PAPER 4

EFFECTS OF ENERGY CONSERVATION MEASURES IN EXISTING BUILDINGS

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EFFECTS OF ENERGY CONSERVATION MEASURES IN EXISTING BUILDINGS

Approximately 40 % of the total energy consumption in Sweden is used for the heating and ventilation of houses and premises. In 1978 the Swedish Parliament passed an energy conservation plan for existing buildings. Aiming at a gross energy saving of between 39 to 48 TWh per annum until 1988. This corresponds to a reduction of the total energy consumption in today's houses by 25-30 %.

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-project. (e.g. Ulvsundaprojektet, Höglund et al 1981)

However, nobody in Sweden has earlier investigated the actual 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. This has now been done in a research project at the Division of Building Technology, the Royal Institute of Technology in cooperation with the other institutes of technology in Sweden.

The main purpose of this investigation has been to evaluate the actual effects of energy-saving measures by selecting a large number of houses at random where such measures have been carried out. The objects have been chosen statistically among houses receiving energy saving loans and grants in different provinces of Sweden. An on-site inspection has been performed of each house which was selected for the investigation. In total, 1144 buildings have been inspected comprising 944 single-family houses and 200 multi- family houses. When calculating the saving obtained, climate corrected energy consumption before and after measures undertaken has been compared. The investigation was carried out in the following five counties: Norrbotten, Västerbotten, Stockholm, Göteborg-Bohus and Malmöhus. See fig. 1.

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

The following measures were studied in one or more counties:

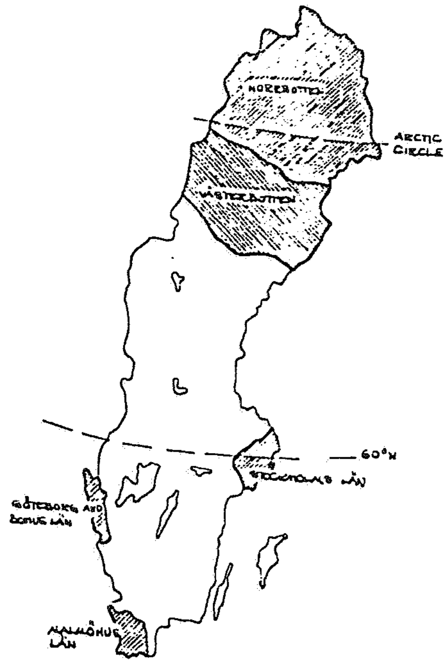

Figure 1.

Single family houses

- additional insulation of external walls
- additional insulation of attics
- additional insulation of external walls and attics
- additional insulation of attics and the installations of radiator thermostatic valves
- installation of radiator thermostatic valves and motor shunt
- change to, or modification to, triple glazing windows
- additional insulation of external walls and change to, or modification to, triple glazing windows.

Multi-family houses

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

RESULTS

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

Energy savings. External wall insulation

Results indicate that supplemantary 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.
Actual energy savings (A) 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		A		T	
Single family houses				$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
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

Single-family houses

The actual energy savings 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. Actual savings greater than those expected were obtained in many houses which in turn may have resulted from the houses being made tighter after modification so that ventilation losses were less.

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 average actual savings are approximately equal, to or greater than, those calculated theoretically. Table 1. The greater savings than those expected might have occured when improvements other than those resulting from supplementary insulation have occured. Improved airtightness may be one example. Better maintenance of the 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 heating 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. In multi-family houses the actual energy savings were greater than the expected from installation of the actual insulation.

TABLE 2. Modification: Attic insulation.
Energy consumption before and after modification.
Actual energy savings (A) 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		A		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

Single-family houses

The actual savings 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 single-family houses in the county of Stockholm are illustrated in figure 2.

