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# PEAK LOAD REDUCTION OF DISTRICT HEATING BY CONTROL OF INDOOR PUBLIC SWIMMING POOL

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## ABSTRACT

In Denmark, the first district heating (DH) plant was built in 1903 and today about 64% of all residential buildings are connected to DH. The demand for DH is steadily increasing in and around major cities as more buildings are built for the increasing population. As a result, larger peak demands occur that might exceed the current DH production and/or distribution capacities. To avoid or minimise this, existing thermal capacities in the city could be utilized to shift loads from peak to non-peak periods and hence reduce or avoid the rather large public infrastructure investments needed to expand the existing DH capacities. Such existing capacities could be for example design containers, swimming pools, underground aquifers, soils, and lakes.

This study investigates the potential of applying a public indoor swimming pool for load shifting. Simulations of alternative control scenarios were performed in EnergyPlus which effectively reduced the peak demand of a district heating area.

## INTRODUCTION

The smaller decentrallized DH plants in Denmark are typically plants consisting of a single distribution network supplying no more than 1,000 consumers and covering a rather small area. Heat is produced primarily by one base load unit and one or more peak load and reserve units. The base load unit is typically a natural gas CHP unit or a biomass boiler (e.g. straw or wood chips), or a municipal solid waste plant. The peak load and reserve boilers are typically simple boilers based on oil or natural gas with high production costs.

A typical DH system may supply residential buildings that are characterized by rather small heating needs as well as industrial facilities, health care facilities, education buildings or public swimming pools, etc characterized by large heating demands. Figure 1 depicts the total hourly heating need for the city of Aarhus, Denmark with approx. 325,000 citizens. This year, the peak consump-tion (4 february 7-8 pm) determined the peak capacity for production, transmission and distribution for the whole city. However, the overall or local peak loads may become even larger in the future due to city densification and expansion. The consequence of this development is a need for significant investments in expanding DH production, transmission, and/or dis-tribution capacities. Reducing or maintaining this peak is therefore of great socio-economic interest. One approch may be to rely more on demand side management[1].

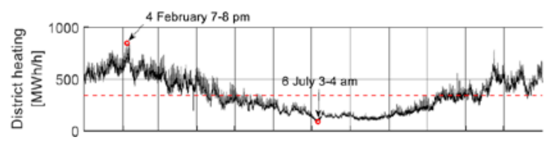

*Figure 1: Hourly peak heating demand for Aarhus, Denmark, in 2015*

The objective of this study is to examine whether demand side management of individual facilities with large DH demands can provide peak load shaving in a primarily residential area of the city with immediate capacity problems due to the addition of new buildings to the existing distribution system. For this end, we assume that we are able to control the heating consumption of a large DH consumer in the form of a public indoor swimming poolwhich needs to heat up a large volume of water in a somewhat unpredictable pattern compared to other city buildings and facilities.

## METHOD

### Energy balance of indoor swimming pool

Heat losses from an indoor swimming pool are schematically depicted in Figure 2. They occur in five different ways which are the convection heat loss at the surface, the conduction heat loss from the bottom surface and side walls to the ground, the latent heat loss due to evaporation from the surface of the water, the radiation

**Nomenclature**

| | |
|---|---|
| $A$ | : area (㎡) |
| $AF$ | : activity factor |
| $C$ | : specific heat (kJ/kg K) |
| $h$ | : convection heat transfer coefficient (W/㎡ K) |
| $H$ | : ceiling height (m) |
| $L$ | : thickness (m) |
| $LH$ | : latent heat (kJ/kg) |
| $k$ | : conduction heat transfer coefficient (W/m K) |
| $M$ | : rate of mass transfer (kg/s) |
| $P$ | : pressure (kPa) |
| $T$ | : temperature (℃) |
| $U$ | : overall heat transfer coefficient (W/m2 K) |
| σ | : Stefan-Boltzmann constant ($5.67 \times 10^{-8}$ W/㎡ $K^4$) |
| Φ | : relative humidity |

