Energy Saving in Existing Residential Buildings

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Background, purpose and aims

Since 1974, the Authorities in Sweden have provided considerable economic support in the form of loans and grants for energy-saving measures in existing buildings. The purpose of this support is to stimulate the more effective use of energy and improved energy management when heating buildings.

In the Spring of 1978 the Swedish Parliament passed an Energy Conservation Plan for existing buildings.

The aim of energy savings is to reduce the gross annual energy usage for heating buildings and premises in Sweden by 39-48 TWh over the ten-year period from 1978-1988. This corresponds to a reduction in energy consumption of 25-30% in existing buildings.

Several different investigations formed the basis for the Energy Conservation Plan and the evaluation of the same. Essentially, these were of two types - substantial theoretical calculations of potential energy saving from different measures carried out and the evaluation of energy-saving effects studied in individual housing groups or in a small number of houses under scientific control, and very accurate condition, so called Pilot-projekt (Höglund et al, 1981).

So far however, nobody in Sweden has investigated the average true effects of different technical energy-saving measures on the basis of energy consumption, in a large number of houses selected at random, where different measures have been carried out. (Bostadsdepartementet 1981).

Both pilot projekts and statistical investigation are necessary for evaluation of the Energy Conservation Plan.

The main theme of this investigation has been to evaluate the true effects of energy-saving measures by selecting a large number of houses at random where such measures have been carried out. In total, 1144 buildings have been inspected comprising 944 single-family houses and 200 multi-family houses. The investigation was carried out in the following five counties: Norrbotten, Västerbotten, Stockholm, Göteborg-Bohus and Malmöhus. See fig. 1.

The measures/combination of measures studied in the investigation were selected becauce they had, to date, attracted most of the government support and/or were very common.

Figure 1.

The Following measures were stu-
died in one or more counties:

Single family houses

- supplementary insulation of external walls
- supplementary insulation of attics
- supplementary insulation of external walls and attics
- supplementary insulation of attics and the installation (radiator thermostatic valve:
- installation of radiator th mostatic valves and motor s
- change to, or modification triple glazing windows
- supplementary insulation of ternal walls and change to, modification to, triple gla windows.

Multi-family houses

- supplementary insulation of external walls
- -"- -"- -"- attic
- installation of radiator thermostatic valves
- -"- -"- -"- variator equipment

Calculating energy savings

Technical data collected from the different houses, information abo houses and information on true energy consumption before and after out energy-saving measures formed the basis for calculating energy Measured savings in this context means the annual energy savings wh could be calculated for the modified houses assuming that climatic were normal for the area.

A number of factors determines a building's energy balance and thus tion of energy consumption is quite a complicated problem. Energy c tion for direct heating is climate-dependent to a considerable deg marily on indoor and outdoor temperatures. Consumption of hot wate domestic electricity depends basically however on occupancy patter to a certain extent, on the season of the year. The efficiency of ting system is reduced considerably when the load is reduced and t also climate dependent.

To reduce the effects of some of the factors noted, the before and periods have been made as long as possible - usually at least a ye

A special calculation model has been developed which considers the in a reasonable manner. See Norlén et al, 1981.

RESULTS

Measured average saving effects of different measures and variations in energy savings in modified houses

The statistical uncertainty of the measured savings effects can be stated with the aid of confidence intervals 1) for the respective modification group and county. These intervals are illustrated in figure 2-4, 6, and 8-10 and contain a confident reflection of the average savings which would have been achieved if all the houses, in the population investigated in the respective counties, had been studied and the energy savings in these determined exactly. The figure illustrates a confidence interval only when there are sufficient houses in the group to consider the results generally valid.

For comparison, the calculated average theoretical savings of supplementary insulation have been given for the group (marked with an arrow).

The following gives examples of some of the results. Importance is attached to comparing the theoretical savings with true savings and showing the variations in savings measured in the modified houses.

Energy savings. External wall insulation

Results indicate that supplementary insulation fitted to external walls produced almost the intended theoretical savings in both single and multi-family houses.

