DEMAND CURVE FOR INDOOR TEMPERATURE IN SWEDISH SINGLE UNIT DWELLINGS

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Summary

Keywords: indoor temperature, economics, dwellings, demand, prognosis

INTRODUCTION

According to economics the demand curve represents the relationship between quantity demanded and price, other things being equal. The quantity demanded is the demanded indoor temperature. The price is the price of indoor temperature or the marginal cost for heating with regard to indoor temperature for a dwelling during a year, MK. This is also the differential of the heating cost with regard to the indoor temperature.

The supply curve shows the price of indoor temperature at different indoor temperatures.

The indoor temperature where supply meets demand is the demanded temperature, t_d figure 1 a).

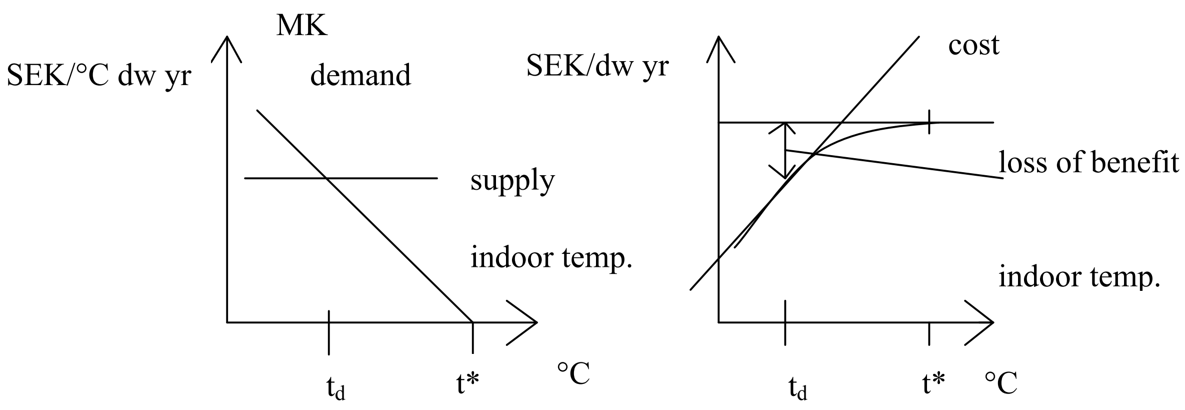

Figure 1 a) Demand, supply and demanded indoor temperature, t_d. b) Loss of benefit.

The demanded indoor temperature is not only a function of the MK, but also a function of the disposable income of the household, DI. The demanded indoor temperature is assumed to follow the function below (1) of MK and DI.

$$t_d = t^* - MK/DI\ k \qquad (1)$$

This means that higher MK gives lower indoor temperature and higher DI gives higher indoor temperature and that, t* is the demanded indoor temperature if heat is free or if the DI is infinitly high.

METHOD

k and t* can bee found if demanded indoor temperatures, t_d are correlated to MK/DI. Since both MK and DI are calculated in the same value of money, the inflation will be reduced.

MK and DI are calculated per household. In a single unit dwelling one household is living in one dwelling and they have control over their indoor temperature and they pay for their heating independant of other households.

In swedish multiple unit dwellings there is one household in one dwelling and they must have the same indoor temperature as the other dwellings in the building. The households pays the heating in relation to the area of their dwelling to the area of all dwellings in the building. This is collective heating, collective heat measurement and collective payment.

Loss of benefit

If a household has the indoor temperature, t* and reduces it then the inconvinience per degree reduction will follow the demand curve. The inconvenience will be added for every reduction so the area under the demand curve will be the sum of inconveniences or the loss of benefit. The loss of benefit, LB SEK / dw, yr is shown in figure 1 b) as the distance between the maximum benefit and the benefit at the demanded indoor temperature.

Disposable income

The disposable income, DI per multiple unit dwelling and per single unit dwelling is calculated by Statistics Sweden. Here it is approximated with 0.8 GNP/cap in multiple unit dwellings and with 1.36 GNP/cap in single unit dwellings since DI-data are not avalable for every year when indoor temperature measurements have been done.

