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District heating cost fluctuation caused by price model shift

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Abstract

District heating (DH) is considered as an efficient, environmentally friendly and cost-effective method for providing heat to buildings, and is playing an important role in the mitigation of climate change. Nowadays, Swedish DH companies are facing multiple challenges, and in urgent need for new price models to increase transparency and keep the competitiveness. In this paper, a survey is carried out to understand the structure of the present price models. Then, two restructured price models are proposed and compared with the price model most commonly used. To increase the transparency, price models should base on users' consumption profile; while to reduce the peak load, adopting the pricing strategy based on load demand is an effective way. Consequently, users with flat consumption profiles will save cost, whereas users with steep consumption profiles will have a cost increase, when charging the load demand cost based on daily or hourly peak load demand.

Abbreviation

DH	District heating
EDC	Energy demand component
EEM	Energy efficiency measure
FDC	Flow demand component
FXC	Fixed component
LDC	Load demand component
PS-LD	Pricing strategy based on load demand

1 Introduction

A District Heating (DH) system is a centralised system that supplies heat to end-users by distributing steam/hot water through a pipe network. The centralised heat generation benefits from possibility to utilize energy resource which is difficult to use otherwise (domestic waste, waste heat from industrial processes, etc.) and is equipped with more advanced control over air pollution. Therefore, DH is considered as an efficient, environmentally friendly and cost-effective method for heating in buildings, and is playing an important role in the mitigation of climate change. Today, more than 50% of heat needed for space heating is supplied by district heating in Sweden [1].

In spite of the success DH companies have achieved, they are facing tougher and growing competitions from other ways of supplying heat [2]. For example, heat pumps represent an energy efficient technology for heat production. They normally have a coefficient of performance (COP) of 3 to 5, which means that a heat pump can deliver 3 to 5 kWh heat by consuming only 1 kWh electricity. Considering the fact that the DH price is similar to the electricity price [3], DH becomes less and less competitive.

Plenty of researches have been conducted to improve DH system's efficiency or reduce the operation cost, for instance: Lund et al [4] and Sartor et al. [5] investigated DH companies' potential

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cost saving achieved by using biomass based combined heat and power (CHP) units; Marbe et al. [6] and Djuric Ilic et al. [7] assessed the efficiency improvement through combining CHP plants with biomass gasification and biofuel production process. However, the cost for DH users is still raised by 31% between 2000 and 2009 in Sweden [8].

Another pressure comes from the general descending trend of heat demand due to the improvement of energy efficiency of buildings and warmer climate [9, 10], which will jeopardize DH companies' revenue [11]. The heat demand can be divided into peak load and base load. The base load is normally covered by CHP plant, which requires large investment but has very low operation cost; while the peak load is usually covered by boilers burning coal, natural gas or oil, which have small investments but high operation costs. DH companies' profit mainly comes from the base load, consequently, when the base load decreases, DH companies have less profit. However, to the contrary of the decline of heat demand, the peak of heat demand becomes even less predictable because of higher frequency of extreme weather [12]. Volatile and extreme peak demand increases the production cost and therefore, worsen the competitiveness of DH.

Hence, if DH companies intend to keep competitiveness by reducing price, it is crucial to reduce peak demand at certain level. Pyrko [13] studied the electricity tariff and found that introducing a pricing strategy based on load demand (PS-LD) in the electricity price model could motivate users to change their consumption pattern, (or in other words, shaving the peak demand) to save their energy expense. The same strategy is suggested in [14] for DH. However, it still remains unclear what the effective way is to implement it in the price model and how effective it is on the change of peak load.

The non-transparency of DH price model has also been criticized for a long time [15], and many efforts have been made to enhance the transparency in the area. For example Li et al. reviewed different pricing mechanisms in [16]; the impact of marginal cost strategy on energy efficiency measures (EEMs) has been analysed in local system's level in [17] and [18]; Lundström et al. [19] analysed the impact of seasonal pricing on EEMs; and Zhang et al. [20] and Poredoš & Kitanovski [21] discussed using exergy as an alternative basis for pricing. Whereas, very little has been revealed to guide DH companies or provide DH users proper insight during the process of price model restructuring. Before the restructuring can be introduced, a comprehensible analyse about the present price models is needed to deeply understand the structure of current price models and identify the factors affecting the transparency of DH price model.

