VENTILATION TECHNOLOGIES IN URBAN AREAS

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EVALUATING THE COMPULSORY PERFORMANCE CHECKING OF VENTILATION SYSTEMS IN SWEDEN

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Synopsis

The Swedish Parliament decided 1991 that ventilation systems in all non-industrial buildings should be regularly inspected in intervals from 2 to 9 years, shortest for schools, hospitals etc and longest for natural ventilated flats. The systems are checked to fulfil the requirements given when installed.

The goals of the evaluation were to give estimated rates for how many systems that were approved at the end of 1997 and the cause of the faults that made the system either not to be approved or to be remedied before next inspection.

The evaluation was made in three steps:

1. A questionnaire was sent out to a selected number of municipality authorities
2. A questionnaire was sent out to housing organisation representing more than 60 % of all apartments in Sweden.
3. Totally 10 300 complete inspection protocols

Results showed the estimated approved rate at the end of 1997to be: schools 85 – 90 %, day nurseries 90 – 95 %, hospitals ≈ 40 %, Offices ≈ 40 %, Dwellings 65 – 70 % (condos 85-90 %, public owned 75-80 %, private <50 %). Stack ventilation has far more faults than any other system. Repeated inspections decrease the number of faults and increase the approved rate. The most frequent fault was insufficient flow rate.

1. Background

The Swedish Parliament decided 1991 that ventilation systems in all non-industrial buildings should be regularly inspected. The exception was single family houses with mechanical exhaust and natural ventilation. The checking intervals are depending on the occupants and on the system principles. There are five classes with inspection intervals from 2 to 9 years:

1. Schools, hospitals, day-nurseries, 2 years
2. Multi family buildings, offices with mechanical supply and exhaust ventilation (**MSE**), 3 years (with or without heat exchanger)
3. Multi family buildings, offices with mechanical exhaust ventilation (**MEO**), 6 years
4. Multi family buildings, offices with passive stack ventilation (**PSV**)
5. Houses with mechanical supply and exhaust ventilation

The main reason for the mandatory inspection was the increased number of oversensitive reaction amongst people, in particular children. Indication showed also that ventilation systems were not working according to the designed intention.

2. Method

The goals with the investigation were to estimate the frequency of approved systems at the end of the year 1997 and the cause of the faults that made the system to fail. At an inspection faults can occur in many different places in a system. A fault can be of two dignities.

1. One is a fault that must be remedied before next inspection. Called Fault/Approved (**FA**).
2. The worse case is a fault, that must be corrected and followed by a new inspection before the system is approved, and a certificate is issued. Called Fault/Failed (**FF**).

To make an estimation of the percentage of ventilation in the non-industrial buildings that passed the regular inspection the approach was made from three "directions".

1. A questionnaire was sent out to a selected number of municipality authorities. Interviews.
2. The number of passed ventilation systems was asked for in three housing organisations. Two are representing most of the condominiums in Sweden and 21 % of all dwellings in multi family buildings. The third organisation is representing the municipality owned companies and 40 % of all apartments.
3. Complete inspection protocols. Totally 10 300 have been used to identify the frequency of faults for different ventilation systems, occupation use, and comparing 1995 and 1997.

3. Statistical Data

To get a brief idea of the representation of the data gathered and the situation of both dwellings in multi family buildings and for non-domestic buildings some statistical data is presented, see figure 1. It must be noted that dwellings stands for 75 % of all non-industrial

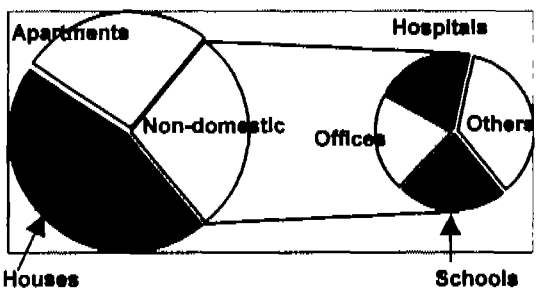


Figure 1. Area proportion of domestic and non-domestic buildings

Table 1 Inhabitants in different sizes of municipalities	
Size	**%**
Cities (Stockholm, Göteborg, Malmö)	16
Suburbs to the above cities	17
> 90 000	15
27 000 – 90 000	25
< 27 000	27