Marginal cost

MK is calculated with data from Statistics Sweden and from the assumption that the oil-consumption should increase with 7 % if the indoor temperature is increased 1°C. The oil consumption for a dwelling is calculated from area of dwelling and specific consumption per area unit. The area of a single unit dwelling is set to 140 m^2.

80 % of the oil consuption is used for heating of the building and 20 % for hot water heating.

The price of oil is a consumer price including tax. This is a simplification since oilheating has been succesivley replaced by electric heating and distict heating. The price of oil 1952 is estimated from the price of oil 1955 and from the price relation of fire-wood 1955 and 1952.

MK = price of oil (SEK/m^3) * spec cons. (m^3/m^2 yr) * area (m^2/dw) * (1 - hot water) * 7 % /°C

Demanded indoor temperatures

The demanded indoor temperature is from measurements by the Swedish Institute of Building Research. The measurements from 1982-85 and 1992 were randomly distributed over the whole country so they are national averages of the indoor temperatures in Sweden. The measurements from 1952 and 1965 are only from buildings in one city but since no systematic variation of the indoor temperature was dicovered 1982-85 and 1992 then the values from 52 and 65 are used as national averages. The value from 1971 is an estimate. The datas and the results are given in table 1 and table 2.

Table 1 Price of oil, Gross national product per capita, Specific oil consumption, Area, Demanded Indoor temperature and MK/DI in Multiple unit dwellings, MU

Year	Price of oil SEK/m^3	GNP/cap SEK/pers yr	Spec. cons l/m^2 yr	Area m^2/dw	Dem. Ind te °C	MK/DI 10^{-3}/°C
1952	200	5976	32	58	20.7	4.35
1965	169,5	12943	32	60	23	1.76
1971	204,1	22222	32	63	23-24	1.30
1982	2396	76352	26	66	21.6	3.77
1983	2488	85511	25	66	21.1	3.36
1984	2686	95603	24	66	21.6	3.12
1985	2912	103660	27	66	21.5	3.50
1992	3633	165310	23	68	22.2	2.41

Table 2 Specific oil consumption, Demanded Indoor temperature and MK/DI in Single unit dwellings, SU

Year	Spec. cons l/m^2 yr	Dem. Ind. te °C	MK/DI 10^{-3}/°C
1952	30	19.8	5.81
1982	23	20.4	4.18
1983	22	20.2	3.77
1984	22	20.4	3.60
1985	22	20.6	3.59
1992	20	21.0	2.28