Indices

| | |
|---|---|
| *cond* | : conduction |
| *conv* | : convection |
| *eva* | : evaporation |
| *fw* | : supplementary feed water |
| *g* | : ground |
| *ia* | : Indoor air |
| *j* | : component number |
| *ps* | : pool water surface |
| *pw* | : pool wall |
| *rad* | : radiation |
| *ren* | : renovated feed water |
| *w* | : water |

heat loss occurring between the surface of the pool and the ceiling, and energy requirements for renovating feed water heating(make-up water). The total heating load of the swimming pool consists of the summation of each heat loss at design operating conditions, as described in the following equation:

$$Q \ = Q_{conv} + Q_{cond} + Q_{eva} + Q_{rad} + Q_{ren} \qquad (02)$$

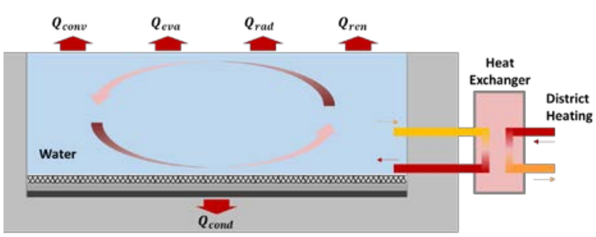


*Figure 2 Heat losses in indoor swimming pool*

Convection heat loss (Q_SPconv) is proportional to the difference between the ambient air and pool water temperatures. Forced convection occurs when ambient air is not stationary (v≠0). Convection heat loss can be calculated on the basis of Newton's formula given below:

$$Q_{conv} = h \cdot A_{ps} \cdot (T_w - T_{SPia}) \qquad (03)$$

$$h = 0.22 \cdot (T_w - T_{ia})^{1/3} \qquad (03)$$

Heat loss by conduction through the poolside and bottom surfaces can be calculated as:

$$Q_{cond} = U_{pw} \cdot A_{pw} \cdot (T_w - T_g) \qquad (04)$$

where $U_{pw}$ is the overall pool wall heat transfer coefficient, which is given as:

$$U_{pw} = \frac{1}{\frac{1}{h_g} + \sum_{j=1}^{n} \frac{L_j}{k_j} + \frac{1}{h_w}} \qquad (05)$$

In the construction of a swimming pool, structure materials should be selected to provide thermal insulation, durability for water pressure, and waterproofing. Thus, thermal and physical properties of suitable materials for swimming pool construction are shown in Table 1.

The evaporation (06) from a water surface depends on the difference between the saturated vapor pressure on the surface of the water and the indoor air saturation pressure. Moreover we need to account for changes/ fluctiations in the activity in the swimming pool (Activity Factor). Fluctuations will also have an effect on the amount of evaporation from the water surface of the swimming pool. This Equation can be used to find the rate of evaporation[2].

$$M_{eva} = \frac{A_{ps}}{LH_{eva}} \cdot (P_w - P_{ia}) \cdot (0.089 + 0.0782 \times u)\ (AF) \qquad (06)$$

where $LH_{eva}$ is the latent heat required for water evaporation at the water temperature, $P_w$ is the saturated vapor pressure at the water temperature, and $P_{ia}$ is the vapor saturation pressure at the indoor air temperature. $(AF)$ is the activity factor for swimming pool.

The latent heat required to water evaporation for the temperature range from -40°C to 40°C is estimated by the following empirical cubic formula[3]:

$$LH_{eva} = 2500.8 - 2.36\,T_w + 0.0016\,T_w^2 + 0.00006\,T_w^3 \qquad (07)$$

Swimmers and spectators are affected by relative humidity, and 50–60% relative humidity is most comfortable for swimmers.

The relative humidity can be defined as:

$$\Phi = \frac{P_{ia}}{P_w} \qquad (08)$$

The swimming pool evaporation heat loss is then given by:

$$Q_{SPeva} = \mathrm{M}_{eva}\,(LH_{eva}) \qquad (09)$$

where $LH_{eva}$ is the latent heat required for water evaporation at the water temperature, $P_w$ is the saturated vapor pressure at the water temperature, and $P_{ia}$ is the vapor saturation pressure at the indoor air temperature, and $(AF)$ is the activity factor for swimming pool.