TABLE 1. Modification: External wall insulation.

Energy consumption before and after modification.
Measured energy savings (U) and theoretical savings (T).
Litres of oil per reference year and apartment for single family houses and per m^2 heated dwelling area for multi-family houses
($\bar{x}$ = average value, s = standard deviation)

House type and county	No.of houses investigated	Heated dwelling area per apartment m^2	Modified area m^2/house for single family houses m^2/apartment for multi-family houses	Energy consumption litres oil/year, apartment, (single-family houses) litres oil/year, m^2 (multi-family houses)				Energy saving litres oil/year, apartment (single-family houses) litres oil/year, m^2 (multi-family houses)			
				Before retrofit		After retrofit		U		T	
				$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Single family houses											
Norrbotten	25	128	124	3628	761	3300	526	327	566	456	236
Västerbotten	20	132	130	3871	842	3523	729	348	366	590	323
Stockholm 1)	10	150	113	4234	1041	3839	964	396	479	414	230
Gbg and Bohus	41	143	125	3538	1188	3054	1091	484	454	614	298
Malmöhus	34	139	97	4234	1303	3471	915	763	716	613	377
Multi-family houses											
Västerbotten	12	77	48	29.0	6.6	23.8	3.2	5.2	5.0	2.5	1.0
Gbg and Bohus	18	55	28	25.7	7.3	23.2	5.1	2.5	4.5	2.9	1.9

1) The population of the group is too small for the results to be generally valid

1) The confidence intervals have been constructed using the mean value ($\bar{x}$), the standard deviation (s) of the measured energy savings and information in the number of houses investigated (n) in each respective group. The probability of a confidence interval ($\bar{x} \pm 2s/n$) containing the average savings effect for all houses in the population is approx. 95%.

Single-family houses

Single-family houses, fitted with supplementary insulation, maintained the average theoretical savings in the confidence intervals for measured savings in the counties of Norrbotten, Göteborg and Bohus, and Malmöhus. In Västerbotten the theoretical savings were somewhat higher than those covered by the confidence interval for the measured saving. Figure 2.

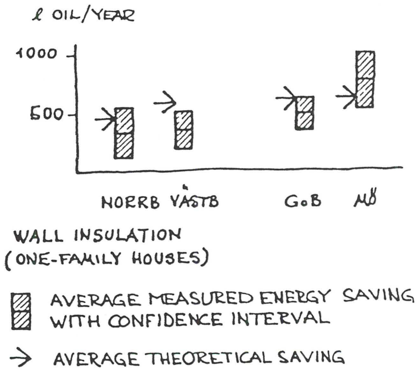

Figure 2.

The energy savings measured varies for different houses within respective counties. Table 1. The reasons for the variations are many. Small or no savings can depend on no adjustments having been carried out on the heating system after modifications wherein the result may have been a higher indoor temperature after insulation. Savings greater than those expected were measured in many house which in turn may have resulted from the houses being made tighter after modification so that ventilation losses were less. In some cases, it may be possible that insulation measures have led to a temperature increase masking draughts remaining after modification.

It is also possible that wall insulation has created conditions to allow a reduction in room temperature whilst still retaining the required comfort. The habits of occupants may have changed consciously or unconsciously as a result of information, cost changes etc.

Multi-family houses

The theoretical savings for multi-family houses which were insulated falls within the confidence interval for the measured savings. Figure 3.

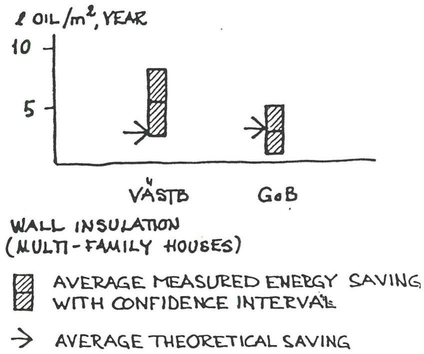

Figure 3.