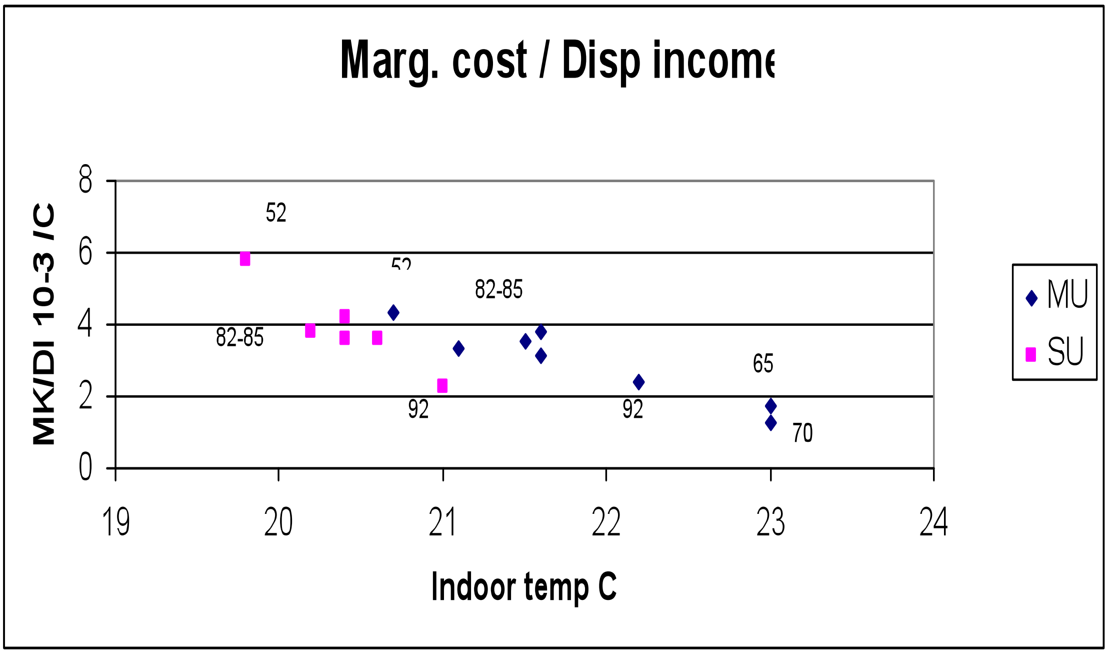

Figure 2 Marginal cost, MK for indoor temperature per year in a single unit, SU resp. in a multiple unit dwelling, MU divided by the disposable income, DI for the household in the dwelling against demanded indoor temperature

MK/DI are correlated against the demanded indoor temperature, t_d. In Single unit dwellings (2) and in Multiple unit dwellings (3).

$$MK/DI = 2.75\ 10^{-3}\ (21.65 - t) \qquad r = 0.95 \qquad (2)$$

$$MK/DI = 1.19\ 10^{-3}\ (24.10 - t) \qquad r = 0.94 \qquad (3)$$

The demanded indoor temperatures have followed two lines one for single unit dwellings and one for multiple unit dwellings. The indoor temperature went upp from 1952 to 1965-70 then down to 1982-85 and then upp to 1992. The path between 82-85 and 92 in the diagram has been passed three times in different directions in 40 years. There are no demanded indoor temperatures with very low MK/DI so the demand curve is perhaps not linear to zero marginal cost.

Demand curves

The demand curves for indoor temperature 1992 in Swedish SU (4) and MU dwellings (5) are shown in figure 3.

$$MK = 618\ (21.65 - t) \qquad (4)$$

$$MK = 155\ (24.1 - t) \qquad (5)$$

The indoor temperature in MU is higher than in SU and the demand curve for SU has about 4 times higher inclination than the demand curve for MU. The higher inclination means that the indoor temperature in SU are less sensitive to price changes than in MU.

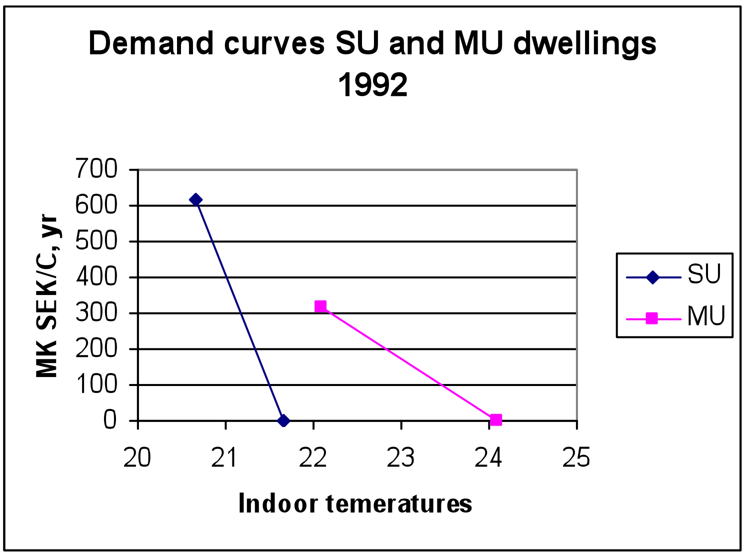

Figure 3 Demand curves for single-unit dwellings, SU and multiple unit dwellings, MU 1992 in Sweden.

This is explained with the lower DI in MU and with the design and control of the heating system. In SU every household control the indoor temperature in their household. In Swedish MU the households in the whole building must have approximately the same temperature. A single household can only reduce the indoor temperature in their own dwelling. Too raise the indoor temperature a household must negotiate an increase with the owner of the building. It is the owner who controls the indoor temperature in the building. The owner has limited possibilities to measure the indoor temperature in the dwellings. So the households who prefers a high indoor temperature demands an increase. They who prefers a low temperature can reduce it themselves in their own dwelling. This gives a higher average indoor temperature in MU than in SU.

