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EC-THERMIE project Heerlerbaan: Multi-functional appliances for retrofitting residential buildings

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THERMIE project

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SYNOPSIS

Many post-war residential buildings in the Netherlands have collective heating systems with poor energy efficiency. Also ventilation and DHW systems usually do not comply with current requirements. In Heerlen, the Netherlands, a demonstration was carried out in the framework of the EC-THERMIE programme in a residential building where the collective heating, DHW and ventilation systems are replaced by individual multi-functional appliances. These appliances are a recent development in the Netherlands, integrating different service functions. A measurement and evaluation programme was completed in May 1997, showing energy savings for space heating of 48 % over a period of 2.5 years and a significant improved ventilation and indoor air quality.

INTRODUCTION

In Heerlen, the Netherlands, an EC-THERMIE demonstration project is carried out, concerning the retrofitting of 120 apartments in a residential building. Individual multi-functional appliances replaced a collective central heating system, unvented hot water appliances and passive stack ventilation. The building is a typical example of a Dutch high rise flat for social housing, built in the sixties. In these types of buildings installations for space heating are usually energy inefficient. Poorly functioning ventilation systems and unvented hot water appliances ("geysers") often cause indoor air problems. Retrofitting installations for space heating DHW and ventilation is a complicated process in which the different components can have a major influence on one other.

In new and retrofitted airtight dwellings ventilation must be carefully designed. Natural supply by using vents in the facade can give problems due to a poor thermal comfort. Occupants close the vents in case of low outdoor temperatures or high wind velocities. This can lead to poor indoor air quality, moisture problems and mould grow. Also a high underpressure can occur if airtight dwellings have mechanical exhaust and vents are closed. This leads to serious problems with spillage of flue gasses from open combustion appliances. This means that also the selection of the type of ventilation system has a close relation with the selection of the types of combustion appliances. Balanced ventilation, especially in combination with closed combustion appliances, gives a good solution to deal with these problems. Even then indoor air quality problems can occur if occupants don't use the ventilation system, for example, by turning off the system. Because in a MFA ventilation is linked with hot drinking water the possibility of not using the ventilation system is minimised (no ventilation means no DHW). MFA's give an integral solution for the selection of ventilation system, combustion appliances for space heating and DHW and minimising malfunctioning of one or more system components because of occupants behaviour.

Another advantage of MFA's is that the number of ducts is limited. There are only two ducts necessary leading from the unit to the outside: one for fresh air and one for mixed exhaust air and flue gasses. For a comparable system (balanced ventilation and a closed combustion appliance) three or four ducts are necessary: fresh air, exhaust air, combustion air, flue gasses (flue gasses and combustion air can be combined in one duct). This can be of special interest for retrofitting when also ventilation and heating systems are involved.

Although originally designed for new built energy efficient dwellings, MFA's are also very suitable for energy efficient retrofitted dwellings. However there still remained risks on some technical and economical aspects for this application. These risks as well as the demonstration character for a large number of dwellings with similar problems all over the European Community, was a reason to submit this project in the EC-THERMIE programme.

Multi-functional appliances (MFA) are a new integral approach to space heating, hot drinking water and ventilation. These three functions are combined in one appliance. Heat recovery (8) takes place from the exhaust air for ventilation (1) and flue gasses (2). Moreover other waste heat such as convection and radiation losses and heat of fans is used. A MFA contains a combi-boiler for the heating systems (for feeding radiator panels 4) and hot drinking water (3). A MFA also contains a balanced ventilation system with mechanical supply (5,7) and exhaust of air (1,6). Extracted air (1) from bathroom, toilet and kitchen is used as combustion air for the boiler. Flue gasses (2) and extracted air (1) are mixed before they pass the heat recovery (8).