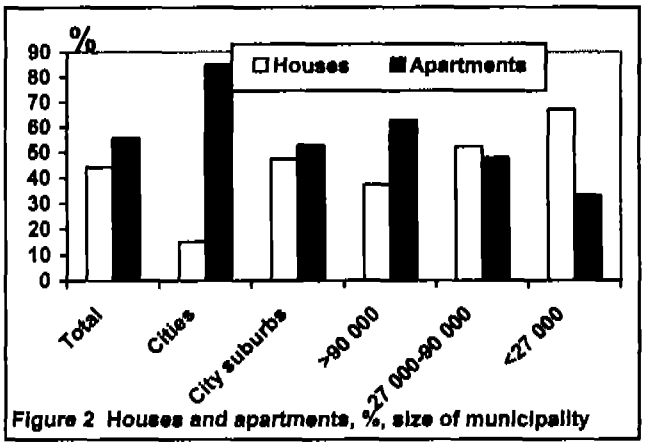


Figure 2 Houses and apartments, %, size of municipality

built areas. The distribution of the 4.1 million dwellings between apartments and single family houses (houses) show us that 50 % of the apartments are found in the three larger city areas of Stockholm, Göteborg, and Malmö. Here are also located 40 % of the non-domestic areas, see figure 2. In Sweden are 33 % living in the three greater city areas, but also 27 % are living in small municipalities with less than 27 000 inhabitants, see table 1. The population in Sweden was 8.85 millions (1996).

As we are to discuss the ventilation the main concern is what type of system the Swedish non-industrial buildings are equipped with. Most of the houses have PSV, even though nearly all have a kitchen fan. For the apartments only the old buildings have PSV and over 60 % have a mechanical ventilation. For the non-domestic buildings nearly all have mechanical ventilation or about 80 %, see also figure 3

For the three approaches the information has been gathered in the following ways:

1. Questionnaire to the municipalities. Well distributed according to the inhabitants and sizes except the three largest cities. By experience now answer was expected even though the questionnaire was sent out by the Board for housing, building and planning.
2. The collection of answers from the housing organisations have a good representation with the exception of one of the condominium organisation for which two of the city areas have large uncertainties. For the large organisation of rented apartments a very good representation is given for all sizes of municipalities and companies.
3. Most of the protocols are collected from inspections in Stockholm and Malmö city areas.

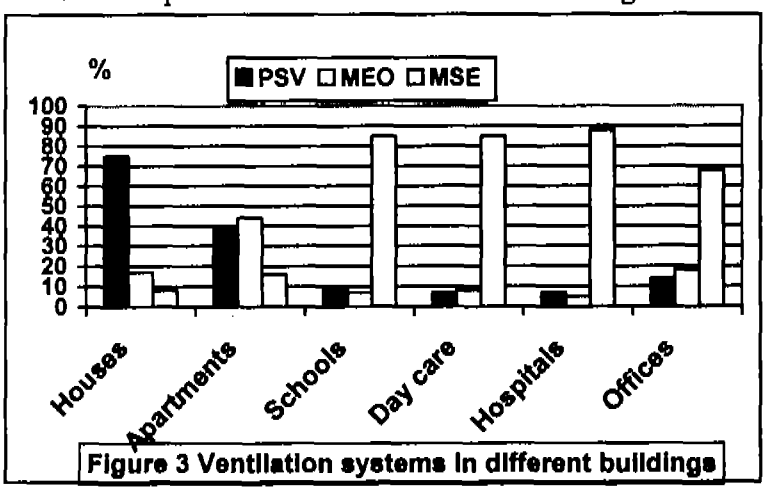


Figure 3 Ventilation systems in different buildings

In a large survey, ELIB-study, 60 municipalities were selected to represent the whole stock, ref Norlén, Andersson (1993).

4. Results

The way towards the estimation of how may ventilation systems that have been approved at the inspections is to give estimations from three different points of views.

4.1 Municipality approach

A questionnaire was sent out to 68 municipalities and answers back from 46 (68 %). It was asked for the percentage of buildings reported to the authorities to have passed the checking. As the municipalities owns most of the schools and day nurseries the reports from those are most accurate and on the other hand the information about houses are more spares or totally missing. It should be observed that all the schools and day nurseries should have been inspected at least 2 times (3 times according to the government bill but could have been postponed once) by the end of 1997. As the questionnaire was sent out in May 1997 still another 7 months of checking and renovation could be carried out. In particular the summer holiday from June to mid August is used for different measures.