The average savings measured are aproximately equal, to or greater than, those calculated theoretically. Table 1. It would appear therefore that improvements other than those resulting from supplementary insolution have occurred. Improved airtightness may be one example. Better maintenance of th heating system after retrofit cannot be discounted either. The variation in results in different houses is however considerable. The potential benefits of supplementary insulation have not always been realised since monitoring and adjustment of the heatin system has not been carried out.

Energy savings. Attic insulation

Attic insulation in single-family houses resulted in the expected energy savings for the most part. Greater energy savings were measured in multi-family houses than could be expected from installation of the actual insulation.

TABLE 2. Modification: Attic insulation.

Energy consumption before and after modification.
Measured energy savings (U) and theoretical savings (T).
Litres of oil per reference year and apartment for single family houses and per m² heated dwelling area for multi-family houses
($\bar{x}$ = average value, s = standard deviation)

House type and county	No.of houses investigated	Heated dwelling area per apartment m²	Modified area m²/house for single family houses m²/apartment for multi-family houses	Energy consumption litres oil/year, apartment, (single-family houses) litres oil/year, m² (multi-family houses)				Energy saving litres oil/year, apartment (single-family houses) litres oil/year, m² (multi-family houses)			
				Before retrofit		After retrofit		U		T	
Single family houses				$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Norrbotten[1]	13	164	93	4517	1182	4022	953	494	482	273	157
Västerbotten[1]	13	182	97	4454	1629	4115	1481	339	464	401	178
Stockholm	23	186	108	4576	788	4246	742	330	398	430	273
Gbg and Bohus	26	149	91	3491	1018	3100	890	391	524	372	364
Malmöhus	31	167	113	4463	2864	3897	2380	566	728	769	542
Multi-family houses											
Stockholm	25	71	16	29.9	3.8	27.4	3.3	2.5	1.5	0.8	0.7

[1] The population of the group is too small for the results to be generally valid

Single family houses

In single-family houses that were attic insulated, the theoretical savings in all three counties with acceptable sample populations fell within the confidience interval for the savings measured. Figure 4.

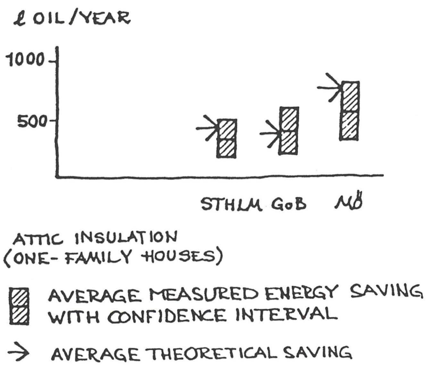

Figure 4.

The savings measured varied considerably between different houses which means that very good savings were measured in many whereas others indicated small or no savings. Table 2. The savings achieved in individual houses in the county of Stockholm are illustrated in figure 5.

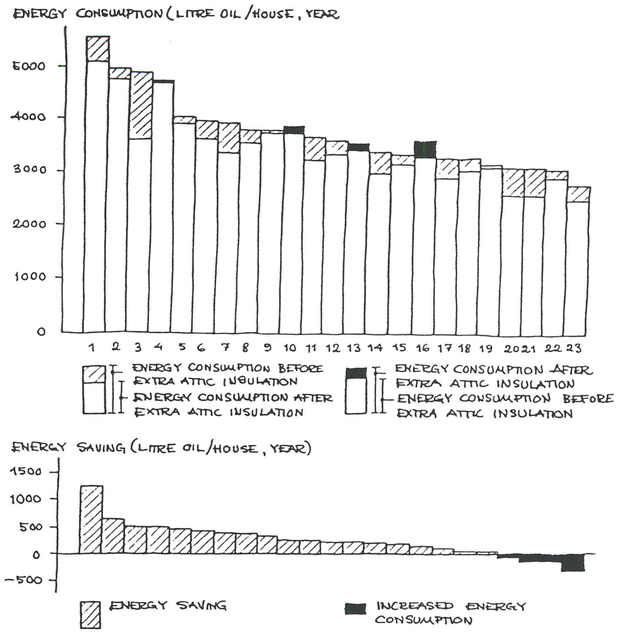

Figure 5. Attic insulation. Single-family houses.

