,AC,EC\}$ (9)

The minimum part load is set to 50% because of technical limitations and also the efficiency of CHP is roughly constant above this point:

$$p_{CHP,lt}^{max} \leq M \cdot \delta_{max,CHP}^{on} \forall i,t$$ (10)

$$0.5 \cdot p_{CHP,lt}^{max} \leq p_{CHP,lt} + M \cdot (1 - \delta_{max,CHP}^{on}) \forall i,t$$ (11)

where $\delta_{max,CHP}^{on}$ is a binary variable and M is an appropriately large number. The formulation ensures that CHP operates between 50% and 100% of installed capacity otherwise it is turned off.

Storage is defined by the following equation:

$$Q_{lt}^{charge} = E_{SOC,lt} + E_{storage,lt} \cdot n_s - (1/n_s) \cdot n_l \forall i,t$$ (12)

where stored heat energy at the next timestep $E_{SOC,lt+1}$ is equal to the amount at the current timestep $E_{SOC,lt}$ plus the charged amount minus discharged amount with losses $n_l$ (%).

The amount of heat energy that can be extracted or stored in the storage during one timestep is limited by the capacity installed:

$$Q_{lt}^{charge} \leq 0.4 \cdot E_{storage,lt}^{max} \forall i,t$$ (13)

$$Q_{lt}^{discharge} \leq 0.4 \cdot E_{storage,lt}^{max} \forall i,t$$ (14)

To constraint storage to daily storage, the state of charge of the storage at the last timestep of each day has to be equal to the state of charge at the first timestep of that day. Initial and final states of charge are not manually enforced but left to be optimized to be more realistic:

$$E_{SOC,lt,first} = E_{SOC,lt,last} \forall i,t \in \text{days}$$ (15)

Both PV and ST power output is determined by the area of panels $A_{techn,lt}$ efficiency $n_{techn}$ and irradiation $p_{t,techn}$:

$$p_{t,techn} = A_{techn} \cdot n_{techn} \cdot p_{t,techn} \forall i, t, techn \in \{PV,ST\}$$ (16)

The sum of area of photovoltaic and solar thermal panels has to be smaller than the total area of roof:

$$A_{LST} + A_{i, PV} \leq A_{i,roof} \forall i$$ (17)

Heat network constraints

The district heating network is assumed to be a decentralised network where each building is a prosumer — heat can be produced or consumed (Brand et al. 2014).

This is ensured by equations (7) and (18):

$$p_{CHP,lt, DH} + \delta_{max,CHP}^{on} \leq \sum_j \delta_{CHP,lt,j, DH}^{out} + \sum_j \delta_{CHP,lt,j, DH}^{in} \forall i, t$$ (18)

$$DH_{lt,j, DH}^{out} + \delta_{max,CHP}^{on} \leq M \cdot \delta_{max,CHP}^{pipe} \forall i, j \text{ where } j \neq i$$ (19)

Heat energy can be exchanged between buildings only if the buildings are connected by the heating network:

$$DH_{lt,j, DH}^{out} + \delta_{max,CHP}^{on} \leq M \cdot \delta_{max,CHP}^{pipe} \forall i, j \text{ where } j \neq i$$ (20)

CASE STUDY

The case study consists of 12 residential buildings. Two types of buildings are considered—existing and low energy, characteristics of which are shown in Table 1. The existing building type has insulated high-density brick walls, flat insulated concrete roof, concrete ground floor slab and single pane windows. The low energy building type has EPS insulated Vietri brick wall, rockwool insulated plywood roof, XPS insulated concrete floor and Argon insulated double pane window. The buildings were modelled in EnergyPlus. For each building, different heating and cooling setpoints as well as occupancy schedules were defined to obtain different electricity, heat (with domestic hot water) and cooling demand profiles.

The simulation was run using a weather file for Zürich, Switzerland. Yearly consumptions are shown also in Table 1. To make optimisation calculations computationally possible, whole year is represented by four average 24-hourly demand profiles for each season making a total of 96 timesteps. This way only daily thermal storage can be modelled and not seasonal.