Table 2 Comparison between the quest 1997 and ELIB. The estimated percentage of apartments approved at the inspection

Size	Number of quest		Representing inhabitants		Apartments, approved %	
	ELIB	Quest 1997	ELIB	Quest 1997	1995	1997
Cities, Stockholm, Göteborg, Malmö	3	0	35	0	-	
Suburbs to the above cities	13	6	14	19	80	75
> 90 000	8	4	24	35	70	42
27 000 – 90 000	19	7	20	23	75	50
< 27 000	17	29	7	23	73	65

In the distribution of questionnaires no cities were included. Many of smallest municipalities were included. Here the number of apartments are lowest. If compared to the number of inhabitants the questionnaire is giving quite a good representation of both apartments and schools and day nurseries, see table 2. However, it must be questioned the quality of the data for the apartments like: No data from the cities are given, in some municipalities only passed checking were registered, some didn't know the number of apartments.

Table 3 Percentage of buildings (bldgs) approved at the inspection. Comparison between 1995 and 1997 of the number (no) of municipalities (mnp)

Comparison	Schools		Day nurseries	
	1995, Dec	1997, May	1995, Dec	1997, May
Total, approved, %	86 %	61 %	92 %	75 %
No mnp better1997 than 1995		8		4
Equal 1995 and 1997	20		20	
All bldgs approved, no. mnp		11	14	
No. mnp 100 % bldg approved 1995 & 0 % 1997		5		4
No. mnp 0 % bldg approved 1995 & 100 % 1997		1		0

In total Sweden has 5200 schools and 15 000 day nurseries. The number that have passed the checking May 1997 is not that high as for December 1995, see table 3. However, the work continued during the whole year and as most of the buildings had been approved at inspections before half of the year had passed it was estimated that the situation was the same 1997 as 1995. But still there are buildings and systems that have not been checked at all since the bill passed the Parliament.

Interviews with responsible employees at 12 municipalities showed that most of them had the opinion that the politician was passively or actively supporting them. In particular the task is very tricky when the inspection has to take measures against the building management

division within the municipality. In one case it has also been issued a penalty of fine unless a school had not been approved before a certain date. The policy is to have all the municipality owned buildings checked and passed before any measure is taken against other owners.

4.2 Questionnaires by the housing companies

Table 4 Structure of ownership for the apartment buildings

Ownership	Organisation	Apartments	
		No	%
Condominiums	HSB	325 000	14
	Riksb.	160 000	7
	SBC	100 000	4
	Others	50 000	2
Public	SABO	900 000	40
	Others	40 000	2
Private		700 000	31

In Sweden it is assumed to be about 2.3 million apartments. In general there are three categories of principal ownership, see table 4. They are condominiums, public companies (usually all shares hold by the municipality), and private companies. Most of the private companies have a much older building stock than the other. Only the organisation for condominiums and public owned companies participated in distributing the questionnaire to all the about 400 companies. For the association for the private owned real estates with about 20 000 members it was not possible to distribute a questionnaire.

Table 5 Answered questionnaire

Organisation	Total apartments	% of apartments in Sweden	Quest answered %	Systems checked %	
				MSE	MEO, PSV
HSB	300 000*	14	80	21	79
Riksb.	190 000*	8	55	26	74
SABO	900 000	40	70	-	-
Total	1 390 000	60	70	-	-

* only technical management

As always the quality of the answers vary within a large range. Some contain very detailed information and some have given rough estimations. But astonishing most of the answers received were very detailed. Only the answers concerning condominiums had distinguished between systems, see table 6. However, not too detailed, the questionnaires give information on the matter that most of the MSE, MSEX systems have been inspected and nearly all have been approved.

Table 6 Approved inspections, no. of apartments

Organisation	Approved dwell.s		Approved inspections, ventilation systems			
	No.	%	MSEX*, MSE		MEO, PSV	
			No.	%	No.	%
HSB	200 000	63	51 300	76	151 100	59
Riksb	80 000	76	23 300	88	53 600	69
SABO	470 000	75	-	-	-	-
Total	750 000	72				

*Mechanical supply and exhaust incl heat recovery

As the data given for the condominiums was given in January 1997 and also information was given of apartments inspected but needed remedial action before approved if is assumed that most of those actions had been undertaken during 1997.