Multi-family houses

In houses that were attic insulated, the theoretical savings fall below the confidence interval for the measured savings. Figure 6. The measured savings were wery good compared with the theoretical savings. Table 2. In large houses (tower blocks) the theoretical savings as a result of attic insolution are very small in absolute figures. Comparison between theoretical and measured savings is therefore somewhat academic since the latter is based in particular differences in energy consumption before and after modification.

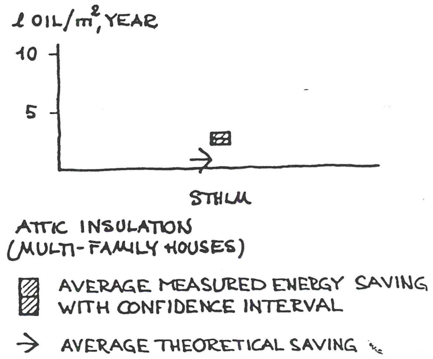

Figure 6.

In many houses with badly adjusted heating systems, the highest situaded apartments are designed in the basis of the radiator supply temperature. Apartments situated lower down in the building are thus supplied with too much heat. Attic insulation reduces heat demand in the highest apartments and this allows a temperature reduction though-out the whole building. When assessing the effects of such a temperature reduction, the modifications are an added bonus since there was no possibility of measuring temperatures before and after insulation. Apart from a temperature reduction, better maintenance of the heating system can have contributed to a good savings result. In figure 7 it can be seen that of the multi-family houses investigated in the county of Stockholm, only two indicated that no savings had been measured.

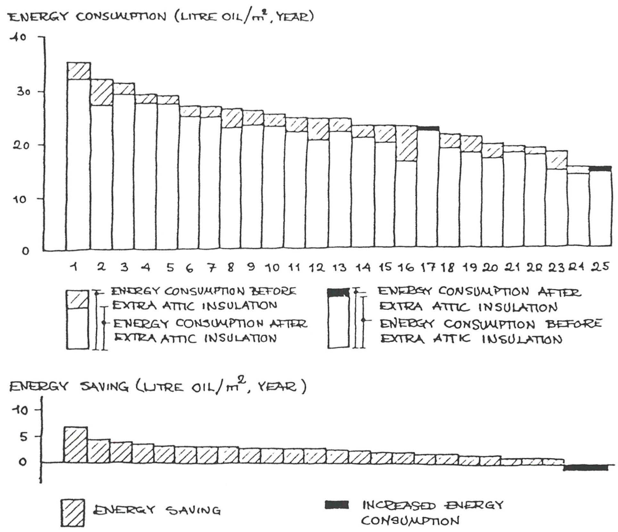

Figure 7. Attic insulation. Multi-family houses.

Energy savings. External wall and attic insulation

The combination of wall and attic insulation did not produce the theoretical energy savings.

TABLE 3. Modification: External wall and attic insulation.
Energy consumption before and after modification.
Measured energy savings (U) and theoretical savings (T).
Litres of oil per reference year and apartment.
($\bar{x}$ = average value, s = standard deviation)

House type and county	No. of houses investigated	Heated dwelling area per apartment m^2	Modified area m^2/house	Energy consumption litres oil/year, apartment				Energy saving litres oil/year, apartment			
				Before retrofit		After retrofit		U		T	
Single family houses				$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Norrbotten	19	139	201	4448	1242	3914	1063	535	571	662	289
Västerbotten	19	118	205	3707	1151	3379	1059	328	717	894	322
Stockholm[1]	12	148	184	4451	989	4054	841	397	670	736	360
Gbg and Bohus	24	152	174	3445	1148	3123	1011	322	525	740	305
Malmöhus	31	147	199	4419	1473	3782	1123	637	736	1554	978

[1] The population of the group is too small for the results to be generally valid

Single-family houses

For single-family houses that were wall and attic insulated, the theoretical savings were above the confidence interval with the exception of the county of Norrbotten. Figure 8.

