A NEW APPROACH PROPOSED TO EVALUATE THE COST OPTIMAL AND NEARLY ZERO ENERGY LEVELS OF BUILDINGS AND DISTRICT ENERGY SYSTEMS TOGETHER IN SETTLEMENTS

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ABSTRACT

European Union has published the directive on the energy performance of buildings (EPBD), first in 2002 and, then, in 2010, aiming to reach higher energy efficiency levels in buildings with a controlled effect on the economy. The second directive has introduced new terms as cost optimal and nearly zero energy levels and proposed a calculation methodology to evaluate the annual primary energy consumptions together with long-term energy-related costs (global costs).

Following the terms of EPBD Recast and taking into account of the further energy efficiency targets of European Union for the years 2030 and 2050, in the study, it was aimed to study at settlement scale to reach higher energy efficiency levels for the building stock. In this way, building level energy efficiency measures and district energy system alternatives could be analyzed together. Thus, a new approach was proposed to calculate the cost-optimal levels of settlements, under the frame of EPBD Recast methodology. This calculation procedure was proposed as a decision-making tool for the settlement design development process.

In the study, the proposed methodology was applied to an example settlement which is located in Eskişehir, Turkey. Several combinations of building energy performance levels and district energy systems were examined and compared for the optimal solution for the whole settlement. The results showed that, compared to the settlement consisting of nearly zero energy buildings, the cost-optimal buildings with district energy systems may have the same energy performance level with lower investment and global costs.

INTRODUCTION

European Union (EU), in the last decade, has set some energy efficiency targets for the years 2020, 2030, and 2050. More specifically, EU aims about 20%, 30%, and 40% energy savings respectively for the mentioned years and intends to become a nearly zero carbon community until 2050 by reducing the greenhouse gas emissions about 80-95% compared to 1990 levels (URL-1). For the building sector, the energy performance of buildings directive (EPBD) has been published within the scope of these long-term energy efficiency targets, first in 2002, to set the minimum performance requirements for buildings and to set the frame of energy performance certification system (European Parliament and the Council, 2002). Then, in 2010, aiming to reach higher energy efficiency levels in buildings with a controlled effect on economy, the directive has been recasted introducing new terms, cost-optimal and nearly zero energy levels, and proposed a calculation methodology to evaluate the annual primary energy consumptions (PEC) together with long-term energy-related costs (global costs) (European Parliament and the Council, 2010). This last directive (EPBD Recast) has also mandated all new public buildings by the end of 2018 and all new buildings by the end of 2020 to be constructed as nearly zero energy buildings. Moreover, considering the aforementioned EU energy efficiency targets, these directives for buildings will continue to be published for stricter energy efficiency objectives.

In the light of this information, in the paper, it was proposed to take measures for more than one building to reach a high energy performance community and focused on energy efficiency of groups of buildings in settlements. Beside the energy efficiency measures proposed for high performance buildings, district energy systems (DES) would be a fundamental element of an energy efficient settlement. Electricity grid distribution losses can be decreased and alternative local energy sources can be utilized with combined heat and power production plants in district energy systems. Thus, while they provide more energy efficient heating and cooling with their advantages, district energy systems are becoming an alternative to the building specific HVAC (heating, ventilating, air conditioning) systems. On the other hand, several studies (Sartori et. al., 2009; Paiho & Reda, 2016) draw attention to a contradiction where high energy efficient buildings decrease the demand in the supply side of a DES which causes its efficiency to decrease. So, different building energy performance levels should be analysed together with DES alternatives to achieve the most beneficial scenario for the settlement.

Another parameter should be considered in the study is that all Member States, after determining the cost-optimal and nearly zero energy levels for buildings, should develop measures and politics to close the financial gap between this two levels to pull the nearly zero energy level close to the cost-optimal level. For that reason, any investment planned at settlement scale should be analysed financially and the global costs should be calculated including the investment, running, maintenance and residual costs during a specified service life.

The aim of the study can be asserted as to research about the potential of closing the financial gap between cost-optimal and nearly zero energy levels of buildings by settlement scale measures and to reach higher energy performance levels at larger scales than single buildings. Within this context, a new approach was proposed to imply the cost-optimal methodology of EPBD Recast to a group of buildings with district energy systems. In this way, it could be possible to reveal the effects of building energy performance levels to DESs, to examine the problem points of settlement scale analyses including both buildings and DESs and to analyse cost-optimal and nearly zero energy levels at settlement scale.