Based on the knowledge gaps identified in the literature, the objectives of this paper are (I) to analyse the potential approach about price model restructuring in order to improve the transparency of heat pricing and (II) to investigate the effectiveness of using load demand pricing strategy to motivate users to reduce their peak demand. This work provides a novel insight of how different components of price models and the share of these components would affect DH user's cost during the process of price model restructuring.

The text is organized in the following way: Section 2 presents a comprehensive survey regarding the current price models applied in Sweden; based on the survey results, two restructured price models are proposed to improve the pricing transparency and reduce the peak demand in Section 3; in Section 4, the impacts of the new models on the heat expense of users are estimated to analyse the effectiveness of the restructuring; some discussions about the future work are shown in Section 5 and the major conclusions are summarized in Section 6.

2. Price model survey

In order to understand the structure of current price models, a comprehensive survey is conducted. Price models used by 80 big DH companies are collected from these companies' website. In general, the price models include four components, including Fixed Component (FXC), Load Demand Component (LDC), Energy Demand Component (EDC) and Flow Demand Component (FDC).

In addition to the structure of price components, the share of each component is also important information, which affects users' cost. But it could not be calculated without knowing the heat consumption profile of users. In order to analyse it, several assumptions are made to form a typical multi-family house as an example. The monthly DH consumption of the typical house used in the survey is shown in Figure 1.

Figure 1. Monthly DH consumption of the typical house.

- Annual DH consumption is 193 MWh, same as the annual cost report of facilities conducted by Swedish housing association;
- 25% of heat is used for domestic hot water and distributed evenly throughout the year;
- 75% of heat is used for space heating, distributed in proportion to degree-days over a normal year (calculated from Västerås's temperature statistic between 1960 and 2014, source: Swedish Meteorological and Hydrological Institute).

The share of each component in those collected price models is shown in Figure 2, in a descending order regarding the share of EDC.

FXC represents the cost that a user needs to pay for staying in the network. FXC is generally related to the user's estimated/measured peak load demand, which is further staged into certain levels. Figure 3 shows the fixed fee in Göteborg Energi's price model, no cost charged for peak demand under 50 kW, 8500kr for peak demand between 50 and 100 kW, and so forth. 60% of investigated price models have this component, but it accounts only for very small fraction (1% in average) in the typical house's total DH cost.

Figure 2. Share of price components in the cost calculation of typical multi-family house, 237 price models included.

Figure 3. Fixed fee in Göteborg Energi's price model.

LDC is usually used to cover DH companies' cost to maintain a certain level of capacity for peak load, investment costs of new facilities, depreciation, etc. Most of included price models determine LDC basing on the equivalent annual consumption, which is corrected according to a typical normal year. LDC can also be determined according to the pricing strategy based on load demand. User's LDC cost depends on the capacity reserved for the specific user. For example, DH companies usually set a price for a unit of load demand (usually in SEK/kW), and use measured or estimated peak load demand to calculate the cost. The survey shows that 51% of investigated price models use assigned consumption hour method for LDC. Other methods include: using the consumption of previous year's/winter's (14%), using real measured peak demand (12%), using load signature (6%) and using subscribed demand (4%). The later three methods are directly related with user's real consumption profile and could, to some extent, enhance the transparency in price model. In the typical house's total DH cost, LDC accounts for about 28% averagely. There are 13% of price models without LDC.

EDC is used to cover the production cost of DH companies, which is mainly the cost of fuel. It exists in all price models, which is charged based on user's energy consumption. 63% of included price models use constant price for EDC. But constant price could not reflect the real production cost as DH system has much lower operation cost at base load and higher operation cost at peak load. 33% of price models use seasonal price, which is high during the peak season (usually winter) and low during other time. Other approaches such as subscribed/exceeded energy price (3%), setting price according to outdoor temperature (less than 1%), and peak-period price (less than 0.5%) are

also used. As EDC is tightly related to the heat consumption, it is the most transparent part in price models. In average, EDC accounts for 68% of the typical house's total DH cost.