The latent heat required to water evaporation for the temperature range from -40°C to 40°C is estimated by the following empirical cubic formula[3]:

$$Q_{SPren} = \left(\mathrm{M}_{eva} + M_{fw}\right) C_w\,(T_w - T_{fw}) \qquad (10)$$

**Indoor swimming pool model**

In this study we are modelling the heat demand needs for an indoor swimming pool shown in Figure 3 using EnergyPlus. The swimming pool was modelled to include the swimming pool enclosures with typical construction materials and pool water that is modelled in a levelled 10 lanes (each lane: 2.5m) of 50m length. The thermal properties of constructions are shown in table 1.

*Table 1. Thermal properties of swimming pool*

| Materials | k (W/mK) | C ( kJ/kg K) | D (㎜) |
|---|---|---|---|
| Brick | 0.89 | | 100 |
| Insulation | 0.03 | | 50 |
| Concreate | 1.95 | | 200 |
| Air space | 0.025 | | - |
| Ceramic Tile | 1.20 | | 8 |
| Gypsum board | 0.16 | | 19 |
| Water | | 4.186 | |

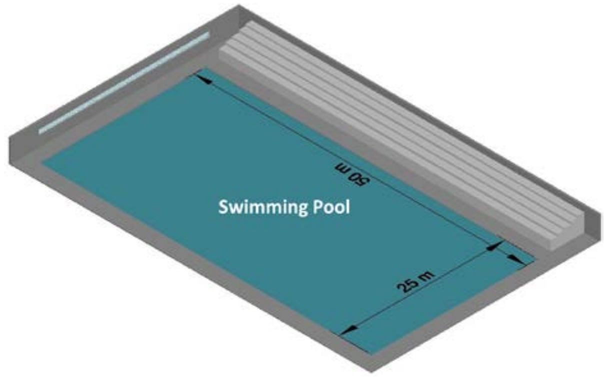


*Figure 3 Indoor swimming pool for modeling*

According to EN 15288-1[4], the air temperature of the indoor swimming pool should be 0 to 4 K higher than the pool water temperature. Furthermore, the relative humidity should be between 40 % and 80 %, and preferably < 60%, and air speed in close proximity with the users' should be ≤ 0.10 ㎧. Thus, for the modelling purpose of this case study, the temperature of enclosure was set +2 K higher than the pool water, and the set point of relative humidity is between 60% and 80% (see the table 1 for further details)

*Table 2. Physical condition of air and water in indoor swimming pool*

| Item | Set value |
|---|---|
| Air temperature of enclosures | 28 ℃ |
| The temperature of pool water | 26 ℃ |
| The pool area | 1,250 ㎡ |
| The temperature of refill water | 10 ℃ |
| Air change rates | 6 ACH[5] |

The system of the indoor swimming pool is shown Figure 4. The heating system used for the swimming pool supplies the pool water with heat from the district heating through a heat exchanger (350kw), and the indoor space of the swimming pool maintains the temperature through the HVAC system and the baseboard heater.

