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District heating in areas of low density

Investment models for district heating in areas with detached houses

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ABSTRACT

District heating supplies heat and hot water to about 10% of the 1.6 million detached houses in Sweden. A future realistic market share of district heating is however 40% in such areas in Sweden according to previous studies. The expansion of district heating into another 600 thousand detached houses in Sweden would probably be accelerated if the profitability was increased for the district heating companies when supplying heat to such areas. Currently, the Swedish district heating industry focuses on reducing the investment costs for construction of distribution systems from the main pipes into the detached houses. This paper presents a model to be used for estimating the investment cost. Actual data was collected from 55 areas with 2500 detached houses district heated in Göteborg, Sweden. Multiple regression analysis was used to determine the model coefficients. The results explain some variations in the investment cost. The model shows that the pipe line layout is important since the pipe length per house and the presence of old tar asphalt in the asphalt layer are decisive to the investment cost per house. It also shows that standstill costs appear when the heat distribution system is constructed.

1. INTRODUCTION

Background

In Sweden, most blocks of flats and office blocks use district heating as heat source, whereas the market share for district heating in detached houses is considerably lower. In 2004, about 10% of the Swedish 1.6 million detached houses were heated by district heating [1]. A possible future market share in Sweden for district heating is 40% in such areas [2]. However, the expansion of district heating into low heat density areas in Sweden depends on such an expansion being profitable for the district heating companies. District heating in detached houses is more common in Denmark, where 46 % of all detached houses used district heating as a heat source in 2004 [3]. The expansion of district heating in Denmark for detached housing areas can primarily be explained by an extensive energy planning supported by high fuel oil taxes and heat zoning [4].

The purpose of the “Sparse district heating” program, funded by the Swedish Energy Agency and the Swedish District Heating Association, was to create incentives for district heating companies to expand into areas with detached houses [5]. The main focus of the “Sparse district heating” project was thus on the cost level. If the district heating companies’ investments could be reduced, such incentives would increase. The term “investment” stands for the company’s expenses for connecting customers to the district heating system. It is thus desirable to find solutions that reduce the investment which also has been the main focus of the project. This project was part of the “Sparse district heating” program.

This paper uses data collected from 55 areas with a total of 2500 detached houses in Göteborg, Sweden, to derive a model for estimating the investment cost. The data set, which is a subset of Göteborg Energy’s 120 areas with approximately 8000 detached houses, will be increased to 85 areas with approximately 4500 houses. The cost model derived herein explains variations in the investment between different areas with detached houses in terms of a set of factors. In this paper, the set of factors explaining these variations are identified as important by multiple regression analysis. The factors explaining these variations are not equally important; some have a greater impact on the investment compared to others. When multiple regression analysis was applied on the data collected, certain factors were also identified as unimportant for the investment and could, accordingly, be excluded from the cost model. The cost model derived in this paper thus answers where efforts should be made in order to reduce the investment so that the district heating companies’ incentives for expanding into areas with detached houses are increased.

Previous studies

A comparison of the cost level for connecting detached houses to district heating systems in Denmark, Sweden, Iceland and Finland showed that the cost level is equal with the exception of Iceland, where unique technical conditions lead to low costs [6]. The investment is also an issue when detached houses are connected to district heating systems in Germany, as discussed in [7].

Comparisons of the cost level between different district heating companies in Sweden were conducted within the sparse district heating program [8, 9]. In a study of 29 Swedish areas, it was concluded that variations in the investment is difficult to evaluate due to differences in what costs the district heating companies include in the investment [8]. Sandberg studies 13 areas with detached houses in Sweden and develops the following cost model for the investment[1]:

$$I = 160 \cdot L_{mp} + 110 \cdot L_{bp} + 3500 \cdot n \qquad \text{(eq.1)}$$

Where, I (€/area) stands for the investment, L_{mp} (m/area) the length of main pipes, L_{bp} (m/area) the total length of branch pipes, n is the number of houses connected. Sandberg did thus not identify costs that are independent of the number of houses or the pipe length. It can be concluded from eq. 1 that the costs in the model are either dependant on the pipe length or the number of houses. No costs independent of neither the pipe length nor the number of houses, for instance costs related to bringing machinery and stagnation during construction, were thus identified in this study.