About 50% of price models have a FDC, which is, in principle, a cost charged based on volume of hot water needed to deliver the energy to a user. It is supposed to cover DH companies' pumping cost and major part of their heat losses. One third of the price models that have FDC use a premium structure. It compares user's heat exchanger's efficiency with the average efficiency in the system. There is a cost reduction if the user has a higher efficiency; otherwise, the cost increases. It provides a good motivation for the users to improve the efficiency of their heat exchanger. The average share of FDC only accounts for 2% in the total cost of the typical house.

The result of the price model survey shows that EDC and LDC account for more than 95% of total cost, whereas FXC and FDC accounts for very small share in existing models. Compared to each other, EDC is the most transparent part, while FXC and LDC are less transparent, since it is not based on the user's actual consumption pattern but based on previous experience and engineering approximation in most of the cases.

3. Restructure price model

Based on the price model survey, a model most commonly used today (reference model) is chosen and two restructured models are proposed. Considering the small shares of FXC and FDC and the non-transparency of FXC, both components are excluded in the new models. PS-LD is also involved in the restructured models and its impact on the reduction of peak load is investigated through the comparison with the reference model. In order to study the model transparency and understand the impacts of LDC and EDC on users' DH cost, sensitivity study is conducted. In the calculation, real hourly consumption data of about 750 larger DH users' during a normal year is used. These users are divided into five groups basing on the type of building, all price models are applied on each user and the energy expenses are calculated and analysed.

3.1. Price models

3.1.1 Price Model I - reference model

For the reference model (Figure 4a) LDC and EDC are determined by using assigned consumption hour method and constant energy price respectively. Assigned consumption hour is an assumption made by DH companies about the number of consumption hours per year (alternatively per winter, typically 2250 hours/year for multi-family house and 1750 hours/year for other buildings) in order to determine the user's peak load demand (Eq. 1). The total DH cost of individual user could be calculated as Eq. 2.

$$L_{ACH} = C/k \quad \text{Eq.1}$$

L_{ACH} : Load demand calculated based on assigned consumption hour method, kW.

C : customer's annual DH consumption, kWh.

k : assigned consumption hours, hour.

$$E = P_{energy} \times C + P_{load} \times L_{ACH} \quad \text{Eq.2}$$

E : the DH cost of a customer, SEK.

P_{energy} : energy demand price, SEK/kWh.

P_{load} : load demand price, SEK/kW.

Figure 4. Proposed price models and sensitivity cases.

3.1.2 Price Model II – measured load demand & seasonal energy price

Different from the reference model, Price Model II (Figure 4b) introduces PS-LD to determine LDC instead of the engineering approximation method, e.g. assigned consumption hour approach. LCD is charged according to the measured daily average load demand. For EDC, two-level seasonal energy price is used to differentiate summer and winter consumptions. Comparing with the constant price in the reference model, this method could reflect the actual production cost in a better way, and motivate users to reduce their consumption during winter time, which is also when expensive peak load plant comes into operation. User's DH cost could be expressed as:

$$E = P_{energy.w} \times C_w + P_{energy.s} \times C_s + P_{load} \times L_{peak} \quad \text{Eq.3}$$

$P_{energy.w}$: energy price during winter season, SEK/kWh.

$P_{energy.s}$: energy price during summer season, SEK/kWh.

C_w : user's winter DH consumption, kWh.

C_s : user's summer DH consumption, kWh.

P_{load} : load demand price, SEK/kW.

L_{peak} : peak of load demand (daily), kW

3.1.3 Price Model III – subscribed load & energy demand

Price Model III, representing another trend of new developments, uses hourly consumption data in the determination of both LDC and EDC. It is also based on PS-LD; however, different from Price Model II, DH company suggests a subscription level on users load demand (usually in proportion to measured peak load demand), users pay for each kW of subscribed load demand. Since the

subscribed level is in proportion to peak load demand, this method motivate users to limit their peak load demand.