METHODOLOGY

As it was explained, the study proposed to scale up the cost-optimal methodology of EPBD Recast from single building level to settlement level to evaluate and ensure the settlement scale cost optimality for high energy efficient settlement. In this new approach, the primary energy consumptions and the global costs of buildings in a settlement were proposed to be evaluated together with the district energy systems serving them. This calculation procedure was proposed as a decision-making tool for the settlement design development process. Each step of the proposed methodology is explained below:

1. Evaluation of the settlement

The methodology can be applied to newly planned or existing settlements. In both cases, the climate, the site orientation, building types and width of the streets that affects the shadow pattern and solar access should be examined to reveal the buildings' energy performance levels. Buildings' location layout would affect the losses of the district energy system distribution network. Additionally, potentials for waste energy, alternative energy sources available in the region and renewable energy should be evaluated.

2. Definition of the reference buildings and determination of cost-optimal and nearly zero energy levels of each building type

According to the EPBD Recast, after 2020, all new buildings will be constructed as nearly zero energy building, so each member state should define nationally the reference buildings, and dependently, the cost-optimal and nearly zero energy levels for each building type in the stock and for each different climate region. For that reason, the method was based on these building energy performance levels. If these energy performance level definitions are already determined in the country where the settlement study will take place, then these levels can be used directly. If not, for the building level study, the cost-optimal methodology of EPBD Recast should be followed.

Implementing the cost-optimal methodology, firstly reference buildings should be defined for each building type. A virtual building can be defined or a real building can be selected. National or regional regulations should be followed to determine the building envelope characteristics, orientations, transparency ratios, internal gains, usage patterns, lighting and mechanical systems for each building type.

Annual primary energy consumptions and the global costs of the reference buildings should be calculated for each type of buildings in the cost-optimal methodology. Different calculation methodologies, monthly, hourly or detailed dynamic, can be chosen for the annual PEC of the reference buildings (ISO, 2017). Global costs should be calculated following the "net present value method" as asserted in the Regulation 244/2012 (European Commission, 2012), including the investment, energy, maintenance and replacement costs during the economic service life, and the residual costs of the building elements which affect the energy performance.

Depending on the building type, different measures can be defined to increase the energy performance of the buildings. These measures can include the improvement of the building envelope, lighting system and mechanical system of the buildings. Also, the measures can be grouped to reach higher energy efficiency levels.

After the definition of energy efficiency measures for the buildings, annual primary energy consumptions and global costs should be calculated for each measure applied to the reference buildings. The same strategy will be applied in the calculations of PEC and global costs as explained for reference buildings. Then, comparing the PEC and global cost results for each type of buildings, the measure with the lowest global cost would be selected as cost-optimal energy level. Secondly, nearly zero energy levels for each type of buildings should be determined as national targets according to financial, social and energy politics. Ideally, nearly zero energy levels should be approximated to cost-optimal levels by closing the financial gap in-between.

3. Determination of district level energy demand

In settlements, energy consumptions of buildings create demand at the supply side of district energy systems. Connecting the buildings to the district energy system requires eliminating the building specific plants, such as boiler, chiller, etc., and including water to water heat exchangers in each building to utilize the hot or chilled water obtained from district energy system. In the simulation model, similarly, building specific plants for heating and cooling should be exchanged with district heating and cooling energy modules for the calculation of total district energy demand. Finally, the distribution losses should be added to the demand caused by buildings.

Energy consumption in settlements is not related only to buildings. Other entries such as transportation, street lighting, or other public services have also considerable effect on energy consumption. However, in the study, energy consumption calculations are limited with buildings and district energy systems to reveal the effects of improvements suggested in buildings and district energy systems.

4. Definition of the reference settlement

Similar to the building level analyses, a reference case should be defined for the settlement to represent best the most common applications in the country. The reference case settlement doesn’t have to necessarily include the district energy systems. However, if national standards exist for the district energy systems, then the district energy system of the reference settlement should be designed based on the relevant standard. In the reference settlement case, the energy performance level of buildings was assumed to be at reference level, also.

Calculation of primary energy consumption of the reference settlement may be different depending on the reference case definition. If the reference case doesn’t have any district energy system, then the total PEC of the settlement can be calculated as a sum of primary energy consumptions of all buildings. Otherwise, if the reference case has district energy system, then the district energy system simulation result, calculated with the reference settlement buildings’ energy demand, should be used.