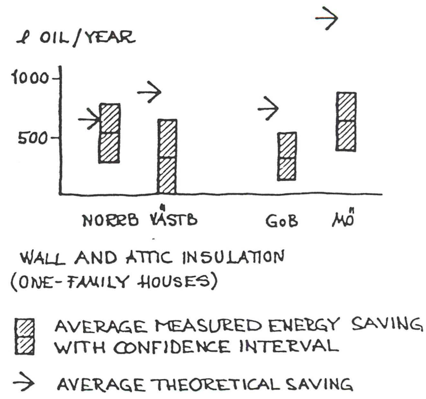

Figure 8.

The measured energy savings in houses with combination insulation measured amount only to about the same as the houses that had been either wall insulated or attic insulated. The theoretical savings from wall or attic insulation was about double that if the average measured savings. Table 3.

The measured savings in this modification group varied even more than houses where only one measure had been introduced. This means that the theoretical value has been achieved in some cases. the measured savings in several houses was very small or non-existant. Table 3.

The reasons for not achieving the theoretical savings can be many. Apart from the inherent uncertainties of the calculation methods, one cannot disregard the fact that part of the possible energy savings employed for increasing comfort have resulted in an increase in temperature after modification. One might assume that a reason for employing comprehensive measures was poor comfort (= low indoor temperature during the winter). When comprehensive measures were carried out, such as both wall and attic insulation, the building's heat demand was reduced considerably. This meant that the existing oil-fired heating system was oversized. The bioler was subjected to less load and full capacity was never used. Thus over the year the system's operating efficiency decreased. The results indicate that comprehensive measures should be combined with retrofits of the building services in order to achieve optimum energy savings.

No definite conclusions can be drawn as to why the combination of wall and attic insulation had not produced the anticipated savings. Further deeper studies are required.

Energy savings. Attic insulation and the installation of thermostatic valves.

The measured energy savings for the combined measure of fitting attic insulation and thermostatic valves are considerable.

TABLE 4. Modification: Attic insulation and thermostatic valves.

Energy consumption before and after modification.
Measured energy savings (U) and theoretical savings (T).
Litres of oil per reference year and apartment.
($\bar{x}$ = average value, s = standard deviation)

House type and county	No.of houses investigated	Heated dwelling area per apartment m^2	Modified area m^2/house	Energy consumption litres oil/year, apartment Before retrofit		After retrofit		Energy consumption litres oil/year, apartment U		T	
				$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Single family houses											
Norrbotten	17	155	102	4415	1026	3888	1041	527	542	257	164
Västerbotten	24	159	72	4857	1501	4146	1054	711	717	272	159
Stockholm[1]	28	151	99	4052	936	3654	945	407	621	430	236
Gbg and Bohus	37	153	86	4083	1013	3417	995	666	757	271	173
Malmöhus	34	145	97	4895	1090	4023	865	872	612	646	456

[1] The population of the group is too small for the results to be generally valid

Single-family houses

In houses fitted with attic insulation and thermostatic valves, the theoretical energy savings were calculated as though only attic insulated had been fitted. The confidence interval for measured savings in four of the five counties was higher than the theoretical savings. Figure 9.

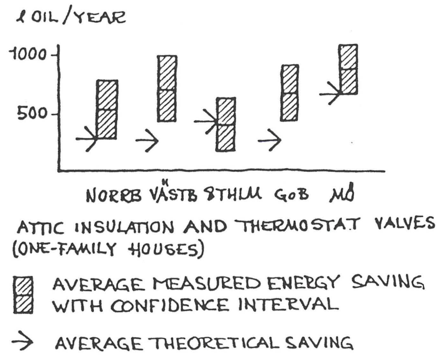

Figure 9.