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>EXISTING BUILDING</th>
<th>LOW ENERGY BUILDING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor area</td>
<td>7 m x 20 m</td>
<td>7 m x 20 m</td>
</tr>
<tr>
<td>Number of floors</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Window area</td>
<td>27 m²/floor</td>
<td>27 m²/floor</td>
</tr>
<tr>
<td>Wall construction</td>
<td>1.7 W/m²K</td>
<td>0.375 W/m²K</td>
</tr>
<tr>
<td>Roof construction</td>
<td>2.75 W/m²K</td>
<td>0.23 W/m²K</td>
</tr>
<tr>
<td>Floor construction</td>
<td>2.85 W/m²K</td>
<td>0.395 W/m²K</td>
</tr>
<tr>
<td>Window glass</td>
<td>5 W/m²K</td>
<td>1.4 W/m²K</td>
</tr>
<tr>
<td>Heat consumption</td>
<td>121 kWh/m²/y</td>
<td>26 kWh/m²/y</td>
</tr>
<tr>
<td>Total consumption</td>
<td>168 kWh/m²/y</td>
<td>76 kWh/m²/y</td>
</tr>
</tbody>
</table>

In Figure 1 the locations of buildings are shown which represent a small neighbourhood. Blue squares are buildings considered in scenarios 1 and 2 (see below), and red buildings are additional low energy buildings considered in scenarios 3 and 4. District heating network investment cost and heat losses depend on the pipe length between the buildings. Since the distances are relatively small, the specific location of the buildings do not significantly influence overall optimal results.
Table 2 shows efficiencies, upper and lower capacity bounds, and fixed and linear costs of the considered technologies based on (Mehleri et al. 2013) (Omu et al. 2013). The carbon factor used for natural gas is 0.202 kg CO₂/kWh and for electricity 0.5 kg CO₂/kWh (Brander et al.). The electricity grid price is 0.2 €/kWh and natural gas price is 0.08 €/kWh. The price for selling electricity back to the grid was assumed not to be subsidized and is taken to be 0.08 €/kWh.

Additional assumptions are: solar irradiation, electricity, heat and cooling demand are known with certainty; the prices are taken to be constant throughout the optimisation period; efficiency is constant if CHP load is higher than the minimum.

Table 2

<table>
<thead>
<tr>
<th>TECHNOLOGY</th>
<th>EFFICIENCY AND CAPACITY BOUNDS</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHP</td>
<td>ηel: 25%, HER: 2</td>
<td>$C_{fix}$: 2000€ $C_{lin}$: 500€/kW</td>
</tr>
<tr>
<td>Gas boiler</td>
<td>$η$: 80%</td>
<td>$C_{fix}$: 50 € $C_{lin}$: 15€/kW</td>
</tr>
<tr>
<td>PV</td>
<td>$η$: 15%</td>
<td>$C_{fix}$: 2000€ $C_{lin}$: 15€/m²</td>
</tr>
<tr>
<td>ST</td>
<td>$η$: 39%</td>
<td>$C_{fix}$: 2000€ $C_{lin}$: 300€/m²</td>
</tr>
<tr>
<td>Thermal</td>
<td>$η$: 99%</td>
<td>$C_{fix}$: 200 € $C_{lin}$: 40€/kWh</td>
</tr>
<tr>
<td>storage</td>
<td>bounds: 10 – 100 m²</td>
<td></td>
</tr>
<tr>
<td>AC</td>
<td>$η$: 70%</td>
<td>$C_{fix}$: 2000€ $C_{lin}$: 500€/kW</td>
</tr>
<tr>
<td>bounds: 0 – 40 kWh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EC</td>
<td>COP: 3.5</td>
<td>$C_{fix}$: 500€ $C_{lin}$: 200€/kW</td>
</tr>
<tr>
<td>bounds: 1 – 100 kW</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Four different scenarios are examined:

(1) Reference scenario where only buildings 1-12 are considered and are of existing type;

(2) Low energy building scenario where only buildings 1-12 are considered and are of low energy type;

(3) Expansion scenario where optimal design and heat network layout from reference scenario is fixed and additional six low energy buildings are built in the vicinity (buildings 13-18);

(4) Expansion scenario with retrofit where optimal design and heat network layout from reference scenario is fixed, buildings 1-6 (see Figure 1) are retrofitted as low energy building type and additional six low energy buildings are built in the vicinity (buildings 13-18).