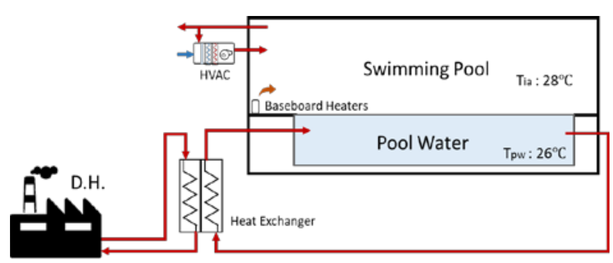


*Figure 4 System of indoor swimming pool*

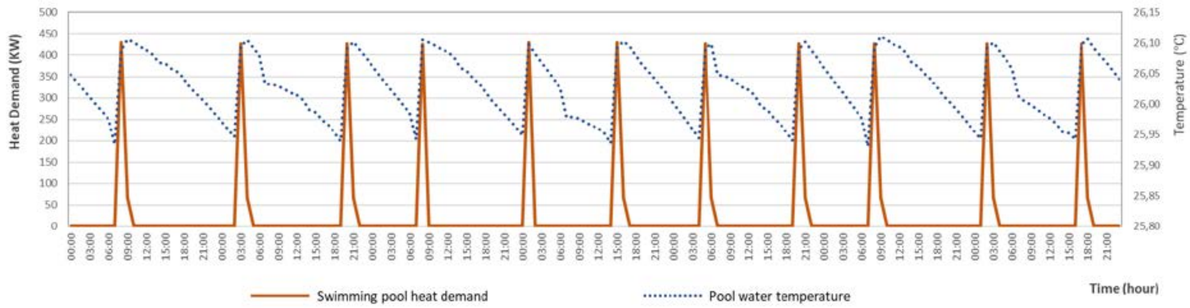


*Figure 5 Weekly heat load profile and pool water temperature of pool water*

**Load profile of swimming pool**

Figure 5 shows the simulated heating load profile and pool water temperature of the pool water. The profile resemples an actual load profile provided by a swimming pool operator. Typically the system will try to maintain the water temperature at 26 ℃ (±0.1 ℃) over a cycle of 24 hours. The water temperature of indoor swimming pool decrease slowly as time passes, but the heat load profile is not systematic because it is affected by the evaporation load, i.e. the AF of the users in the swimming pool and local weather condition: thus the operating time of the heating system is not constant and rather unpredicted. Moreover AF in swimming pool water accelerate the decrease of pool water temperature.

**Load profile of DH area**

In order to demonstate the effect of a large consumer on the load profile of a single DH network, actual consumption data of of 176 single-family house near Aarhus, Denmark, during winter season was averaged and scaled to represent a DH area of 1,000 users. The heating energy demand in DH network is depicted in figure 6.

The data in figure 6 represents quite well the typical energy profile of a 120-150 ㎡ single family houses in Denmark with a relatively predictable load profile with peak load in the morning between 7 to 10 o'clock.