The greatest savings in terms of litres of oil per apartment was achieved in the county of Malmöhus. Using radiator thermostatic valves and attic insulation, considerably greater energy savings were achieved than would have been the case had only attic insulation been fitted. This so-called free energy have been used more profitably and the periods of excess temperature reduced with the aid of thermostatic radiator valves. Variations in energy savings were also considerable in thus group. Table 4.

Average measured savings effect of other measured studied

The confidence interval after having changed to triple glazing windows, figure 10, includes the theoretical savings. When the measure was combined with wall insulation, the theoretical savings were greater than those actually measured. Thus a combination of measures did not realise the anticipated savings.

The installation of thermostatic radiator valves in multi-family houses in the counties of Stockholm and Malmöhus produced an average measured savings of approximately 6% of the original consumption.

Thermostatic radiator valves and motor shunts in single-family houses in the county of Stockholm resulted in an average savings of 12%.

Variator equipment in multi-family houses in the county of Stockholm produced an average energy savings of around 11%.

The installation measures studied have on average led to satisfactory savings.

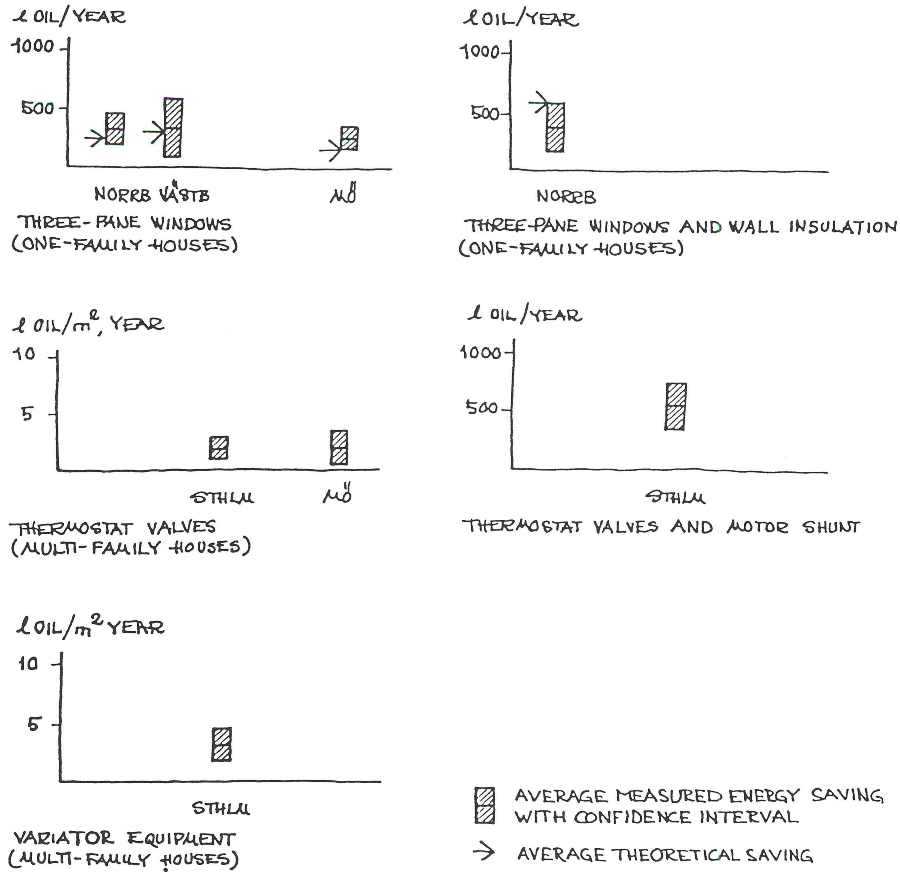

Figure 10.

A summary of comments and conclusions.

The houses design, age and sizes varied considerably in the different groups modified.

Houses in southern Sweden often have external walls of a noninsulated brickwork construction. These are often insulated at a later date by injecting foam. Plank, timber or framework walls were common in other counties and often had additional external insulation and a new facade leyer.