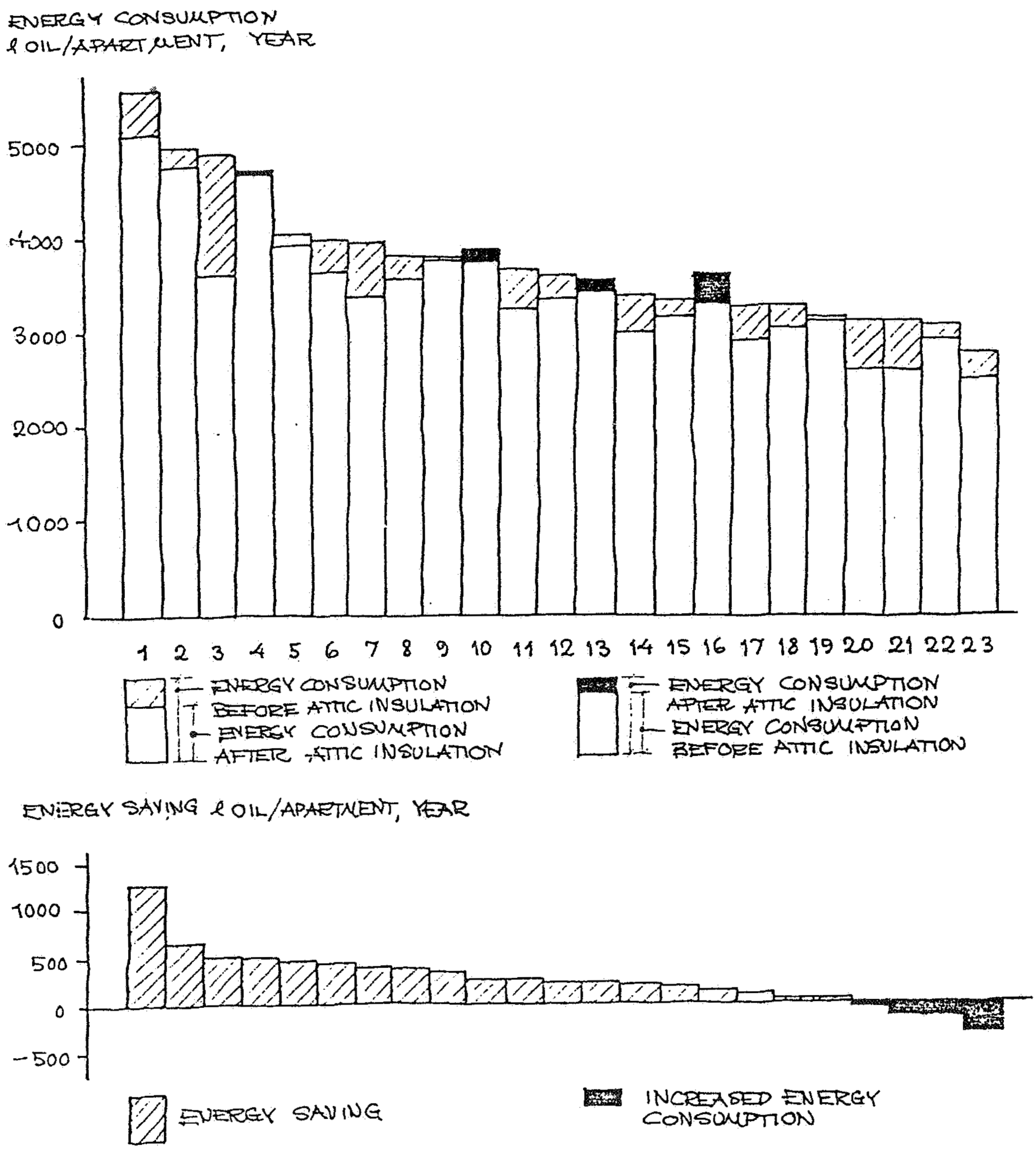

Figure 2.

Multi-family houses

The actual savings in multi-family houses were very good compared with the theoretical savings. Table 2.

In many houses with badly adjusted heating systems, the highest situated 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 thoughout 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.

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.
Actual energy savings (A) 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		A		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

The theoretical savings from wall and attic insulation was about the double of the average actual savings. Table 3. The actual 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.

In this modification group the actual savings 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 boiler 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 actual 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.
Actual energy savings (A) 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		A		T	
Single family houses				$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
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 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 the case was for the group where only attic insulation was fitted. The 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 this group. Table 4.