2. MODEL

The investment, I (€/area), is often separated into two parts; costs for constructing a district heating pipe system, C_P (€/area), and costs for installing substations, C_{SS} (€/house), for n number of houses connected, see equation 2.

$$I = C_P + C_{SS} \cdot n \qquad \text{(eq.2)}$$

The costs for constructing a district heating pipe system, C_p (€/area) in order to connect the detached houses in the area can be estimated by equation 3.

$$C_P = C_{P1} \cdot L + C_{P2} \cdot n + C_{P3} \qquad \text{(eq.3)}$$

Where L is the total pipe length (m/area), C_{P1} (€/m) stands for costs that are dependent on the pipe length, for instance costs of pipe materials and excavation. The next coefficient, C_{P2} (€/house), stands for costs that are dependant on the number of houses, n, such as costs of pipe installation inside the houses and administrative costs. Finally, C_{P3} stands for costs that neither are dependant on the pipe length nor the number of houses connected, for instance start up costs to bring machinery and sheds to the site and costs of standstill. The total investment, I (€/area), see equation 4, is thus estimated by the sum of costs for constructing the district heating pipe system (€/area) and costs for installing district heating substations in the area, C_{SS} (€/area).

$$I = C_{P1} \cdot L + C_{P2} \cdot n + C_{P3} + C_{SS} \qquad \text{(eq.4)}$$

An estimation of the average investment per house can then be made by equation 5.

$$\frac{I}{n} = \frac{C_{P1} \cdot L}{n} + C_{P2} + \frac{C_{P3}}{n} + C_{SS} \qquad \text{(eq.5)}$$

Equation 5 is adapted to the following linear regression model

$$y = \alpha + \beta_0 \cdot x_0 + \beta_1 \cdot x_1 + \varepsilon \qquad \text{(eq.6)}$$

[1] This value is calculated from SEK to EUR. All calculations from SEK to EUR in this study are conducted with the average exchange rate for 2002, 9.163 [10]. The year 2002 was chosen since most areas studied in this paper were connected to district heating in 2002.

The coefficients of equation 6 are then obtained by fitting the model to a sample of actual data. The adequacy of the model can be improved if additional factors that explain the variation in the investment are found. Therefore, the following factors are added to the model:

- 1/(The connection rate). The connection rate stands here for the number of connected houses/the total number of houses in the area [8, 9]
- Technical difficulties during the construction of the pipe system. These parameters are added as dummy variables (1/0):
  - Presence of ground frost (1/0)
  - Presence of tar asphalt in the asphalt layer (1/0)
  - Presence of rocks (1/0)
  - Pre investments due to future expansions (1/0)

3. DATA

Data was collected for areas with detached houses connected to the district heating system between 1998 and 2005 in Göteborg and Partille, Sweden. Data on the parameters shown in Table 1 was collected from the Göteborg Energy internal documentation and compiled in a database. The database includes data on 110 areas of which 55 areas, totally including 2500 houses, were used in this study. The remaining 55 areas were not used due to scarcity in data.

Table 1. Real input to the database

Parameter	Source within Göteborg Energy	Comment
Investment per project	Cost accounting system	Includes the total costs of constructing an operational distribution system of pipes and substations and the contractor's overhead and profit. Includes also project management costs penalty costs for future maintenance of the asphalt layer. Sales costs are excluded[2].
Number of houses in the area	Final Report, written by the project leader	
Number of houses connected to DH	Final Report, written by the project leader	
Pipe length, pipe dimension, pipe material, insulation	Digital map documentation of the distribution system in Map Info	District heating pipes existing in the area prior to the connection were excluded. Includes main pipes, branch pipes and pipes inside the house that were installed in connection to the present investment.
Technical difficulties	Final Report, written by the project leader	The difficulties are explanations to deviations from the initial estimated investment. Four dummy variables; Pre investments in large pipe dimensions due to future expansion, the presence of tar in the asphalt layer, ground frost, rocks

[2] This value is calculated from SEK to EUR. All calculations from SEK to EUR in this study are conducted with the average exchange rate for 2002, 9.163 [10]. The year 2002 was chosen since most areas studied in this paper were connected to district heating in 2002.

The original data shown in Table 1 was converted to parameters that fit equation 5. The relation between the investment per house and the following parameters were then studied by regression analysis.