The ratio between subscribed and measured peak load demand is determined by the ratio between base load plant and peak load plant's capacity in DH system. For example, if a DH system is consisted of a base load plant with a capacity of 200 MW and a peak load plant with a capacity of 100 MW, this level should be set at 200 MW/(200+100) MW, thus 67%. In this analysis, the subscribed load demand is set at 60% of measured peak load, which is based on local DH system's structure.

The EDC consists of two price levels: the users are entitled to pay a lower price (so called base price) for their energy demand under the subscription level (base load); nevertheless, if the demand exceeds the subscription level, the exceeded part of energy (peak load) is charged at a higher price (so called peak price), as shown in Figure 4c. Since the peak price is higher, this method encourages users to limit their peak load. The cost could be calculated using the formula below.

$$E = P_{energy.b} \times C_b + P_{energy.p} \times C_p + P_{load} \times L_{peak} \times \alpha \quad \text{Eq. 4}$$

$P_{energy.b}$: base energy price (subscribed part), SEK/kWh.

$P_{energy.p}$: peak energy price (exceeded part), SEK/kWh.

C_b : user's base load, kWh.

C_p : user's peak load, kWh.

P_{load} : load demand price, SEK/kW.

L_{peak} : peak of load demand (hourly), kW

α : the subscription level, proportion of base load plant's capacity compared with system's total capacity, %.

3.2 Sensitivity studies

In order to improve the transparency of the price model, a proper share of LDC compared to EDC is preferred. To better understand how this ratio impacts user's DH cost during a price model restructuring process, three sensibility cases are included in this study:

- Case 1: EDC only (EDC/LDC: 100%/0%), which is more transparent since the cost of users is proportional to the heat they consume. This case is commonly preferred by users according to the previous survey;
- Case 2: base case (EDC/LDC: 70%/30%), which corresponds to the average share of EDC and LDC among price models in the price model survey. Together with the Price Model I, this case gives the baseline for comparison.
- Case 3: high LDC (EDC/LDC: 55%/45%), which reflect DH companies' cost structure, it is favoured by DH companies, as it can reduce the risks caused by reduced heat demand and secure aimed profit level for DH companies.

3.3 Data selection and assumptions

Weather conditions, especially parameters such as the annual average temperature and lowest outdoor temperature, have significant impacts on users' heating demand and consumption profile. Therefore it is important to find a normal year, during which the lowest outdoor temperature and average temperature level are close to the historic average ones. According to weather statistics from the Swedish Meteorological and Hydrological Institute (SMHI), year 2012's lowest outdoor

temperature (-17.3°C) and average temperature (6.2°C) are close to the average historic ones between 1985 and 2014 (-16.5°C, 6.6°C) respectively, and therefore the data from 2012 are used in the analysis.

The analysis mainly focuses on larger DH users, which are categorized into five groups: multi-family house, office & school building, commercial building, hospital/social services building and industry building. Figure 5 shows the distribution of different groups regarding number of users and total energy consumption. Smaller users are excluded due to their small share in the total DH consumption.

Figure 5. Distribution of number of user groups and their consumption between investigated groups.

To determine the component prices in different price models and for different sensitivity study cases, the DH companies' total revenue is kept unchanged. Based on this prerequisite, the calculated price levels are listed in Table 1.

Table 1. Price-levels of proposed price models (dash line framed price represents baseline case).

	Case 1 100% / 0%	Case 2 70% / 30%	Case 3 55% / 45%
Price Model I (reference)			
Price level for Energy component (SEK/kWh)	0.603	0.422	0.332
Price level for Load component (SEK/kW)	0.000	0.362	0.543
Price Model II (measured load demand & seasonal energy price)			
Price level for Energy component in summer (SEK/kWh)	0.361	0.253	0.199
Price level for Energy component in winter (SEK/kWh)	0.650	0.455	0.357
Price level for Load component (SEK/kW)	0.000	0.560	0.840
Price Model III (subscribed load & energy demand)			
Price level for Energy component base (SEK/kWh)	0.528	0.369	0.290
Price level for Energy component peak (SEK/kWh)	1.979	1.386	1.089
Price level for Load component (SEK/kW)	0.000	0.729	1.093