Earlyer estimates of the demand curve

Boardman ref.   presents data from a Better Insulated House program 1985 in UK where additional insulation reduced the marginal cost from 66 to 44 £ /°C dw yr wich increased the indoor temperature from 12.9°C to 14.4°C. The dwellings were individually heated. The inclination of the demand curve in tabel 3. 13 SEK / 1 £

Friedman ref.   is using indoor temperature in MU dwellings in Chicago and Los Angeles as an example in economics. His diagrams says that an increase in MK of 0.10 $/°day reduces the indoor temperature with 10°F. This gives the inclination of the demand curve in table 3. 9 SEK / 1 USD, t* = 75°F = 23.9°C

Table 3 Inclination of demand curves and t*.

Location, period	Incl. dem. curve SEK/°C^2 dw yr	t* °C
Chicago, LA, MU 1986	73	23.9
UK, 1985	190	17.5
Sweden, MU 1992	155	24.1
Sweden, SU 1992	618	21.65

Loss of benefit

The loss of benefit, LB in Swedish SU (6) and in MU (7) dwellings at the indoor temperature, t is found from integration of the demand curve from t* against lower temperatures.

$$LB/DI = 1.38\ 10^{-3}\ (21.65 - t)^2 \qquad (6)$$

$$LB/DI = 0.60\ 10^{-3}\ (24.10 - t)^2 \qquad (7)$$

The loss of benefit related to the DI is 2 times higher in SU (6) than in MU (7) dwellings. This does not mean that the dwellers in MU dwellings are 2 times more sensitive to low temperatures, but it probably comes from the negotiation process with the owner to find a common temperature in the building. Equation (6) says that 2°C lower temperature than 21.65°C in SU gives a loss of 0.5 % and 4°C lower temperature gives a loss 2,2 % of the DI.

Loss of benefit or rather loss of production in offices has been measured in work rate studies. Ref finnish found the loss of production to be 2.8 % of the production if the indoor temperature was 25.3°C instead of 23.6°C

RESULT

The design indoor temperature is used to determine the optimal insulation thickness and as a basis to determine the profitability of energy saving equipment like 3-glass windows and heat recovery ventilation. The MK/DI relations can be used to prognosticate the indoor temperature and get a design indoor temperatures that includes the increase of the indoor temperature that comes in the future.

The GNP/cap was 258 000 SEK/yr and the oil price was 6740 SEK/ m^3 in Sweden year 2002. This gives an indoor temperature in SU at 21.0°C and in MU at 22.4°C according to the line of regression. The relation between GNP/cap in Sweden and Lithuania 2002 was 6.8. The relation between price of energy in Sweden and Lithuania is assumed to be 2.5 mainly due to the high taxes on energy in Sweden. This gives an indoor temperature of 19.9°C in SU dwellings in Lithuania if the differences in size and insulation standard between Sweden an Lithuania compensates each other. The indoor temperature in MU in Lithuania ought to be 19.5°C if the houses have collective heating, collective heat measurement and collective payment and if the differences in size and insulation standard compensates each other.

If the economic growth in Lithuania will be 4 % per year and if the price of energy is fixed (in fixed price) then the indoor temperature will be 20.5°C in SU and 21.0°C in MU year 2012.

DISCUSSION

Indoor temperature in Swedish dwellings 1952 -1992 is correlated to the relation between marginal cost of heating and disposable income.

The line of correlation can be used to prognosticate the indoor temperature at given economic conditions. More data over indoor temperatures and economic conditions is necessary to verify if the indoor temperature in other countries follow the same line of correlation as in Sweden.

The loss of benefit in relation to the DI calculated from demanded indoor temperatures and from work rate studies have the same magnitude.

NOMENCLATURE

MK	Marginal cost with regard to indoor temperature in a dwelling one year, SEK /°C dw yr
DI	Disposable income in a dwelling one year, SEK / dw yr
k	constant
t_d	Demanded indoor temperature, °C
t	Indoor temperature, °C
t*	Indoor temperature if heating was free, °C
LB	Loss of benefit SEK / dw yr
MU	Multiple Unit dwelling
SU	Single unit dwelling

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