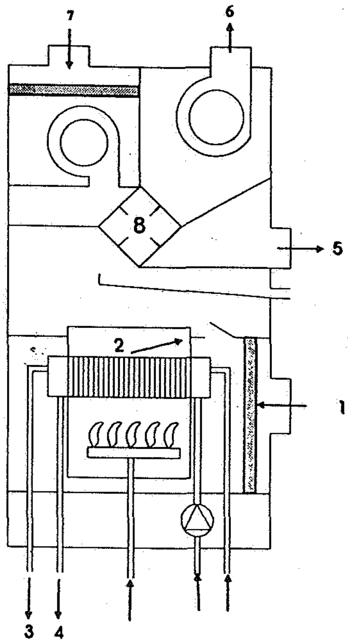

Figure 1: Principle of the appliances used in this EC-THERMIE demonstration project.

EC-THERMIE DEMONSTRATION PROJECT "HEERLERBAAN"

Multi-functional appliances are demonstrated in a retrofitted residential building in Heerlerbaan, municipality Heerlen, the Netherlands. This building is a part of a complex with five similar buildings. The building has 12 stocks and contains 120 apartments. The apartments have a floor area of 88 m^2 and have a living room, three bedrooms, a kitchen, bathroom and toilet. In the situation before retrofitting the building had a collective central heating system. The apartments had floor heating and one radiator in the living. There were no individual control devices. There was passive stack ventilation and natural supply through small ventilation windows. Hot drinking water was supplied by unvented hot water appliances in the kitchen. In the non-retrofitted situation there were many problems with the heating system. Specially the energy use was very high and the poor control systems cause overheating in many apartments. There were also indoor air quality problems caused by the hot water appliances (CO, NO_2). The natural ventilation system did not comply with Dutch ventilation standards.
A MFA is more or less designed for (new built) energy efficient single family dwellings and low rise residential buildings. However, there appeared to be no objectives using these appliances in this particular situation. As well, MFA's appear to be a very interesting solution for the complicated selection of heating, ventilation and DHW system for retrofitted buildings. Moreover, the occurring problems could be solved with one appliance. However, there were some technical risks for applying MFA's in high rise buildings. An important aspect was the functioning and the safety of the collective duct for combined exhaust of flue gas and stale air. In 12 apartments, connected to one collective duct, the performances and functioning of the different components were monitored and evaluated during one full year. After a successful test year the rest of the building was retrofitted between March and October 1996.

METHODS

The demonstration project is supported by an extended measurement and evaluation programme. This programme contains:

- Performances of the appliances and system components
- Ventilation rates measured with PFT and constant tracer gas technique.
- Indoor air quality by measuring TVOC, CO_2, CO, NO_2, relative humidity and temperature.
- Air tightness of the building envelope.

- Monitoring monthly energy uses.
- Occupants survey on using ventilation provisions.

Ventilation rates were measured during one heating season by means of PFT technique. These measurements were carried out in five retrofitted dwellings and five non-retrofitted dwellings. In four retrofitted and four non-retrofitted dwellings ventilation rates were measured with constant tracer gas method during one week. Simultaneously In these dwellings indoor air quality parameters were measured. During the measurements occupants recorded the use of the ventilation provisions, window airing, inner doors and heating system. CO_2, CO, TVOC, temperature and relative humidity were measured during one week by using a Bruel & Kjaer 1302 gas monitor and 1303 sampler and doser unit. NO_2 was measured by using Palmes tubes.

RESULTS AND DISCUSSION

Energy saving in the complex

Energy use is monitored from October 1994 up to May 1997. From October 1994 till May 1996 monitoring took place in twelve test apartments and in the other non-retrofitted part of the same building (118 apartments with a collective central heating system). In October 1996 the renovation of the whole complex of 120 buildings was completed. Energy use was monitored in the total complex from October 1996 up to May 1997 as well as in two similar non-retrofitted complexes (240 apartments). In this way energy use before and after retrofitting could be compared. In figure 2 the gas use for space heating is given for the period from October 1994 till May 1996. In figure 3 the gas use for space heating is given for the period from October 1996 till May 1997. In the first period the average gas consumption for space heating decreased by 49 %, from 1688 m^3 nat.gas/dwelling per year to 862 m3 nat.gas/dwelling per year. In the second period the average gas consumption for space heating decreased by 48 %, from 1610 m^3 nat.gas/dwelling per year to 844 m3 nat.gas/dwelling per year. These reductions were achieved by only applying multi-functional appliances. No further measures for thermal insulation or air tightness were taken.

