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The Dutch E'Novation Program: Indoor Air Quality in Dwellings Before and After Renovation

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THE DUTCH E'NOVATION PROGRAM: INDOOR AIR QUALITY IN DWELLINGS BEFORE AND AFTER RENOVATION

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ABSTRACT

The Dutch "E'novation program" is a national demonstration program in which dwellings with high energy consumption, moisture and mold problems and poor indoor air quality were renovated, with special attention to the selection of the heating and ventilation systems, thermal insulation and the building physical details. A number of indoor air quality parameters were monitored before and after renovation, showing an important improvement in the indoor air quality. Moreover, energy consumption for space heating decreased by 39%, which, meets the targets of the Dutch National Environment Policy.

INTRODUCTION

In 1988 NOVEM (Dutch Company for Energy and Environment) started a national demonstration program in The Netherlands, involving the renovation of 2800 dwellings with high energy consumption, moisture and mold growth, poor indoor air quality etc. This program is called the "E'novation program". E'novation is a contraction formed by the two key words of this program: "Energy" and "Renovation". Many post-war buildings in The Netherlands have the above mentioned problems. The characteristics of these buildings are: no or insufficient thermal insulation, many air leakages, often no central heating, unvented geysers and inadequate physical details. The addition of thermal insulation often causes problems with moisture, ventilation and indoor air quality. The purpose of the E'novation demonstration program is to achieve both energy savings and good indoor air quality through an integrated handling of energy retrofitting, ventilation and heating systems and good physical details. In some projects special energy savings technics were applied, such as heat recovery, passive solar energy and demand controlled ventilation systems.
The Dutch Ministry of Economic Affairs has made available USD 3.800.000,-- for this program. This amount also includes the costs of a pre-study, the evaluation and measurement program and "knowledge-transfer" about this program. An amount of USD 1.100,-- per dwelling will be paid to the building corporations. NOVEM manages the program.
All the projects were supported by an extended program of measurement and evaluation. The measurement and evaluation program concerns:

- the performance of the ventilation, heating and heat recovery systems applied;
- the predicted and achieved energy consumption for space heating and warm water;
- the airtightness of the building envelope;
- evaluation of the overall quality of the renovation;
- evaluation of the experiences and opinions of the occupants.

In some projects a special measurement program was carried out to monitor indoor air quality. The measurements were taken before and after the renovation. The dwellings and the measured indoor air components and pollutants were chosen in such a way that the quality of the renovation process and its impact on the indoor air quality was measured as accurately as possible. Therefore any disturbing influence on the part of occupants (i.e. smoking) was eliminated.

This paper will focus on indoor air quality measurements in relation to energy savings and the results of airtightness measurements.

METHODS

The measurement program is set up as follows. In each dwelling the measurements were taken over the course of one week. CO_2, CO, CH_2O, TVOC (ref. to CH_4), relative humidity and temperature were continuously sampled and monitored in four rooms (living room, kitchen and two bedrooms) as well as outdoors by a B&K 1302 gas monitor and B&K 1303 sampler and doser unit combination. NO_2 was measured by passive sampling by means of Palmes diffusion tubes. Volatile organic compounds (VOC) were measured by active sampling and a G.C. analysis of aromatic hydrocarbons and halocarbons.
Respirable dust was measured continuously by a tyndallometer. Radon was measured for four months by passive sampling in the living room and in the crawl space.
The measured concentrations were checked with the guideline values of the WHO (1), and the target guidelines for VOC's (2).

RESULTS AND DISCUSSION

Indoor Air Quality

Before renovation most of the dwellings had unvented geysers in the kitchen. A number of these dwellings had local heating. During the renovation all unvented geysers were replaced by combi-boilers for heating and hot water supply with a closed combustion system (direct combustion air in take). The ventilation is improved by applying an individually controlled mechanical exhaust ventilation or by a balanced ventilation system.
In table 1 a summary is given of a number of measured indoor air quality parameters. It shows the averages during 1 week, measured in dwellings before and after renovation. In table 2 a summary is given of the measured concentrations of VOC before and after renovation.