- Pipe length per house
- Connection Rate
- Technical difficulties

Generality of the data

The applicability of the model development is dependent on the generality of the areas' properties. The areas included in the study have already existing houses, often a mixture of detached houses and terraced houses. Steel twin pipes were used almost exclusively as main pipes and flexible copper pipes, either twin or single, were used as branch pipes. The investment per house is showed as a function of pipe length per house in Figure 1.

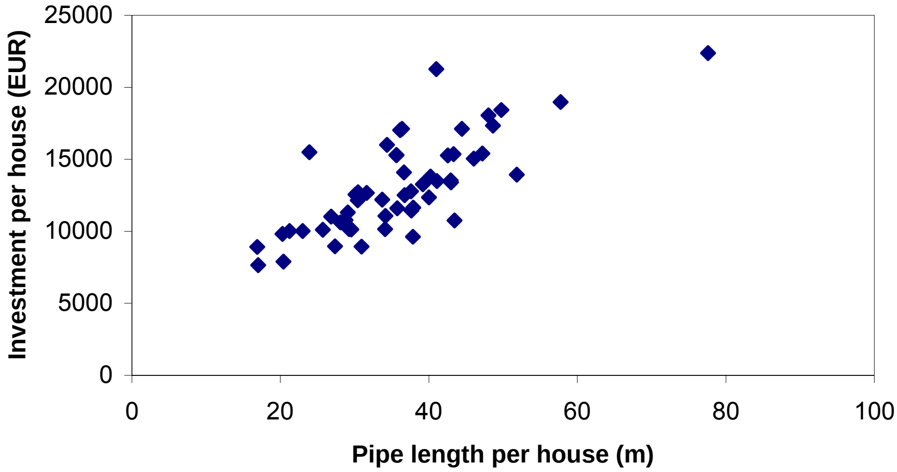

Figure 1. Investment per house as a function of the total pipe length per house for the studied areas

The properties that differ between the areas are the number of houses, which varied between 16 and 118 with an average of 55. The number of houses connected to district heating in each area was between 12 and 103 with an average of 45. The connection rate varied between 0.5 and 1.0 with an average of 0.7. The total pipe length per house varied between 9 metres and 76 metres with an average of 36 metres per house.

Technical difficulties during construction were reported for the following number of areas: tar asphalt in 13 of the areas, ground frost in 12 areas, pre investments in 15 areas, and rocks in 15 areas.

4. RESULTS & DISCUSSION

The fitting of the model showed in equation 5 to data shows that two parameters are significant on a significance level of 5%; the pipe length per house and the presence of tar asphalt, see Table 2.

Table 2. Significant factors in the model

Independent variable	Coefficient	t-value for n = 55	The probability for no correlation
Constant	4230	4.92	0.0%
Pipe Length per house	232	10.3	0.0%
The presence of tar in the asphalt	2360	4.11	0.0%

The value of R^2 = 0.70 indicates that the model explains approximately 70% of the variations in the data of the investment per house.

Costs of the district heating pipe system dependant on the number of houses, but independent of the pipe length and costs of the substation/house and project management costs are totally 4230 €/house. Costs related to the substation were estimated to approximately 3000 €/house in [9], project management costs approximately 300 €/house[3], penalty costs for future maintenance of the asphalt layer approximately 100 €/house[4] which indicates that costs independent on the pipe length but dependant on the number of houses is approximately 800€/house. Such costs could for instance be related to construction standstill.

The analysis shows that the investment in distribution systems in areas with detached houses depends on the pipe length of 230 €/pipe meter, which corresponds to the result from the previous study in [9]. An efficient pipe line layout that minimizes the pipe length is thus beneficial.

The investment is increased by 2360 €/house when the asphalt layer at the construction site contains tar asphalt. Roads built between 1945 and 1973 can be built with asphalt mixes containing coal tar, grouted macadam in the road base. The waste is considered hazardous due to carcinogenic PAHs. Asphalt masses containing PAHs are handled different depending on the level of PAHs. Waste with low levels of PAHs can be crushed at the site and reused whereas waste with higher levels must be disposed at special recycling plants [11]. This results in transportation costs and disposal costs. The access to information regarding which roads that contain asphalt tar before planning the pipe drawing could thus be beneficial. The development of an efficient process to handle tar asphalt with low levels of PAHs in the field with intermediate storing of the masses and crushing is important to avoid the expensive disposal. It is possible that the presence of tar asphalt in 13 areas is correlated to other factors not identified in this study that increase the costs.