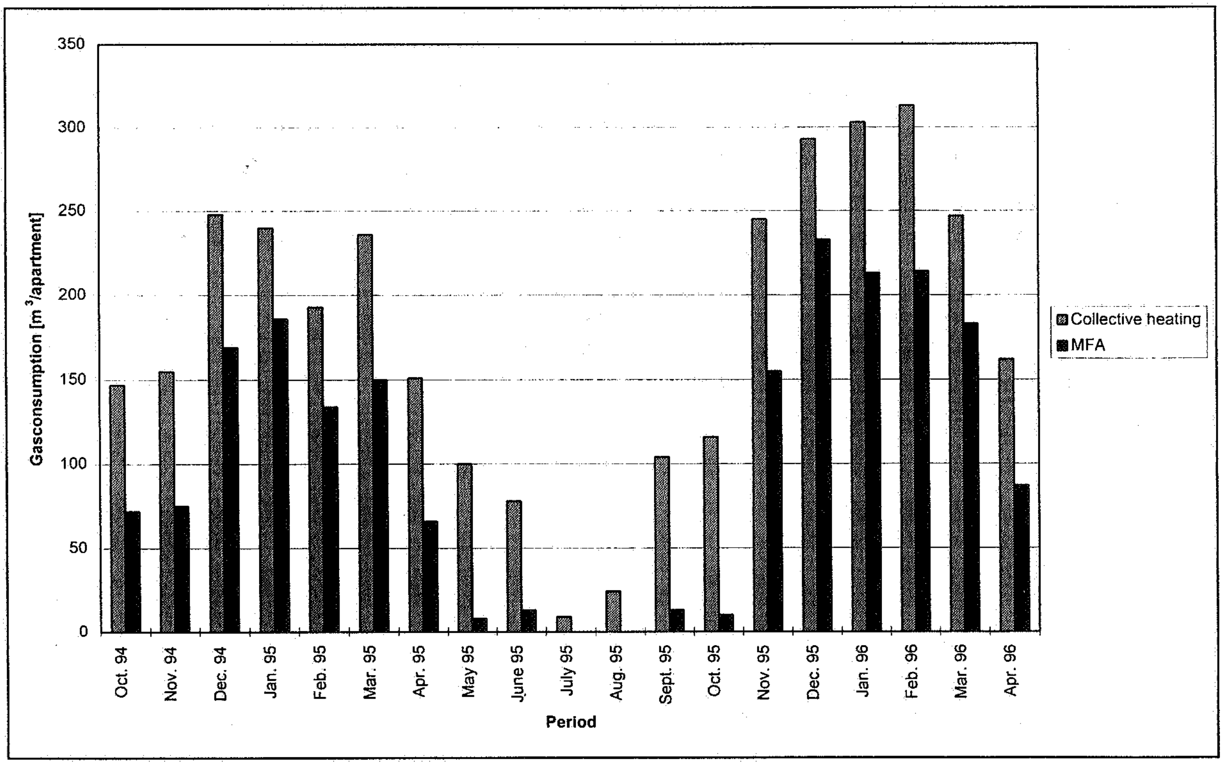

Figure 2 Gas consumption for space heating 12 retrofitted test apartments (MFA) and 118 non-retrofitted apartments in the same building.