Before renovation the indoor air quality was generally poor and in some cases even hazardous. The main sources were unvented geysers installed in most of the homes. It was known that these geysers could result in the guidelines for NO_2 and in some cases for CO and CO_2 being exceeded. Continuous measurements showed that CH_2O also frequently exceeded the guideline values.
After the renovation there was an obvious decrease in all measured indoor air quality parameters. The following was observed:

- The most significant decrease was the reduction in the NO_2 concentrations. Before renovation the weekly average values measured in kitchens exceeded the 24 h guideline value. After the renovation these values decreased to values much lower than the guideline values.
- The CH_2O concentrations also showed a large reduction. A comparison with the guideline value of 120 ug/m ^{3} is not quite correct because the filter reacts upon formaldehyde as well as upon a number of other aldehydes and upon C_5H_{12} and C_6H_{14}. Figure 1 shows a typical example of CH_2O concentrations measured in a kitchen before and after renovation. Before renovation extreme peak values occured during the moments that the unvented geyser was in use. After renovation these peaks disappeared.
- The measured CO concentrations were reduced by 50% or more in the renovated dwellings. Table 1 shows that the weekly averages measured did not exceed the guideline value. Nevertheless there were situations before the renovation in which this limit had been exceeded in shorter periods (about 10 to 12 hours) such as in the living room as a consequence of the flue gass backdraft from gas heaters.

Table 1. Measured indoor air quality parameters before and after renovation (mean values and standard deviations, n=16).

		before renovation			after renovation			
		living room	kitchen	bedrooms	living room	kitchen	bedrooms	guideline values
CO_2 (ppm)	mean	1024	1013	927	882	836	672	1200
	std	184	277	193	160	122	148	
CO (mg/m^3)	mean	3,9	4,3	4,2	2,2	2,0	1,4	10 (8h)
	std	0,4	0,2	1,6	1,0	0,5	0,5	
CH_2O* (ug/m^3)	mean	665	577	530	405	357	231	120 (0,5h)
	std	214	51	234	167	153	188	
TVOC (ref CH_4) (mg/m^3)	mean	-	-	-	4,5	4,1	2,9	-
	std	-	-	-	1,0	1,0	1,0	
NO_2 (ug/m^3)	mean	84	160	30	30	34	16	150
	std	40	127	9	16	14	3	(24h)
Resp.dust (ug/m^3)	mean	30	-	-	30	-	-	70
	std	16	-	-	15	-	-	(PM10 24h)
RH(%)	mean	42	41	57	45	44	45	30-70%
	std	4	6	9	4	3	4	

* including a.o. other aldehydes, C_5H_{12}, C_6H_{14}

Table 2. Concentrations of VOC in ug/m^3 before and after renovation.

	before renovation		after renovation	
	livingroom	kitchen	livingroom	kitchen
benzene	8,6	12,3	1,3	2,1
ethylbenzene	2,6	3,3	1,9	1,7
toluene	38,0	40,0	32,0	21,0
xylenes	3,0	7,0	1,3	1,4
styrene	1,1	0,9	0,6	0,4
n-propylbenzene	16,7	8,3	0,2	0,3
i-propylbenzene	0,2	0,2	<0,1	<0,1
1,2,4-trimeth.benz.	3,0	3,4	1,2	1,7
1,3,5-trimeth.benz.	1,4	1,5	0,7	0,6
naftalene	0,5	0,5	0,1	0,3
chlorobenzene	2,1	1,1	<0,5	<0,5
1,2 dichl.benzene	0,8	0,8	<0,5	0,5
1,3 dichl.benzene	<0,6	<0,6	<0,5	<0,5
1,4 dichl.benzene	0,8	0,8	<0,5	<0,5
1,2 dichl.ethene	2,1	1,3	0,7	0,7
dichloromethane	6,1	3,4	1,6	2,0
trichloromethane	2,1	2,1	1,7	2,3
1,2 dichl.ethane	<0,6	<0,6	<0,5	<0,5
trichl.ethene	11,5	11,5	7,3	7,7
tetra chl.ethene	6,6	7,8	5,9	6,2
tetra chl.ethane	1,4	1,4	<0,5	0,9
1,1,1.trichl.ethane	1,4	1,9	0,8	<0,5
1,1,2.trichl.ethane	1,4	<0,6	0,9	1,5