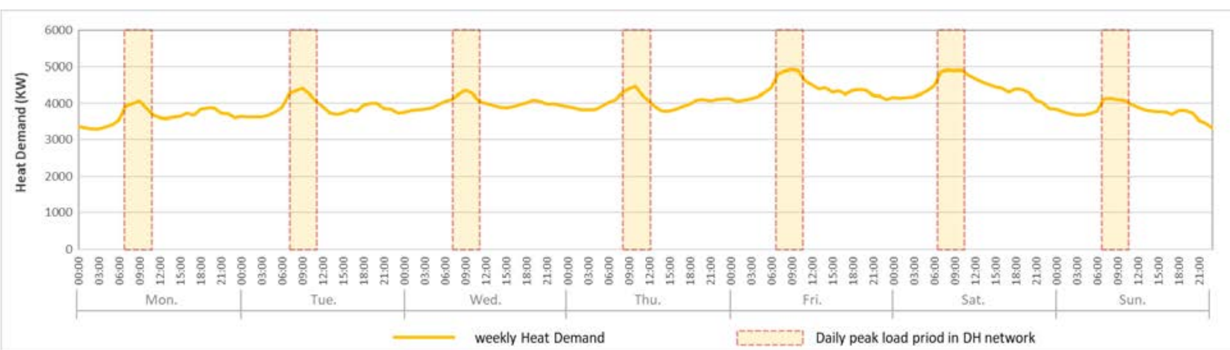


*Figure 6 Weekly District heat demand profile in Aarhus area*

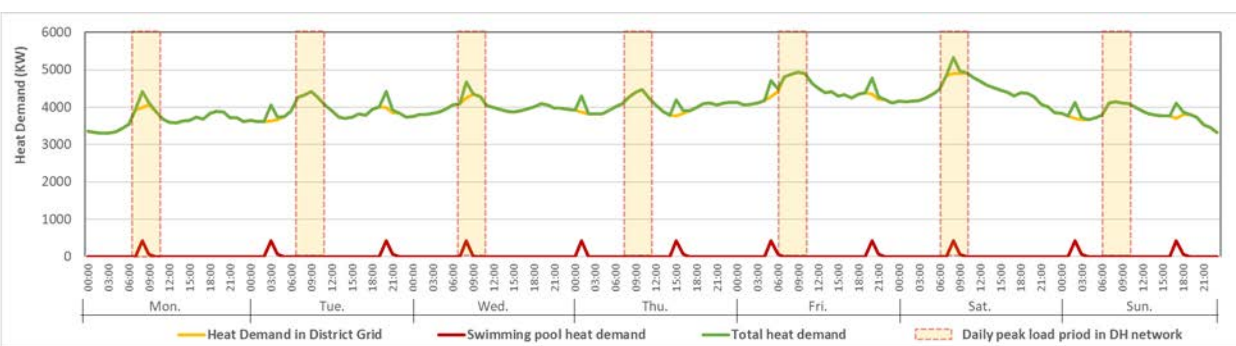


*Figure 7 weekly Heat demand of entirety in DH network*

*Table 3. Swimming pool control scenarios*

| | Time | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| Base case Swimming pool Control | | | | | | | | On/ Off Control: 24 | | | | Pool water temperature: 26.05 < 0<br>Pool water temperature: 25.95 > 1 | | | | | | | | | | | | |
| Scenario 1 | | | | Time Control: ···· < 0 ― > 1 | | | | | | | | Pool water temperature: 26.10 < 0<br>Pool water temperature: 25.90 > 1 | | | | | | | | | | | | |
| Scenario 2 | | | | | | Time Control: ···· < 0 ― > 1 | | | | | | Pool water temperature: 26.10 < 0<br>Pool water temperature: 25.90 > 1 | | | | | | | | | | | | |

## RESULT

Figure 6 and 7 show that the swimming pool heat demand may coincide with the heat demand of the residential buildings. The heat demand of the swimming pool corresponds to the needs of approximately 100 single family houses in this DH network (during peak load time) which makes the swimming pool a rather large consumer that would affect the overall heat demand in the network. The summasion of the two demands indicate the peak load needs when the DH consumers were combined.

The objective of this study is to examine the peak shaving in such scenario where a dominant user in the network could be shifted to non-peak periods. Since the heating of the swimming pool sometimes occurs simultaneously with the peak of the domestic consumers, new control scenarios for the heating system of the swimming pool were implemented to investigate whether it was possible perform peak shaving.

**Control scenarios of heating to pool water**

Two scenarios for peak load shaving in DH network by controlling the heating pool water was simulated see table 3. The control of the base case is an on/off control, which operates 24 hours maintaining the temperature of pool water between 25.9℃ and 26.1℃. Scenario 1 operates outside the peak load time for the dwellings in the DH network. During the off time, if the temperature of pool water is under 25.9℃, it will be on for heating pool water.

According to base case control, operation time for heating up pool water is approximately three hours. Therefore in the scenario 2, the operation method is to preheat the pool water 3 hours prior to the opening hours of the swimming pool, and then turned off during the swimming pool open hour (until 20:00). However, if the temperature of pool water falls below 25.9℃, the heating system will be on similar to scenario 1.