3.5 Individual analysis

Analysis of cost variation caused by price model shifting is also done for individual users besides for the five user groups. To exclude the impact of other factors, only the results under case 2 (base case) are included here. Since the annual consumption of individual user differs a lot from one to another, comparing their duration curves directly could not tell whether one user's consumption profile is more volatile than the other's, especially if the their consumption have magnitude difference. Hence standardized duration curve is introduced here to facilitate this kind of comparison.

Different from a normal duration curve, a standardized duration curve is consisted of data points that represent the ratios between the instant load demand and the average load demand (Eq 5) in a descending order.

$$D_i' = \frac{D_i}{D_a} \quad \text{Eq. 5}$$

D_i' : data point in standardized duration curve.

D_i : instant heat demand of a user.

D_a : average heat demand of the same user during a year.

4. Impacts of restructured price models on user's heat expense

The cost of DH users is evaluated based on the real consumption data. Since the combination of Price Model I and Case 2 represents the most commonly used price model today, the DH cost calculated using this model is set as baseline for comparison. DH costs calculated using other price models in different cases are compared to this baseline to evaluate the relative change caused by price model restructuring.

4.1. Price Model I - the reference model

The impacts of LDC and EDC on the energy cost for different user groups are shown in Figure 6. It is clear that for multi-family house, the energy cost rises along with the increase of the share of EDC (e.g. Case 1), while decreases along with the increase of LDC (e.g. Case 3). It is shown in Figure 6, when the share of LDC rises from 30% (Case 2) to 45% (Case 3), multi-family house's DH cost would decrease by 2%; if the share of LDC declines from 30% to 0%, this group's cost increases by 3%. However, the share of LDC and EDC affect other groups in an opposite way: when the share of LDC rises (from Case 2 to Case 3) all groups' costs increase by 2% except group multi-family house; and when it declines (from Case 2 to Case 1), their costs decrease by 4%. It implies that group multi-family house benefits from a higher share of LDC under this model.

For the reference price model, once the assigned consumption hour is determined, user's DH cost solely depends on the annual consumption. Therefore users that have same amount of assigned consumption hour are affected in the same manner when share of price model component changes. As shown in Figure 7, when shift from the base case (Case 2) to Case 1 (Figure 7. a), all 356 users from group multi-family house experience a slight cost increase; while shift from Case 2 to Case 3 (Figure 7. b), 392 users from other four groups experience a mild cost increase.

Figure 6. The cost variation under the reference model.

Figure 7. Number of users experience certain range of cost variation under the reference price model

Because of lacking of PS-LD, EEMs that can reduce same amount of annual consumption can save users the same amount of cost under this price model. Since Price Model I does not differentiate reduction in base and peak demand, it could not encourage users to specifically limit their peak demand.

4.2. Price Model II - measured load demand & seasonal energy price

The cost change resulted from the application of Price Model II is illustrated in Figure 8. Comparing to the reference model, Price Model II has very limited effect on groups of multi-family house and office & school building, which cost remain at the same level (99% and 101% respectively) for the base case, whereas other three groups face higher levels of cost variation. The costs of

commercial building and industry building increase about 3% comparing with base-line and the cost of hospital & social service declines 4%.

Figure 8. The cost variation under Price Model II.

The impacts of LDC and EDC are similar to those for the reference model (Figure 8). As the share of EDC increases (Case 1), group multi-family house's cost encounters an increase (3%) while the costs of all other groups drop 1% to 5%. For the case of high LDC share (Case 3), multi-family house's cost decreases from 99% to 98%, group hospital & social services' cost remains as the same, while the costs of other groups increase 1% to 3%.

EDC in this model depends on heat consumption during winter and summer time respectively. As stated in section 3.1, since the winter price is higher than the summer price, it is more beneficial to reduce the consumption during winter than during summer. Since PS-LD is also considered, user's LDC cost depends solely on actual peak load demand (in daily average), hence users could reduce their cost directly by limit their peak demand.