The houses in southern Sweden fitted with supplementary insulation all had bad high k values (= poor insulation) in walls and attics before retrofit. Walls and attics in northern Sweden however had relativiely low k values (= good insulation) before retrofit.

External walls had not been fitted with supplementary insulation to the extent that newbuilding standards, according to current requirements in Sweden, had been achieved on average. table 5, whereas attics often achieved newbuilding standards after retrofit. Table 6.

TABLE 5. Modification: External wall insulation.

Change in thermal resistance (ΔM value), thermal transmission coefficient (k value) before and after modification, and change in thermal transmission coefficient (Δk value).

($\bar{x}$ = average value, s = standard deviation)

House type and county	Change in thermal resistance °C, m²/W		Thermal transmission coefficient (k value) W/°C, m²					
			Before modification		After modification		Change	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Single family houses								
Norrbotten	1.26	0.62	0.44	0.10	0.28	0.05	0.16	0.08
Västerbotten	1.19	0.45	0.53	0.14	0.32	0.05	0.21	0.12
Stockholm	1.00	0.59	0.60	0.18	0.36	0.08	0.24	0.17
Gbg and Bohus	1.11	0.34	0.77	0.19	0.42	0.08	0.35	0.14
Malmöhus	1.19	0.54	1.04	0.44	0.46	0.13	0.58	0.38
Multi-family houses								
Västerbotten	1.17	0.24	0.55	0.04	0.33	0.03	0.22	0.08
Gbg and Bohus	1.03	0.26	0.88	0.39	0.44	0.08	0.44	0.32

TABLE 6. Modification: Attic insulation

Change in thermal resistance (ΔM value), thermal transmission coefficient (k value) before and after modification, and change in thermal transmission coefficient (Δk value).

($\bar{x}$ = average value, s = standard deviation)

House type and county	Change in thermal resistance °C, m²/W		Thermal transmission coefficient (k value) W/°C, m²					
			Before modification		After modification		Change	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Single family houses								
Norrbotten	2.50	1.01	0.29	0.07	0.17	0.04	0.12	0.06
Västerbotten	2.73	0.84	0.38	0.09	0.19	0.03	0.19	0.07
Stockholm	3.04	1.25	0.43	0.20	0.19	0.07	0.24	0.15
Gbg and Bohus	2.73	1.15	0.47	0.16	0.21	0.06	0.26	0.15
Malmöhus	2.49	0.73	0.88	0.46	0.27	0.08	0.61	0.42
Multi-family houses								
Stockholm	2.44	0.54	0.44	0.22	0.21	0.05	0.24	0.19

The average energy consumption prior to retrofit was roughly the same in all modification groups in all counties. There was a tendency towards lower measured consumption in the county of Göteborg and Bohus.

Bearing in mind the differences in climate, it is surprising that consumption in fact certain groups in southern Sweden that had the highest consumotion. This can be explained to a certain extent in that the houses in northern Sweden were better insulated. One can also assume that living patterns are different in different parts of the county.

Energy consumption varied considerably between houses within individual groups. Conclusions related to differences in consumption levels should therefore be viewed with a certain amount of reservation.

Building modifications such as wall insulation, attic insulation and changing to triple glazing windows have, in average, led to the anticipated savings when modifications were carried out individually. When more comprehensive building modifications were embodied, the anticipated savings were not always realised. That could for instance be explained by bad adjustment of the heating system to the building's new energy demand.

Good energy savings were achieved in houses where building modifications were combined with adjustment to the heat supply. The technical modifications in building sevices investigated had on average led to good savings.

Large variations in saving measured were noted. This means that many houses produced better savings results than the average. The revers also applies in that savings were small or none existant in many cases.

Where future energy savings are concerned, more importance should be attached to combining the right modifications for each individual house and making sure that the work is carried out correctly. Poor houses should be insulated properly and the heating system should be adapted to the new heat demand. In houses of a good technical standard, only limited building modifications should be carried out for the time being. Instead, effort should be directed to improving installations.

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