Average actual savings effect of other measured studied

After having changed to triple glazing windows, the actual savings are equal to theoretical savings. When the measure was combined with wall insulation, the theoretical savings were greater than the actual savings. 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 actual 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. (See table 5)

TABLE 5 Other measures studied.

Energy consumption before and after modification.
Actual energy savings (A) 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, retrofit 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 $\bar{x}$	Before retrofit s	After retrofit $\bar{x}$	After retrofit s	A $\bar{x}$	A s	T $\bar{x}$	T s
Single family houses											
Triple glazing [1] Norrbotten	38	160	15,9	4506	987	4159	1030	347	440	282	91
Triple glazing [1] Västerbotten	22	188	20,3	4533	1356	4176	1243	357	627	329	74
Triple glazing Malmöhus	51	170	16,6	3790	1164	3530	1049	261	410	171	75
Triple glazing and wall insulation Norrbotten	17	144	102+13	3832	858	3452	970	380	464	623	150
Thermostatic valves and motorshunt Stockholm	32	180	-	4675	1241	4106	1023	569	592	-	-
Multi-family houses											
Thermostatic valves Stockholm	29	70	-	26,6	5,8	24,8	5,2	1,8	2,3	-	-
Thermostatic valves Malmöhus	20	74	-	27,6	7,4	25,9	5,5	1,7	3,6	-	-
Variator equipment Stockholm	14	86	-	29,5	5,0	26,3	6,0	3,2	2,7	-	-

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

A summary of comments and conclusions

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 consumption. 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 country.

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 realized. 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 service investigated had on average led to good savings.

Large variations in actual saving 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.

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 new building standards, according to current requirements in Sweden, had been achieved on average, table 6, whereas attics often achieved newbuilding standards after retrofit. Table 7.

TABLE 6. 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 7. 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

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.

MOISTURE PROBLEMS DUE TO ENERGY CONSERVATION MEASURES

Moisture problems in houses can be related to low indoor temperature and especially to low surface temperature on the inner surface of windows. Also high humidity in houses can during the winter time create such problems.

Some common causes when retrofitting houses which might increase the risk of moisture are for example:

- When houses are made more airtight the ventilation rate can be reduced and as a consequens of that moisture content might increase in the houses.
- Additional insulation measures implies that the heating demand in houses can be reduced. It is also possible to decrease the room temperature without changing the indoor comfort for the people living in the houses. After measures being undertaken it is possible that the radiators below the windows cannot provide enough heat to keep satisfactory temperature on the inner surface of the windows why condensation will occur.

At the inspection of each house in the investigation the house keepers were interviewed about occurrence and extent of moisture before and after retrofit.

The evaluation of the information obtained shows in most of the cases that condensation problems did not increase after the insulation measures were carried out. Instead the condensation problems before retrofit in many houses had decreased in extent or compleatly disappeared after measures being undertaken (see table 8).

This can among other things depend on that the warm air from the room prevents to leak in between the window panes and condensate on the inner surface on the cold outer pane because of better weatherstrips between the window-frame and casement after retrofit.

One must also bear in mind that, as mentioned above, when houses are made tighter moisture problems can occur due to insufficient ventilation. That can be an explaination to increased moisture problems in some of the houses in the investigation.

Condensation after retrofit \ Extent of condensation before retrofit	More than after retrofit	Similar to after retrofit	Less than after retrofit	Condensation dit not occur before retrofit	No answer has been given
Condensation on windows	23	87	15	9	9
Condensation on other parts	2	9	-	2	-
Condensation both on windows and other parts	-	2	1	1	-
No condensation after retrofit	28	X	X	161	140

Table 8. Condensation

Occurrence of condensation after retrofits compared with extent of condensation before retrofit.

Retrofits: All additional insulation retrofits except groups with changing to triple glazing windows.

Single-family houses

Change to, or modification to, triple glazed windows would result in higher temperature on the inner pane so that the risk of condensation therefore is less after the measures were carried out.

When evaluating the measure changing to, or modification to, triple glazing windows the results also points out that condensation problems which occured before triple glazing windows were installed in most of the cases have decreased or entirely disappeared after measures being undertaken.
Though in some cases the occurrence of moisture have increased after modification. See table 9.