Figure 9 is the statistical result of cost variation under different sensitivity study cases. In Case 1, where LDC is absent, the majority (ca 92% users) only has a mild cost change ($\pm 5\%$), as shown in Figure 9a. But as the share of LDC increases, more users face higher levels of cost variation. Under Case 2 (Figure 9b), 1.2% of users face 10% or higher cost decrease, 6.7% of users encounter a cost increase of 10% or even higher, and another 0.5% of users face a cost increase over 50%. In Case 3, 3.2% users have 10% or higher cost decrease, whereas 13.1% users face 10% or higher cost increase, and two of which even have doubled cost. In general, more users benefits from higher share of EDC compared to LDC.

Figure 9. Number of users experience certain range of cost variation under Price Model II

As mentioned before, the total cost depends on the proportion of heat consumption during winter time and user's peak load demand, both of which are related to the user's consumption profile. Therefore a closer observation on individual users' consumption profiles is conducted to understand the impact.

Individual analysis is done between two users facing significant cost increase and decrease: user 207 from hospital & social service group, which annual DH cost declines mostly; and user 801 from office & school, which cost increases mostly under Price Model II.

The consumption profiles of these two users are illustrated in Figure 10. The profile of user 207's fluctuates much less than that of user 801. A flat profile is good for DH companies, since it could contribute to save the high operation cost at the peak load production.

Correspondingly, the cost of user 207 decreases by 10% when the price model shifts from Price Model I, about 9% of which is contributed by the reduced LDC; whereas the cost of user 801 increases by 216%, where 215% comes from the increased LDC. Assuming user 801 would like to keep DH cost at the same level, the load demand must be reduced by 78%, equivalent to a 50% of energy demand reduction during their consumption peak.

Figure 10. Standardized duration curve (daily average) of two customers, facing cost increase and decrease respectively.

In general, Price Model II benefits users with flat consumption profile (in daily resolution). LDC charged based on the peak demand in daily resolution can motivate users to adopt EEMs that could reduce peak demand at the same resolution (better insulation, exhaust air heat exchange etc.); and EDC with seasonal energy price encourages energy saving during winter rather than summer time, which satisfies the desire of DH companies.

4.3. Price Model III - subscribed load & energy demand

Figure 11 shows the change of DH costs for different groups at Price Model III. Comparing with the baseline, Price Model III has very limited impact on the groups of multi-family house and commercial building, which costs vary less than 1%; while the group of office & school faces a 4% cost increase; and the groups of hospital & social service and industry building face 3% and 2% cost decreases respectively.

Figure 11. The cost variation under Price Model III.

As the share of EDC rises (Case 1), the costs of multi-family house and hospital & social service increase 6% and 2%; while, the costs of other groups follow an opposite tendency, reduce 9%, 11% and 7% respectively. As the share of LDC rises (Case 3), the costs of group multi-family house and hospital & social services decrease 3% and 1% respectively, while the costs of other groups increased by 5%, 6% and 3% respectively. Under Price Model III, user's DH cost also depends on detailed consumption profile. The EDC part is determined by both the subscribed consumption and the consumption exceeding the subscribed level, whereas the LDC part is determined by user's actual peak load demand in hourly resolution.

By comparing Figure 12 with Figure 7 and 9, it could be seen that more users experience a higher cost variation under Price Model III than under Price Model I and II: for the base case (Case 2), about 4% of users have a cost decrease over 10%; 12% encounter a cost increase higher than 10%; 1.7% of users even encounter a significant cost increase (+50% or higher). It is even more obvious if the share of LDC increases (Case 3), there are 7% of users facing cost decrease higher than 10%, 21% of users facing cost increase higher than 10%, and 3% of users facing cost increase higher than 50%. Whereas for Case 1, there are fewer users (about 2%) having cost increase higher than 10%, but more users (around 35%) having high cost decrease (higher than 10%). It can still be observed that more users benefit in Case 1, with a higher share of EDC.