RESULTS

Pareto-fronts for reference and low energy building scenarios

In Figure 2 the Pareto fronts for reference and low energy building scenarios are plotted against the two objective of total cost summed over 20 years and emissions per year per m². Emissions points correspond to each subsequent ε constraint on carbon emissions until the minimum emissions are reached. Letters correspond to the cases shown in Figure 4. The total cost of reference scenario with existing buildings for initial single-objective solution (lowest cost) is 1115 k€ and carbon emissions are 459 kg/m²/y. The carbon emissions can be decreased by 70% to 139 kg/m²/y ton but the total cost increases by 65% to 1170 k€. If we look at the low energy buildings scenario, the single-objective solution moves to 619 k€ with 247 kg/m²/y ton of carbon emissions. The minimum achievable carbon emissions are 7 kg/m²/y ton with increase of cost to 1124 k€. Overall emissions can be decreased more in the reference scenario than in the low energy scenarios. This is because the demand that can be met by renewables is lower. Additional decrease in emissions could be possible if electricity storage is included and/or with larger available roof area.

Looking at the breakdown of the total cost, the investment cost increases for both scenarios as carbon emissions decrease, but operational cost in the low energy buildings scenario is much lower. That means if existing buildings are to be retrofitted to low energy buildings, looking only at investment cost needed for energy system for short-term period, it would not be economically feasible to retrofit. On the other hand, if long-term investment and operation is considered, both retrofitting and building new low energy buildings could become economically feasible due to much lower operational cost.
Design variable results for reference and low energy building scenarios

Figure 3 shows installed capacities for all technologies for different carbon emission limits. As carbon emissions decrease, the following observations can be made for the reference scenario:
- boiler is substituted almost completely by CHP and ST and the remaining installed capacity is used for meeting periods when there is not enough heat energy from ST and/or when the heat demand is below minimum load of CHP;
- the capacity of storage increases proportionally to the amount of ST and CHP installed and drops again at very low carbon emissions;
- most of the cooling demand is met by EC, and AC is used only when there is enough heat energy from CHP and ST; PV area increases and it substitutes area used for ST near minimal emissions.

Looking at low energy buildings scenario, less chained interaction between technologies of different energy types is observed (e.g. heat from CHP used by AC) due to demands being smaller. Boiler, CHP and storage capacities are mostly constant with a decrease for boiler and increase for CHP at the lowest emissions. The absorption chiller is not used at all for cooling demand. The roof area is mostly used by PV.

Network layout results for reference and low energy building scenarios

Figure 4 shows the optimal heating network layouts for different carbon constraints. The squares are coloured depending on the capacity of CHP that is installed. The lines represent heating network connections between buildings, with arrows showing...
the direction of the connection and the colour of the line indicating the amount of heat energy transferred. Corresponding values to colour are shown in colour bars (note that the minimum and maximum values change).

For both reference and low energy scenarios, in the lowest cost solution, there is no heat network apart from between buildings 1 and 8 for reference scenario and most of the buildings have CHP of 2 kW installed. As the carbon emissions decrease, network connections noticeably increase for the reference scenario. For carbon limit of 273 kg/m²/y, the heating network consists of two subnetworks; in the case of minimal carbon emissions, all buildings are connected by a single heating network. For the low energy building scenario, the heating network is almost non-existent until the minimal emissions case. The reason is that the heat demand of the low energy buildings is already low and combined with renewables, it is not economically viable to form a district heating network. 2 kW CHP capacities for the low energy scenario are installed for all buildings, except in the last case. On the other hand, for reference scenario, a pattern can be noticed for lower carbon emissions cases. There is always one or two CHPs with big capacity and many smaller ones. This are because the big ones provide base and peak heat load for all buildings and the small ones provide heat for demand below minimum load of the big CHPs.

**Expansion scenarios with and without retrofit**

For this case, the optimal design and network layout of reference scenario with carbon limit of 273 kg/m²/y is fixed (case B) and taken as input for expansion planning. It is assumed that an additional 6 buildings are built in the vicinity (red buildings in Figure 1), all of low energy type, in order to analyse how DES and heating network should be expanded with respect to the existing optimised systems. The optimal DES is determined only for new buildings, the heat network can be expanded in any way in addition with the existing one, and optimal operation is determined for all buildings.