Global cost calculation for the reference settlement should be made including all the buildings and district energy system, if defined. Similar to the building level procedure, the economic service life period should be determined and the net present value method should be used. Thus, the investment, long term energy, maintenance, replacement and residual costs should be calculated for all the buildings and district energy systems.

5. Definition of district energy system alternatives

For settlement scale analyses, similar to the building energy performance improvement measures, different district energy system configurations can be proposed. These configurations can include different plant combinations, waste heat utilization, alternative energy sources, renewable energy system, etc.

6. Determination of cost-optimal and nearly zero energy levels of the settlement

Both annual primary energy consumptions and global costs should be calculated for each building energy performance level and DES alternative at settlement level. PEC of the settlement will be total consumptions of all buildings or the consumption of district energy system serving the buildings. For the global costs, the costs related to buildings, building systems and district energy systems should be considered. Thus, the determination of cost-optimal and nearly zero energy levels of the settlement could be done by comparing both annual primary energy consumptions and global costs calculated at settlement level.

CASE STUDY IMPLEMENTATION

The proposed methodology was applied to a virtual case which was proposed to be a newly planned settlement located in Eskişehir, Turkey. The climate of Eskişehir is cold with high precipitation in winter. In summer, the temperature differences between day and night are high with low humidity. Designing the new settlement in such a cold climate, the building locations were designed to minimize the shading effect on each other during winter period when the solar altitude angles are low. Also, the district energy grid was designed as compact as possible and distribution losses were assumed to be as 15% of the total consumption. These losses in district heating and cooling were added to the total building energy demands at the district scale calculations. Waste energy usage or alternative source potentials were neglected in the study to focus directly on the effectiveness of the district energy systems. 34 residential buildings, 7 offices and 1 light industry buildings were located in the settlement.

In Turkey, the cost-optimal and nearly zero energy level goals were not determined yet for any type of buildings or climates. For that reason, in the case study, the cost-optimal methodology of EPBD Recast was applied to each building type included in the settlement and for each type, reference cases were designed according to the national and international standards.

Energy performance improvement packages for buildings included the measures of increasing the thermal insulation thicknesses in all envelope elements, different glass and frame combinations, different transparency ratios, solar control alternatives, natural and hybrid ventilation alternatives, efficient lighting alternatives, increasing the efficiencies of mechanical equipment, different mechanical systems and renewable energy systems. Building level primary energy consumptions with all these measures were calculated by dynamic hourly simulations, using EnergyPlus (v8.3) program (URL-2). Global costs were calculated by using the “net present value method” as explained in EN 15459-1:2007 (CEN, 2007). Finally comparing the results, the solution with the lowest cost was chosen as “cost-optimal” and the one with the lowest primary energy was chosen as “nearly zero energy” cases for each type of building. More detailed information about the building level analyses and all characteristics of the reference, cost-optimal and nearly zero energy buildings can be found in the previous article (Kalaycioglu & Yilmaz, 2017) of the writers.

Reference settlement case was constituted with reference case buildings and without any district energy systems. Then, similar to the building level calculations, energy performance improvement study was performed over the reference case. Cost-optimal and nearly zero energy levels of buildings and district energy system alternatives were proposed as ‘energy performance improvement measures’ of the settlement. The combination of building energy performance levels with district energy system alternatives are shown in Figure 01. The abbreviations used in following graph and tables for the building energy performance levels were written in brackets. District energy system alternatives were configured with cogeneration (CHP), boiler and air-cooled chiller (Chiller) units. Depending on the demand level generated by buildings, the capacities and the numbers of the plants change in each alternative. As renewable energy system, photovoltaic panels (PVs) were used with 280 000 Wp total capacity. All DES alternatives can be seen in Figure 01.

In the case study, a bottom-up approach was used to determine the settlement scale energy demand or consumption generated by buildings. Energy demand or consumption of each building type was multiplied by the number of buildings and then all summed up for the settlement’s energy demand. For the cases without district energy system, annual primary energy consumptions and global costs of all buildings were summed for the whole settlement result. However, for the cases with district energy systems, firstly, building final energy consumptions were converted into district energy system demands as explained under “determination of district level energy demand” title above. Annual primary energy consumptions of DESs were calculated by hourly simulations using EnergyPro (V4) program (URL-3). While calculating the settlement scale global costs of the alternatives, investment, maintenance, renewal, residual and operational costs were calculated both for all buildings in the settlement and the district energy systems.