Condensation after retrofit \ Extent of condensation before retrofit	More than after retrofit	Similar to after retrofit	Less than after retrofit	Condensation dit not occur before retrofit	No answer has been given
Condensation on windows	22	6	3	2	2
Condensation on other parts	1	-	-	-	1
Condensation both on windows and other parts	1	-	-	-	-
No condensation after retrofit	40	X	X	21	32

Table 9. Condensation

Occurrence of condensation after retrofits compared with extent of condensation before retrofit.

Retrofits: o Changing to triple glazing windows

o Changing to triple glazing windows + wall insulation

Single-family houses

DIFFERENT TYPES OF WEATHERSTRIPS BETWEEN WINDOW-FRAME AND CASEMENT

Different types of weatherstrips seems to affect the energy consumption in different ways.

In the investigated single-family houses one can notice that expanded, angle - and tubular strips provide a lower energy level than weatherstrips made of foam and/or fibre.

There is a obvious difference in energy consumption after retrofit between houses where weatherstrips did not exist and houses where fixed windows were installed.

The results which are shown in table 10 corresponds quite well to the results of an earlier investigation[1] where different types of weatherstrips efficiency due to airleakage have been evaluated in laboratory tests. Though one can see a difference for expanded strips (see figure 3).

At this time there is some uncertainty about the results because of the great deviation in energy consumption between the houses in each group. The results seems to indicate that expanded, angle- and tubular weatherstrips prevent airleakage better than fibre and foam strips which in turn leads to a lower energy consumption.

[1] Höglund I, Wånggren B. 1979

TABLE 10 Other measures studied.

Energy consumption before and after modification.
Actual energy savings (A) 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, retrofit 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)			
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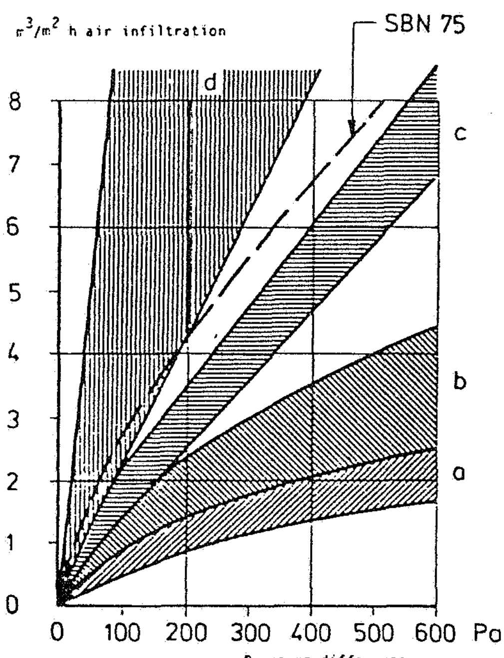
Single family houses				$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Triple glazing [1] Norrbotten	38	160	15,9	4506	987	4159	1030	347	440	282	91
Triple glazing [1] Västerbotten	22	188	20,3	4533	1356	4176	1243	357	627	329	74
Triple glazing Malmöhus	51	170	16,6	3790	1164	3530	1049	261	410	171	75
Triple glazing and wall insulation Norrbotten	17	144	102+13	3832	858	3452	970	380	464	623	150
Thermostatic valves and motorshunt Stockholm	32	180	-	4675	1241	4106	1023	569	592	-	-
Multi-family houses											
Thermostatic valves Stockholm	29	70	-	26,6	5,8	24,8	5,2	1,8	2,3	-	-
Thermostatic valves Malmöhus	20	74	-	27,6	7,4	25,9	5,5	1,7	3,6	-	-
Variator equipment Stockholm	14	86	-	29,5	5,0	26,3	6,0	3,2	2,7	-	-

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



a = tubular strip
b = angle strips
c = expanded strips
d = foam and fibre strips

The Swedish code of practice, SBN 75

Figure 3

Tubular and angle strips provide a high degree of airtightness in windows while airleakage is somewhat greater for expanded strips and considerably greater for foam and fibre strips.

Höglund I, Wånggren B. Weatherstripping windows and doors. Meddelande 126. Stockholm 1979.