Table 7 Approved apartments (aptms), public companies (SABO). Size of municipalities

Size of municipality	Answers received	Approved aptmts	Aptmts total
	aptmts	%	
Cities, Stockholm, Göteborg, Malmö	170 000	61	225 000
Suburbs to the above cities	104 000	78	145 000
> 90 000	116 000	85	150 000
27 000 – 90 000	125 000	83	220 000
< 27 000	109 000	74	160 000
Total	625 000	75	900 000

A slightly less number of apartments were approved in the three largest cities, see table 7. This trend was also shown for the condominiums.

4.3 Protocol evaluation

From the real estate owners 10 289 protocols from the inspections have been collected from 1997. The owners are in all categories mentioned above including municipalities. The main reason for the collection of the protocols were to form a basis for a computerised management of at first the ventilation checking and in a longer perspective the total management and in particular the maintenance. This means that the protocols are the ones before any remedial action has been taken. The percentage of approved systems is less than reported from the questionnaires but it must once again be observed that in the questionnaire was asked for the approved buildings after remedies and the protocols are the step before. It must be noted that in table 8 is giving results from protocols per systems (not buildings).

Table 8 Protocols split on usage and ventilation systems

Type	Protocols	Approved		MSEX		MSE		MEO		PSV	
		No.	%	No. syst.	Approved %	No. syst.	Approved %	No. syst.	Approved %	No. syst.	Approved %
Total 1997	10289	4518	44	2866		3670		3044		788	
Total 1995	8089	3013	37	2132		3205		2237		443	
Hospitals 1997	670	217	32	216		292		105		4	
Hospitals 1995	403	101	25	101		182		92		2	
Medical care 1997	194	86	44	76		91		26		7	
Medical care 1995	73	46	63	29		25		20		4	
Day nurseries 1997	645	436	68	324	66	198	64	135	80	10	40
Day nurseries 1995	332	160	48	142	51	111	40	65	70	8	38
Schools 1997	2444	1417	58	789	63	1089	53	542	64	50	44
Schools 1995	2299	791	34	562	44	1081	27	544	41	48	23
Offices	2321	893	38	788	50	1250	34	200	29	83	19
Shops	277	204	74	163	95	92	47	26	19	10	10
Apartments	2589	709	27	209	36	93	34	1737	28	550	21
Houses	78	26	33	78							
Others	857										