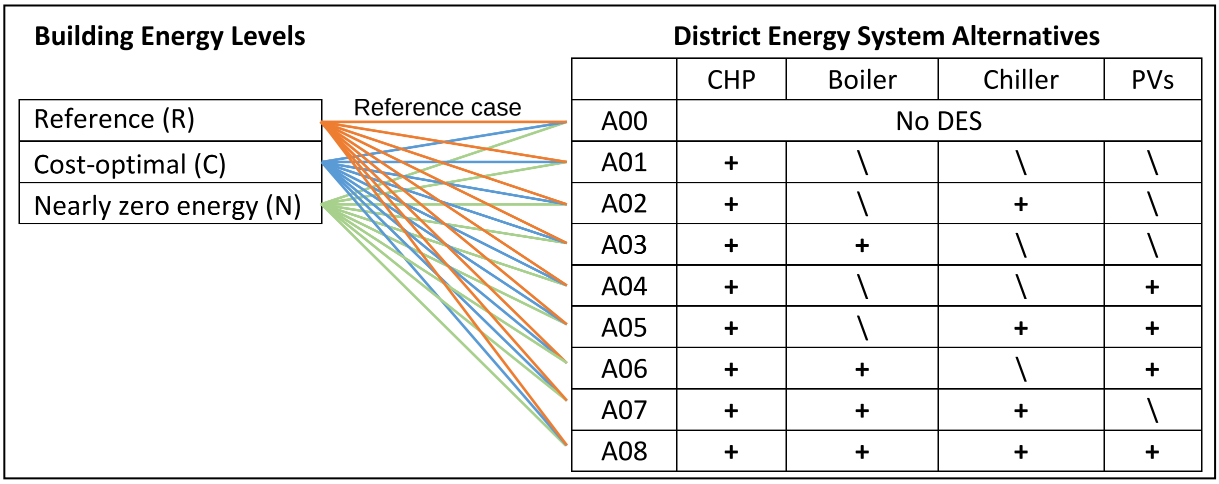

Figure 01. Building energy levels and district energy system configurations for the case study.

RESULTS AND DISCUSSION

In this section, the results of the case study implementation of the proposed method are given. The results were evaluated both at building and settlement scale to reveal the effects of building energy performance levels on the district energy system efficiencies, settlement energy performance, overall investment costs and global costs.

As asserted before, in the settlement, three building types were located and the first results in Table 01 show their energy consumptions for reference, cost-optimal and nearly zero energy levels. The table shows also the total final and primary energy consumptions (PEC) of all buildings in the settlement without any district energy system.

	Reference		Cost-Optimal		Nearly Zero Energy	
	Electricity consumption [kWh/m²]	Natural gas consumption [kWh/m²]	Electricity consumption [kWh/m²]	Natural gas consumption [kWh/m²]	Electricity consumption [kWh/m²]	Natural gas consumption [kWh/m²]
Residential	20.23	49.10	15.35	25.48	10.10	12.66
Office	65.39	20.68	44.76	0.00	37.64	0.00
Light Industry	134.57	74.75	89.28	20.81	40.65	21.17
Buildings total in the settlement	41.30	39.22	29.05	15.66	21.59	8.16
	80.51		44.71		29.75	
Total PEC of the settlement	136.68		84.22		59.11	
Improvement Percentage [%]	/		38.38		56.75	

Table 01. Building level results.

According to the building level analysis results given in Table 01, cost-optimal levels of buildings decreased the PEC of the settlement by about 38%. The reduction of PEC reaches about 57% by nearly zero energy levels of buildings. Figure 02 shows the settlement level results, primary energy consumptions and global costs of each case on a graph. The values given in Table 01 can also be seen in the graph in Figure 02, as no DES cases. Global costs of these cases decreased about 24% with cost-optimal and 18% with nearly zero energy buildings. Furthermore, it can be seen that for each building energy level, DESs improve the settlement energy performance by decreasing the annual PECs. However, the ratio of the improvement decreases, while the buildings' energy performance increases, from reference case to nearly zero energy case, which was an expected result. Additionally, it can be seen that the global costs of the DES alternatives with high energy performance buildings (nearly zero energy building) are higher than the alternative with same buildings without DES. Nevertheless, the global costs are still lower than the reference case.