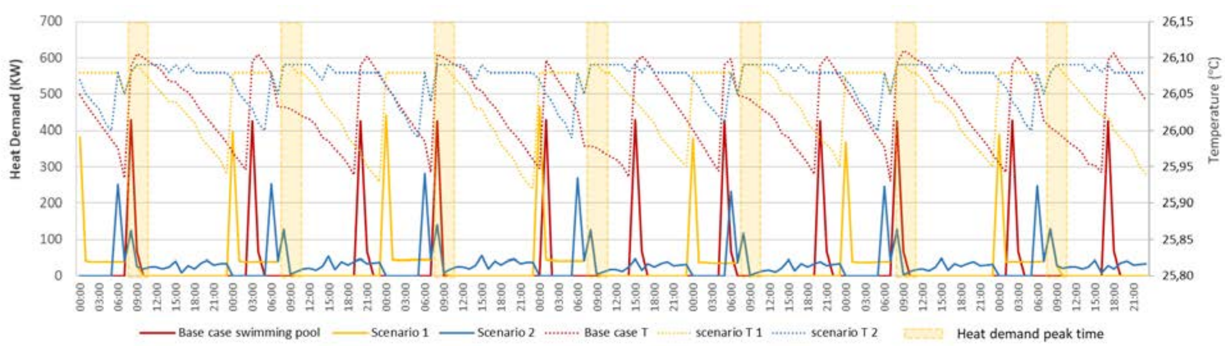


*Figure 8 Heating demand in water pool according to control scenarios*

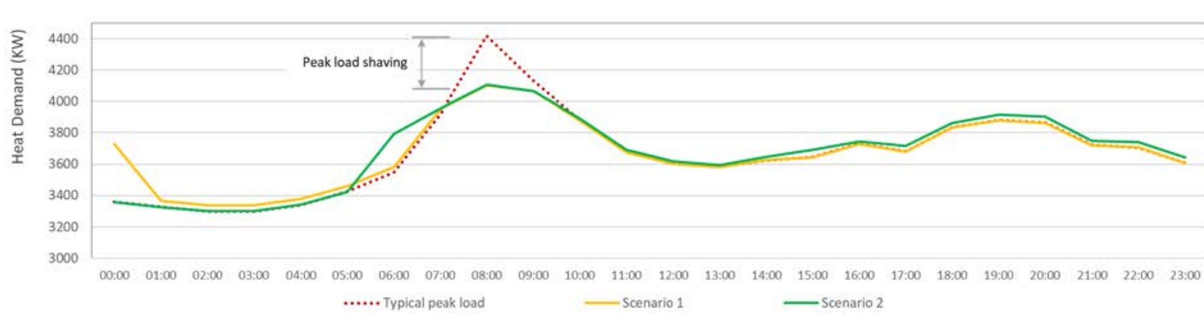


*Figure 9 Peak load shaving by control scenarios*

The simulation result of base case and the two scenarios are depicted in figure 8 and figure 9. Both figures indicates that the alternative control scenarios were able to provide a peak load shaving in DH network.

There are two inputs affecting the operation of the controller for the system. First is the control schedule (Table 3), meaning the time that the controller is set on or off based on the scenarios, and second the pool water temperature (set point 26℃ ±0.1). To exemplify, if the temperature set points are satisfied during the control operation schedule, the controller will remain off or switch off in case is operating. This is can be seen for example in figure 9 where the controller remains off despite the that the control schedule indicates that it should be in operation.

In scenario 1 the heating is turned on from midnight to 6 AM. In order for the needed heating load to be shaved (as depicted in Figure 9), the system will need to run for two hours. After the two hours, the system is in idle heating mode until 6 o'clock in case there is an additional need for heating load in pool water due to evaporation load. If no additional heating is needed because of additional evaporation, then the heating system will be kept off until the next day.

In scenario 2, the heating control of the swimming pool starts three hours prior to the opening hours. During opening hours of the swimming pool, the heating system is active with a total heating load for the pool water as in Scenario 1.

## CONCLUSION

This study purposed a method for peak load shaving based on handling the heating supply for the larger consumers in the DH network.

An indoor swimming pool was selected as a such large consumer for this case study. The typical control heating method of the pool water (24 hour operation based on pool water temperature) indicated that the heating system operated do not follow a repeatetive pattern but are unpredicted. Once the heating system is on it will operate for approximately 3 hours. In instances were the swimming pool heating demand occurs in the same time with the peak demand in DH network, this triggers increased production price of heat source. This is the base scenario simulated in this study.

In order to avoid the swimming pool heating system to be triggered at the same time with the peak demand in the DH network two control scenarios were examined. Scenario 1 utilizes a thermal energy storage storage method during nighttime. This is be actiavting the heating system from midnight to 8 o'clock.

In scenario 2, the swimming pool control system activates the heating 3 hours prior to the openning hours. It in scenario the heating load can not be entirely shaved and a remainign heating demand would be needed at 8AM. In addition depending on the evaporation load in the pool water the opening time of swimming pool might be vary in this scenario accordingly.

According to the study both scenarios are indicating a reduction rate of peak load in DH network approximately 7% comparing to the base case control method.

## ACKNOWLEDGMENT

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