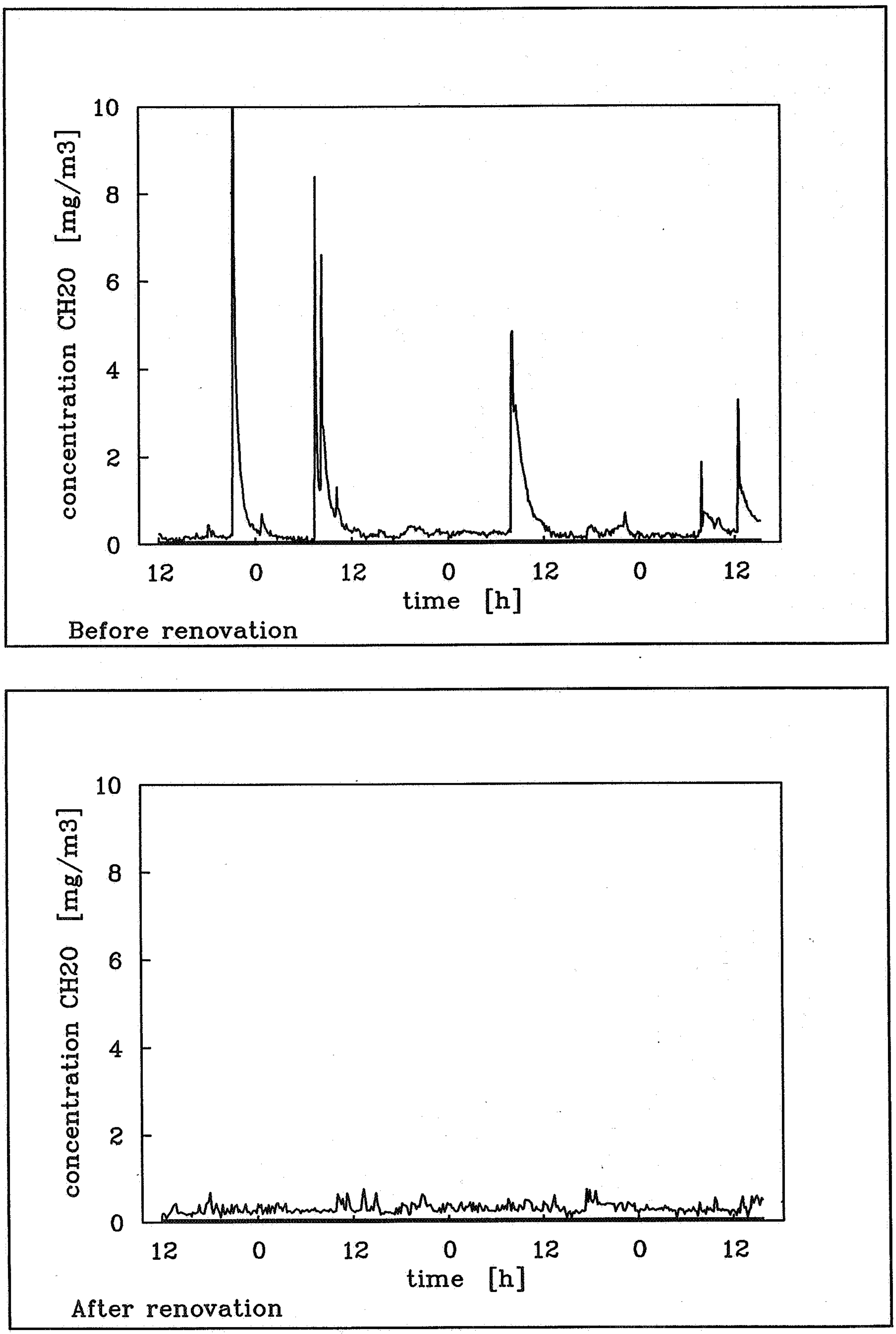

Figure 1. Concentrations of CH_2O (and o.a. other aldehydes, C_5H_{12}, C_6H_{14}) measured in a kitchen before and after renovation.