Furthermore, investigating each building energy performance group separately, A03 is the cost-optimal solution with the lowest global cost and the A04 is the nearly zero energy solution with lowest primary energy consumption. On the other hand, A06 is the most favourable solution both for its PEC which is close to A04 and global cost which is slightly higher than A03. Comparing the A06 results with the reference settlement case, PECs are decreased about 42% with reference case buildings, 56% with cost-optimal buildings and about 68% with nearly zero energy buildings. Additionally, comparing the A06 results separately for each building energy performance level, DES contributions for energy efficiency are about 16% with cost-optimal buildings and 11% with nearly zero energy buildings.

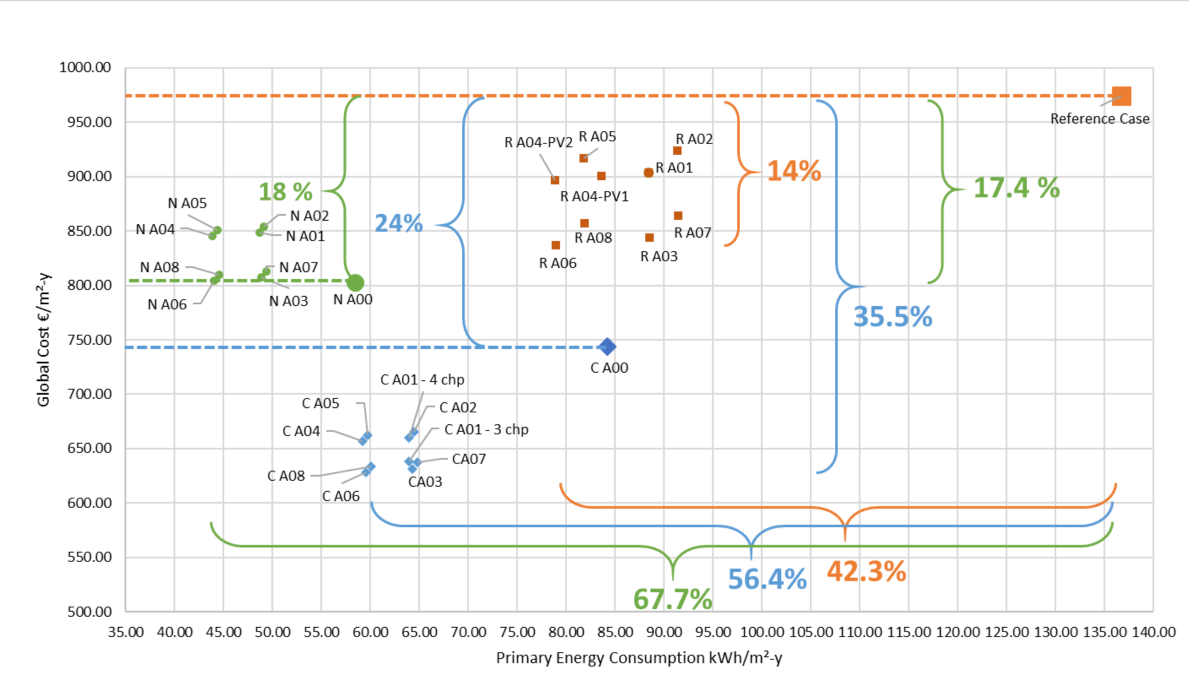

Figure 02. Settlement level primary energy consumptions and global costs.

During the design development phase of a settlement, deeper considerations should be made to reach both economically and energetically feasible solutions. Investment costs are also important as much as global costs for large-scale ventures like constructing a new settlement. For this purpose, comparison of several settlement cases was given in Table 02 including their investment costs.

	Reference Settlement Case	N A00 Case	N A04 Case	C A06 Case
Total Primary Energy [kWh/m2-y]	136.69	59.11	43.89	59.54
Primary Energy Improvement Percentage	-	56.76%	67.89%	56.44%
Investment Costs [€/m²]	333.78	528.59	635.51	379.25
Investment Cost Difference		+58.36%	+90.39%	+13.62%
Global Costs [€/m²]	974.09	802.60	845.24	628.30

Table 02. Comparison of some settlement cases.