The unstandardized residuals of the model, i.e. the deviations between the actual investment per house and the investment per house calculated from the model is shown in Figure 2 where only the pipe length is considered and in Figure 3 where the pipe length and the presence of tar asphalt is taken into account. It can be seen that the residuals are closer to zero in Figure 3 when tar asphalt is considered compared to Figure 2. A comparison of the sum of squares of the residuals shows that the

[3] The average project management cost for 15 of the areas included in this study.
[4] The average penalty costs for future maintenance for 15 of the areas included in this study.

model taking tar asphalt into account is more correct since the sum of squares of the residuals is $1.8*10^{10}$ when the pipe length is considered in the model and $1.4*10^{10}$ when the pipe length per house and the presence of tar asphalt are considered.

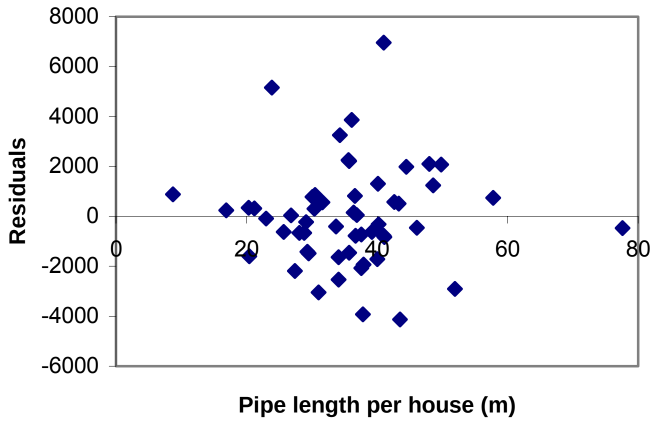

Figure 2. Deviations from the model (unstandardized residuals) when the pipe length per house is taken into account

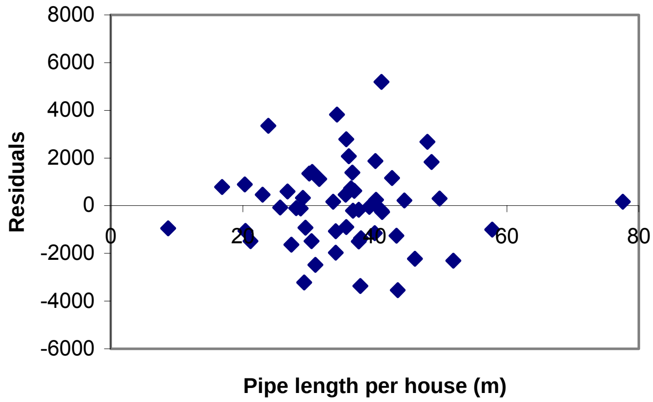

Figure 3. Deviations from the model (unstandardized residuals) when the pipe length per house and the presence of tar asphalt are taken into account

The following parameters turned out to be insignificant on the significance level of 5%, see section 3 for more information on the parameters:

- 1/(the number of connected houses)
- The connection rate
- The presence of ground frost
- The presence of rocks
- Pre investments due to future expansions

No correlation with the investment per house and the connection rate in the area can be shown in this study. The average connection rate was 0.7 and all areas had a connection rate higher than or equal to 0.5, which is relatively high compared to other studies [8, 9].

It could not be shown that costs of pipes that are dependant on the number of houses connected, but independent on the pipe length per house, are significant.

5. CONCLUSIONS

The developing of a model describing the variation in a district heating company's investment cost per house when connecting detached houses to the system showed the following:

The variation in the investment can be explained by the pipe length per house and costs of standstill during construction. The presence of tar in the asphalt layer is also an important factor explaining the variation in the investment when the handling of asphalt tar is regulated due to health hazards. There is an individual variation that can not be explained by these factors.

It could not be concluded from the present used data set that the connection rate or technical difficulties during construction such as ground frost and rocks had an effect on the investment. The variation in the investment is not dependant on pre investments in large pipe dimensions due to future expansion which shows that costs of ground work are high compared to costs of pipe materials.

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