- Before and after renovation the weekly averages of the CO_2 concentrations were lower than the hygienic limit value.
  However in many shorter periods these limits were exceeded.
- The measured respirable dust concentrations appeared to be far below the limits both before and after the renovation.
- Almost all concentrations of VOC's showed a reduction. Before renovation the sum of the aromatic hydrocarbons exceeded the target value of 50 ug/m^3. In some dwellings benzene exceeded the guideline value of 12 ug/m^3. After renovation the target guidelines for the aromatic hydrocarbons and halocarbons were not exceeded.

Airtightness

An important part of the measurement program concerned the measurement and evaluation of the airtightness of the building envelope. In every project measurements took place before and after renovation. According to the Dutch standard NEN 2686 "Airpermeability of buildings. Method of measurement" airtightness is expressed as the airleakage flow in dm^3/s by a pressure difference of 10 Pa. Figure 2 shows the results of the measurements before and after renovation.
Before renovation the mean airtightness for the whole project was about 144 dm^3/s. For the single family houses the average was 290 dm^3/s; for the multi family houses 91 dm^3/s. After renovation airtightness improved with 25%. The average for the whole project after renovation was 107 dm^3/s. For the single family houses it was 185 dm^3/s; for the multi family houses it was 74 dm^3/s. These results meet easily the Dutch Building Code which demands a maximum airleakage flow of 200 dm^3/s by 10 Pa for new dwellings (this corresponds with a n50-value of 6 for a buildingvolume of 350 m^3).

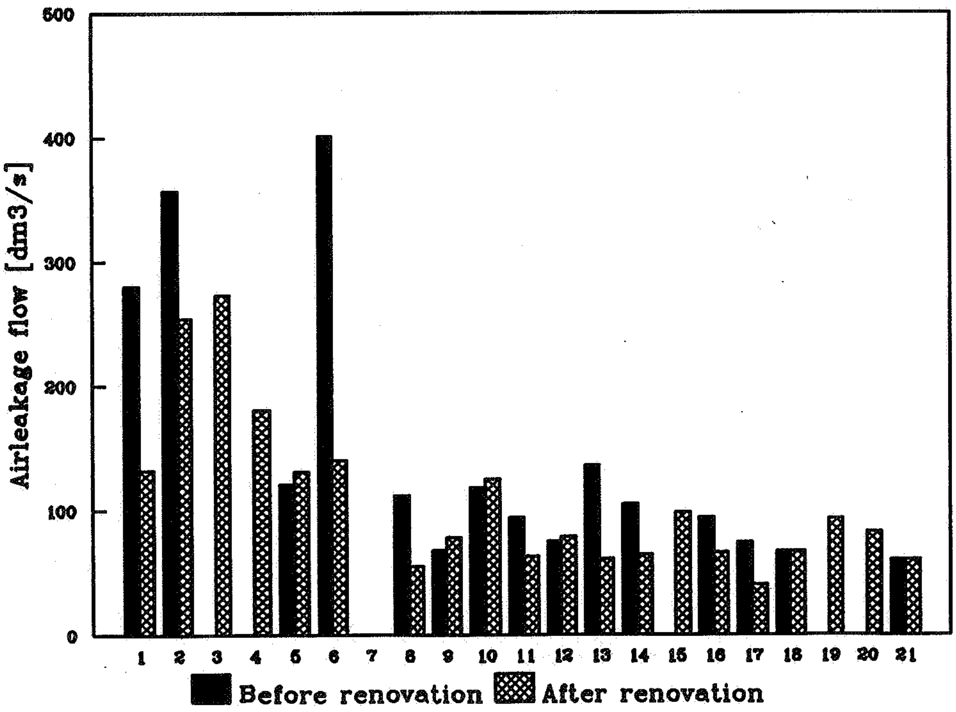

Figure 2. Measured airleakage flows in dm^3/s by 10 Pa.