Investigating the Table 02, the lowest primary energy consumption could be reached by the case with nearly zero energy levels connected to DES alternative 04 (N A04 Case) which reaches nearly 68% of PEC reduction compared to the reference case. On the other hand, looking to the cost analyses, even though the global cost of the N A04 case is still below the reference, it requires 90% higher investment cost. It is also important to see that the case with nearly zero energy buildings and no DES (N A00

Case) and the case with cost-optimal buildings connected to DES alternative 06 (C A06 Case) have nearly the same energy performance, about 56%. However, comparing their investment and global costs with reference case, it can be seen that C A06 case is much more advantageous with much lower investment and global cost level. It can be asserted that by settlement scale measures, nearly zero energy levels determined for buildings can be achieved with less investment and global cost levels. The study showed that if nearly zero energy levels were determined not only for buildings, but also for the settlements, the investment costs, and the global costs relatedly, can be decreased dramatically.

CONCLUSION

EPBD Recast, which was published lastly by EU Commission in 2010, introduced the cost-optimal methodology which takes into account the long-term energy-related costs while examining the measures to improve the building energy performance. The main target that EPBD recast set for 2020, within each Member State, is to determine the cost-optimal and nearly zero energy levels of buildings and to close the financial gap between them by research activities and by developing politics. Relatedly, this study was performed to reveal how much of the financial gap between cost-optimal and nearly zero energy levels of buildings can be closed by settlement level measures. In line with this purpose, the cost-optimal methodology of EPBD Recast was scaled up from buildings level to settlement level to examine the effectiveness of DESs to reach higher energy efficiency in building sector with less global costs.

The cost-optimal methodology was applied to a newly planned example settlement. Reference, cost-optimal and nearly zero energy level buildings were analysed with several DES alternatives to determine the settlement level cost-optimal and nearly zero energy levels. Several cases of buildings' energy performance levels with and without DESs were compared and the results showed that DES contribution levels to the overall energy performance decrease while building energy performance increases. However, the DES contribution was at least 11% with nearly zero energy level buildings. Another important outcome of the study showed that, instead of constructing all building at nearly zero energy level, implementing a cost-effective DES alternative to a settlement with cost-optimal buildings would provide same energy performance with less investment and global cost.

According to these results of the study, it can be asserted that, a settlement with cost optimal buildings can be diverted to a nearly zero energy community with DES contribution. So, DESs can be utilized to close the financial gap between cost-optimal and nearly zero energy levels of buildings at settlement scale. Here, there is an important issue to pay attention, as DES effectiveness decreases with high energy efficient buildings, further and deeper analyses and achievements are needed to reach nearly zero energy levels both at buildings and settlements scale.

The given results belong to a newly planned (virtual) settlement case, as it was assumed to be located in Eskişehir, Turkey where the new construction rates are high. In newly planned settlements, building locations can be optimized according to the solar accessibility and DES energy intensity and loss factors. What's more, larger available spaces for renewable energy systems could be reserved. However, implementing the proposed method in existing settlements may face some limitations. Determining the DES location for the lowest distribution losses requires further analyses and any appropriate space for large renewable energy installations couldn't be found except from the building roof surfaces.

Other limitations of the proposed method can be about the country where the study takes place. Nationally determined reference building definitions and nearly zero energy levels are the basic inputs of the proposed method. However, In Turkey, there are no strategies or determined levels for cost-optimal and nearly zero energy levels of buildings, yet. Thus, in the study, these levels were determined theoretically and not based on the financial effects on the community. Additionally, it should be asserted that the reference case definitions, as well as nearly zero energy level targets, should be determined also for the settlements connected to district energy systems.

Finally, for the further studies, this study should be extended including the below studies about the settlement scale nearly zero energy level analyses:

- Alternative energy sources for DES and waste energy potential

In the study, natural gas and electricity were used as energy sources both for buildings and district energy systems. However, in settlement scale, there may be utilized more local energy sources in DES units, such as methane obtained from organic wastes or biomass products like woodchips. Here, the waste energy potential, which can be very effective in settlement scale, should be examined, also. In this way, the fossil fuel usage would still be lowered.

- Storage utility of DES

Storage utility was neglected in the case study for the simplicity. However, storage units are fundamental for the DES to increase the efficiency and flexibility of the system. Thus, the results should be re-evaluated with the storage facility for hot and chilled water. However, the storage would also affect the electricity production by cogeneration units and grid integration alternatives should be studied for excessive electricity production.

- The pricing strategy of DES companies

In the study, DES and buildings were taken into account as a whole, as settlement, and the energy selling politics of DES companies were neglected, again for the simplicity. The study, thereby, should be extended in the scope of buildings' energy cost within DES system and DES company economics with energy pricing strategies.

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