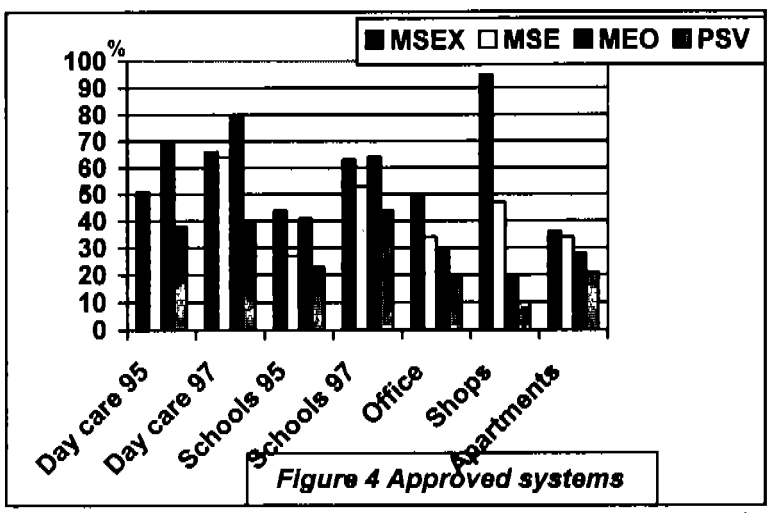


Figure 4 Approved systems

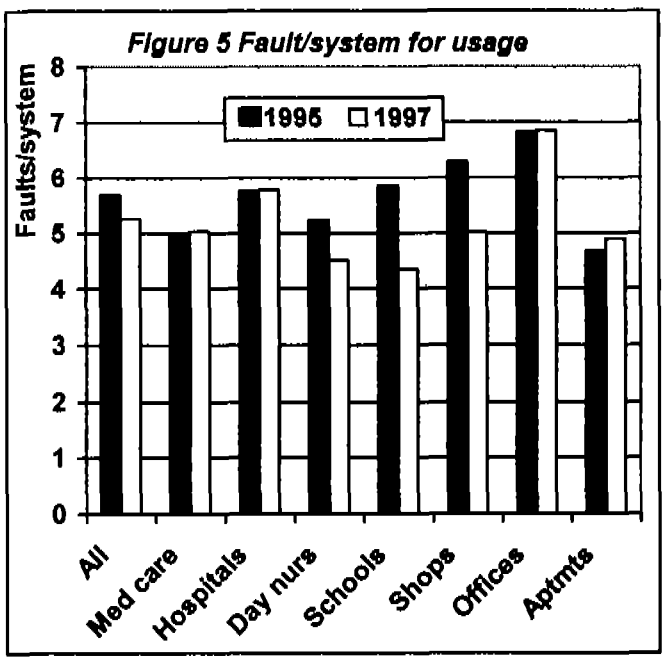
The percentage of approved systems have increased from 1995 to 1997 for the categories that have had the shortest intervals between the inspections: day nurseries, schools, hospitals. See table 8 and figure 4. The general trend is also that MSEX is the most approved system and PSV least. MSE and MEO is similar. The trend remains similar between the compared years. One explanation is that while MSE systems are designed as component delivery and installed according to drawings and also older systems, the MSEX are younger and delivered as systems with responsible producer and understanding of system approach. The PSV is old systems in old buildings. Sometimes it had been claimed that PSV suffered from lack of maintenance and could be better after remedy. But this is not shown as PSV both has least approved and most faults, see table 9. The situation for day nurseries, schools and hospitals are very relevant for the situation as most of the systems in Stockholm and Malmö is included. For offices some very big owners are

included. For apartments the relevance is a little less while for shops it is a very special type of shops thus not giving the general trend. Houses are in to low number to be evaluated.

The protocol have 37 inspection points. All have been divided into building usage and system type. For each of those the percentage of approved, fault to be remedied before next inspection (FA), and fault that made the inspection to fail an approval (FF). As this is impossible to read all the material have been grouped in 5 different classes. Faults including both FA and FF for the frequency of more than 50 % or 30 % of the inspections. Faults that fail an approval FF for the frequency of more than 30 %, 20 %, 10 %. For each of the inspection points this has been noted. The sum of each of those has been noted and added. This sum is given in the last line in table 9.

Table 9 Number of inspection positions giving faults. The number of Inspection Positions that Fails are added and called "[IPF]"

	Apartments				Schools				Day nurseries						Butik		Kontor			
	MSEX	MSE	MEO	PSV	MSEX	MSE	MEO	PSV	MSEX	MSE	MEO	PSV	Hospitals	Med. care	MSEX	MSE	MSEX	MSE	MEO	PSV
Fault. Incl both fault that cause failure of approval and fault accepted to be remedied before next inspection																				
No. insp pos. >50 %	6	11	5	11	3	4	2	5	3	4	4	7	5	3	1	8	4	5	7	10
No. insp pos. >30 %	6	21	18	13	5	8	5	9	4	5	9	9	12	4	3	19	10	20	16	13
Fault, failed to give approval of systems																				
No. insp pos. >30 %	5	7	4	8	0	1	0	1	0	0	0	3	1	1	0	2	1	2	3	9
No. insp pos. >20 %	5	9	4	9	1	1	1	3	1	2	0	3	4	1	0	3	2	3	9	11
No. insp pos. >10 %	9	19	8	11	2	5	3	9	1	2	2	4	9	3	0	11	7	15	15	12
Sum of inspection position failures	31	67	39	52	11	19	11	26	9	13	15	26			4	43	24	45	50	55



The number of faults FA+FF in general was 5.3 faults/system for 1997 compared to 5.7 faults/system for 1995. If a system is not approved it has in general more than 3 faults that each cause a disapproval of the system, see figure 5.

In order to judge or rank the systems the evaluation has been made from different points of views. It is a qualitative ranking based on the inspections giving the number of approved systems and the frequency of faults for each inspection point. The ranking is from "1" to "4" with the best given the rank "1". Then the rank is added and a sum given. See table 10.