Energy savings

As a part of the evaluation of the E'novation program, energy use has been calculated and monitored, both before and after renovation. The calculations concerned gas use for space heating, cooking and warm water and also electricity use. Before renovation expected decrease of 50% Figure 3 shows the measured gas consumption for space heating for the projects before and after renovation. The mean measured saving is about 39%. This is 11% less than the predicted decrease of gas use for space heating. While gas use for space heating decreased by 39%, gas use for warm water almost doubled. This was because in almost all the projects, the unvented geysers were replaced by combi-boilers for heating and hot water supply. This gives a large increase in the warm watersupply from 2,5 l/min to 5 to 7 l/min (60°C). Therefore the total measured gas use decreased only by 24% which is 13% less than the predicted decrease of 37%.
Figure 3 shows that the gas savings for space heating appear to be less in a number of projects. This is due to the fact that in these projects a local heating system was used before renovation (only a gas heater in the living room) and a central heating system after renovation. This meant that the average temperature of the dwelling and also thermal comfort increased.

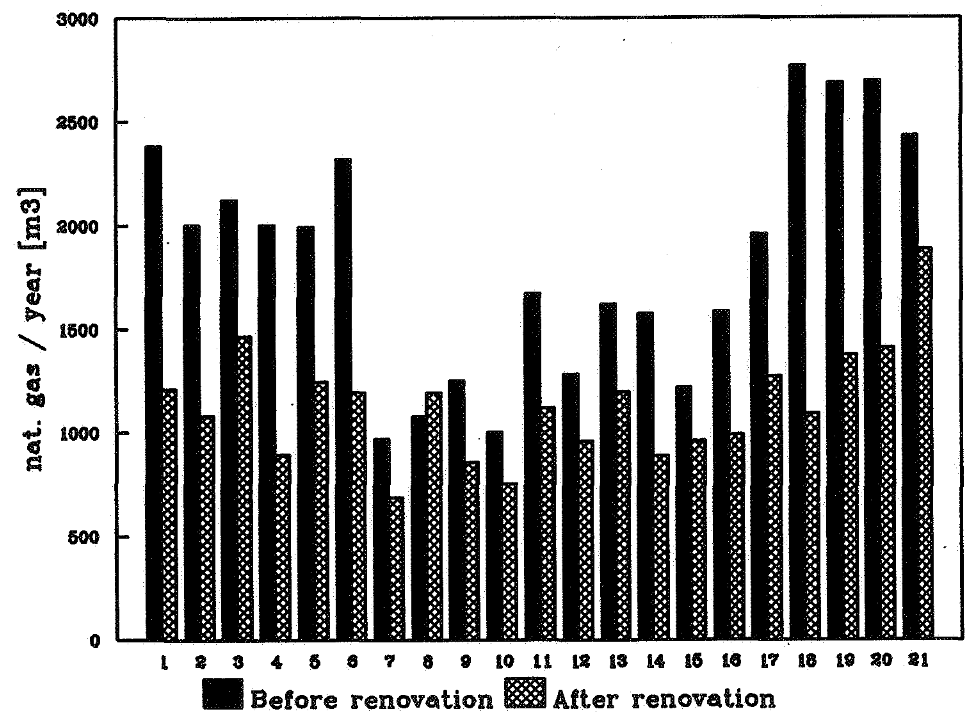

Figure 3. Measured energy consumption for space heating before and after renovation.

CONCLUSIONS

- The selected dwellings for the E'novation program had problems with high energy use and poor indoor air quality, often in combination with moisture and mold growth.
- The measurements carried out in all the dwellings did indeed show poor indoor air quality. For example NO_2 and CH_2O frequently exceeded the guideline values.
- The E'novation program, in which a well-considered choice has been made between various heating and ventilation installations in combination with improved physical details, results in significant improvement of indoor air quality.
- In all projects, problems with moisture and mold growth were consistently eliminated.
- The average airtightness increased by 25 %.
- The gas saving for space heating of 39% meets the target of the Dutch National Environment Policy. It appears that these savings are accompanied by an increase in thermal comfort, a larger warm water supply and improved indoor air quality. This also indicates that a renovation on "E'novation level" will be necessary if the same goals are to be achieved in most of the existing dwellings in The Netherlands.

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