An additional scenario is for the new system defined where all mentioned constraints apply but in addition, existing buildings 1-6 are retrofitted to low energy type to see the impact of partially retrofitting a neighbourhood on the existing and new DES. However, with inclusion of new buildings, there is no single point optimal solution but more options for decreasing carbon emissions. Therefore, a new Pareto-front of cost versus emissions is obtained.

**Pareto-fronts for expansion scenarios**

Figure 5 shows the Pareto fronts of investment cost against carbon emission for the two expansion scenarios (with and without retrofit). Colours of the markers correspond to total operating cost. Minimal achievable emissions are naturally lower for retrofitted case. With retrofit additional 25% decrease in carbon emissions can be achieved. Investment costs for retrofitted case are on average smaller for same relative decrease in carbon emissions. Also, operating costs are smaller. The cost of retrofitting was not taken into account. Looking only at investment cost as a criterion for retrofitting, as before it is not economically viable to retrofit. If operating costs over the long term are taken into account then it may be reasonable to retrofit some of the buildings, in addition to building new low energy ones.

![Figure 5 Pareto front for expansion scenarios with and without retrofit for case B](image)

**Design variables results for expansion scenarios**

In Figure 6 total installed capacities are shown for different carbon limits for only the new buildings. There is not much difference between the retrofitted and non-retrofitted cases. In both cases, the area of installed PV and ST gradually increases with larger share of PV as carbon limits get lower; in the lowest carbon emissions, only PV is installed. Furthermore, the total capacity of gas boilers decreases; storage capacity is mostly constant. The only difference between cases is that CHP capacity increases in the without retrofit case due to higher heat demand.

![Figure 6 Capacities for different carbon limits for expansion scenarios for case B](image)

**Network layout results for expansion scenarios**

Figure 7 shows the optimal heating network layouts for different carbon constraints for expansion scenarios with and without retrofit. Compared to the network layout of starting case, in the no retrofit case, the heating network is extended to buildings 13 and 15 and a single network is formed. For the retrofit case, buildings form a single network including buildings 13, 16 and 17. As carbon emissions decrease, more heat energy is exchanged...
through the heat network. The total amount is higher for the no retrofit scenario due to the higher heat demand. In general, the heat network gets extended but never to all new buildings. Furthermore, a similar pattern as in reference scenario is observed in the lowest carbon emissions case – there are two high capacity CHPs and many smaller ones. This is not the case for the retrofit scenario where only small capacity CHPs are installed in the new buildings.

CONCLUSIONS

A multi-objective MILP model of DES with a decentralised district heating network is used. The objective functions are minimisation of total cost and carbon emissions. The impact of low energy buildings on the optimal design of DES is determined and compared to a reference scenario.

The results showed that with low energy buildings, there is much less interaction between various energy streams. The optimal DES mostly consists of PV, ST and electric chiller. Absorption chiller is not used at all and CHP is used at the same capacity through all carbon limits. There is almost no need for district heating network, except at the lowest achievable carbon emissions. However, this may change with introduction of low temperature district heating networks where not only CHP can produce heat for the network but other technologies such as ST. Furthermore, the simulation was carried out on relatively small distances where building a district heating network is more feasible. This may not be the case for long distance networks. In the future, district heating network could be connecting groups of low energy buildings that are not interconnected.

Expansion scenarios for existing optimised DES, with new low energy buildings in the vicinity, are considered with and without partially retrofitting existing buildings. Investment costs for the retrofitted case are on average smaller for the same relative decrease in carbon emissions but, again, it is not economically viable to retrofit if long-term investment is not considered. Furthermore, the only difference in the optimal capacities, for only new buildings, is that in the retrofit case CHP is more common. Only electric chiller is used for cooling demand. Lastly, the heating network is expanded for both cases but never to all buildings.

In this work cost of retrofitting was not taken into account, and the heat network is modelled by heat losses and investment cost proportional to the distance. In the future work, retrofitting cost and more detailed representation of the heat network will be included in the model.
ACKNOWLEDGEMENTS

This research has been financially supported by CTI within the SCCER FEE&B (CTI.2014.0119) and by the nano-tera HeatReserves project.

REFERENCES


Available at: http://www.sciencedirect.com/science/article/pii/S0377221704005715