The result of this sum gives a fault ranking sum in the proportion

1 : 2 : 3 = MSEX : MEO,MSE : PSV

To be read as: the ranking with regard to the number of faults for inspection positions and overall approval of systems. This gives that PSV has three times as high fault index compared to MSEX. Also that PSV can be expected to have faults in that magnitude compared to MSEX.

Table 10 Ranking ventilation systems				
Building use	**Vent. system**			
	MSEX	**MSE**	**MEO**	**PSV**
With regard to % of approved systems				
Day nurseries 1997	2	3	1	4
Day nurseries 1995	2	3	1	4
Schools 1997	2	3	1	4
Schools 1995	1	3	2	4
Offices	1	2	3	4
Shops	1	2	3	4
Apartments	1	2	3	4
With regard to the number of inspection position failures				
Day nurseries	1	2	3	4
Schools	1	3	2	4
Offices	1	2	3	4
Shops	1	2	3	4
Apartments	1	4	2	3
Sum of ranking all above. FI = fault index	15	31	27	47
Sum of ranking above except 1995. FI	12	25	24	39
Sum of ranks above except 1995 & shops. FI	10	21	18	31
Ranking total	①	③	②	④

Table 11 Most frequent faults (max possible score is 100)		
Inspection point	**Score**	**Place**
Air flow, (function)	90	1
Other functions	72	2
Handling instruction	57	3
Air intake, (supply)	30	4
Device, duct (function)	29	5
Drawings	29	6
Ducts (exhaust)	28	7
Fan (function)	26	8
Control	22	9
Duct (supply)	19	10
Device (exhaust)	19	11
Device (supply)	17	12
Filter (supply)	16	13
Fan (exhaust)	13	14
User opinion	13	15
Others (exhaust)	12	16
Fan (supply)	10	17
Filter (exhaust)	6	18

The most frequent fault that either fails to give approval of the system or can be accepted to be corrected to the next inspection has been identified. For that the frequency intervals have been used. In table 11 is given the ranking and the score. This score is given by: If the inspection point has resulted in either FA+FF in the frequency 50 %, 30 % or FF in the frequency 30 %, 20 %, 10 %. Every building usage and every system is included. If an inspection point fails for all building usage and all 4 systems the maximum number is "20". As there is 5 different frequency indication the total can be 5*20 = 100. In the table 11 is the most frequent failure "the function air flow". It is a sort of resulting fault for what can go wrong in many other positions in a system. As number 2 is "other functions". Under this heading is collected such as "dirt and disorder, bad organisation".

4.1 Costs

Estimations have been made for the cost. This is based on figures collected at the questionnaire to the housing companies (4.2), ventilation market analysis.
To upgrade the ventilation systems to the situation when it was installed an estimated cost for
Apartment buildings of 2 – 2.5 billion SEK (250 – 310 M$ or 230 – 280 MECU)
Non-domestic buildings 6 – 8 billion SEK (750 – 1000 M$ or 680 – 910 MECU)
Of this cost about half is still remaining to be undertaken.
Running maintenance cost, regular checking, and inspection is estimated to be 1.5 – 2 billion SEK (190 – 250 M$ or 170 – 230 MECU) per year to keep the achieved level after the upgrading of the ventilation systems

5. Conclusions

The estimated approved rate at the end of 1997 are:

- ❖ Schools 85 – 90 %
- ❖ Day nurseries 90 – 95 %
- ❖ Hospitals ≈ 40 %
- ❖ Medical care ≈ 40 %
- ❖ Offices ≈ 40 %
- ❖ Dwellings 65 – 70 %
  - ➢ Of which condos 85-90 %
  - ➢ public owned 75-80 %
  - ➢ private <50 %

- Fault index are in the proportion 1:2:3 = MSEX : MSE,MEO : PSV
- Stack ventilation has far more faults than any other system regardless installed in multi family buildings, schools or offices
- Repeated inspections decrease the number of faults and increase the approved rate
- The number of faults are 5.3 per system and the most frequent fault is the function of "air flow".
- The estimated remaining cost for upgrading of the ventilation systems to the standard at the installation is about 4 billion SEK and the yearly cost is 1,5 – 2 billion SEK.

6. Acknowledgement

The Swedish work was sponsored by the Swedish Board of Housing, Building, and Planning. The collection and data processing of the protocols that were made by Walter Cederholm and his colleagues at the consulting company JBS in Vällingby, Stockholm.

7. References

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