Figure 12. Number of users experience certain range of cost variation under Price Model III

Two users which cost increases and decreases mostly under Price Model III are also examined individually: user 793 and user 801's consumption profiles are shown in figure 13.

User 793 has the highest cost reduction (12%), including 7% and 5% reductions in LDC and EDC respectively. Whereas, for user 801, even though EDC decreases 7%, LDC induces 355%, and therefore, the total cost increases 348%. In order to keep the DH cost of user 801 at the same level, the peak demand have to be reduced by 86%, equivalent to a heat consumption reduction by 56% during peak demand periods.

Figure 13. Standardized duration curve (hourly average) of two customers, facing cost increase and decrease respectively.

Same as Price Model II, users with flat consumption profile tend to have a cost reduction when the price model is shifted from the reference model. Since the load demand at higher time resolution is used for charging LDC, EEMs that can even out demand in hourly time frame become more attractive, such as using building envelope as short term heat storage. Using the hourly consumption and subscribed/exceeded structure in EDC motivate users to keep a close look and control their demand all the time. This makes the model even more attractive to DH companies if the peak load in DH system lasts only for a few hours.

388 5. Discussion

389 Price Model II and III could generally give higher incentives to DH users for limiting their peak
390 load demand. Since Price Model II uses daily average demand, it is more effective to limit daily load
391 demand; whereas Price Model III uses hourly average demand, it could encourage load demand
392 reduction in shorter time frame. Yet, neither Price Model II nor Price Model III could always reflect
393 the actual production cost. Seasonal price in Price Model II is a best estimation based on previous
394 years' experiences, but as weather aberrations occur more frequently, the production cost during
395 warm winter/cold summer tends to deviate from the estimated cost by a lot. Price model III charges
396 a higher price for user's peak consumption, which, in most of the cases, occurs during the period the
397 peak load system is in operation. However, there are some exceptions. For example for an aquatic
398 park, which is only open during summer, its peak demand occurs when no peak load system is in
399 operation. DH companies can actually benefit from this user as it consumes much base load.
400 However, there is a risk to lose the user due to the wrongly charged high peak load.

401 In addition, the mismatches between DH price and the actual production cost indicates that pre-
402 determined price leads to significantly higher financial risk [22]. The real-time price basing on the
403 actual operation could be a plausible alternative.

404 More DH users benefit from high share of EDC, but it does not necessarily mean this is a proper
405 choice. Weather users that help to increase DH system's efficiency benefit from the high share of
406 EDC is the key to answer the question here. So a closer investigation is needed at the individual level.
407 Standardized duration curve could be a useful indicator to identify users preferred by DH companies
408 and to find out if they benefit from this kind of shift.

409 6. Conclusion

410 A price model survey was conducted to capture the present structures of DH price models in
411 Sweden and the new development of price models. Four price model components were identified. In
412 order to improve the transparency of price models, users should be charged based on their actual
413 consumption pattern instead of based on previous experience or engineering approximation. The
414 pricing strategy based on load demand was introduced to effectively limit peak load.
415 Correspondingly, two restructured price models based on daily average load (Price model II) and
416 hourly average load (Price model III) were proposed and compared with the reference price model
417 most commonly used today (Price Model I). The result shows that

- 418 (I) In general, more users will benefit from the higher share of EDC compared to LDC. It can
419 motivate users to apply EEM and reduce the total heat consumption. However, this will
420 put a high risk on DH companies, as it may not effectively reflect DH companies' actual
421 cost structure.
- 422 (II) When introducing pricing strategy based on load demand (shifting price model from
423 Price Model I to Price Model II or III), users with flat consumption profiles, such as group
424 multi-family house and hospital & social service, will benefit from the change; whereas
425 users in the groups of office & school, commercial building and industry building, which
426 have steep consumption profiles, will have a cost increase.
- 427 (III) Price Model II is more effective to restrict user's winter consumption and reduce peak
428 load demand in daily resolution since the energy price in winter is higher and LDC is
429 determined based on daily average peak load demand. Price Model III gives high
430 incentive to reduced energy and load demand over the subscribed level in shorter time
431 frame (hourly resolution).

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