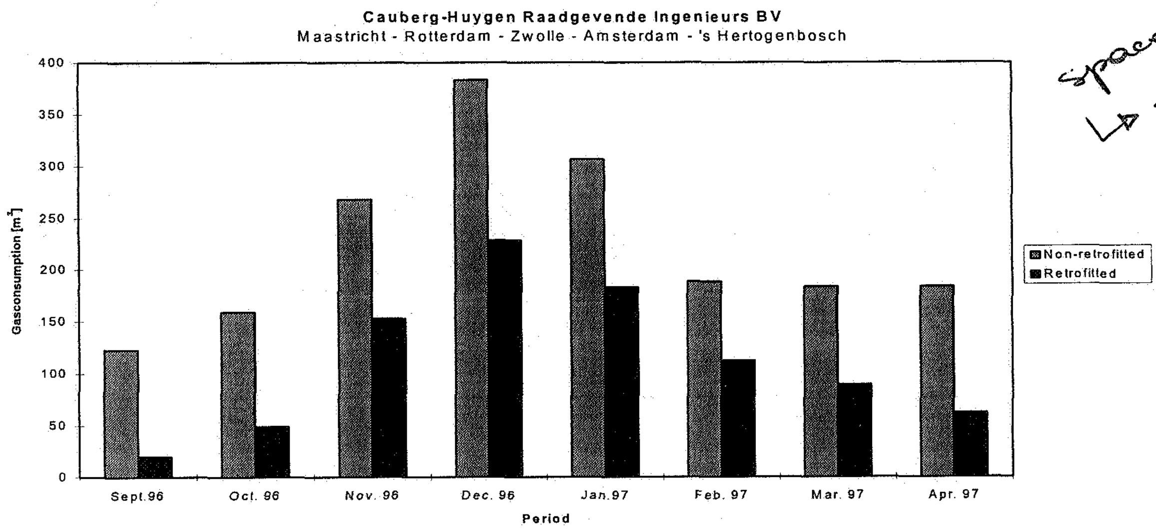

Figure 3 Gas consumption for space heating 120 retrofitted apartments (MFA) and 240 non-retrofitted apartments.

Also the electricity use of the MFA's (fans, pump, electronics) and the total electricity use (household) was monitored. Before renovation the electricity use for installations was 210 kWh/dwelling per year due to the central pumps of the heating system. The monitored electricity use of the MFA's during the first year was 850 kWh/year. This was 200 kWh more than the prognosis of 650 kWh. The total electricity use was 2783 kWh/dwelling which approaches the average electricity use for Dutch households (approximately 2900 kWh/year).

Energy performance of the appliances

The total energy performance of the installed multi-functional appliances is measured and evaluated under practice circumstances during 24 hours, an outdoor temperature of approximately 0° C and simulated habitants behaviour. This is done by real time measuring all input energy (gas and electricity, input air flow) and output energy (hot water and output air flow). Most energy flows are defined by their temperature, specific heat and mass flow. For the results of this measurements it cannot be claimed the same accuracy as measurements under laboratory circumstances. An energy balance for the complete period is based on the calculated energy transmissions.

The first conclusion of a total energy balance is that the total input energy is 13 % more than the total output energy. This is a common value for measurements under practice circumstances and is caused by electric losses (pump, valves and fans) and non-measurable radiation losses.

The net unit efficiency, defined as the useful output energy divided by the total input energy is 92,5 % while the gross unit efficiency, which is calculated without the electric input energy is 95,9 %. The efficiency for making domestic hot water is 81,7 %.

An indicator for the economic efficiency of the unit is the energy-index, defined as the total energy cost during one period divided by the total amount of output energy. For this unit the energy-index becomes DFL 20.50/ GJ (price level 1997).

Table 1: Input and output energy during measurement period

INPUT	Description	Value	Energy [MJ]	Cost [Dutch guilders]
Natural gas	total	4.41 m^3	155.1	2.65
Electricity	total	3.9 kWh	14.0	
	peripherals	2.3 kWh	8.3	
	net	1.6 kWh	5.7	0.40
		Total:	**160.8**	**3.05**

	Description	Value	Energy [MJ]
Water	space heating	7112 kg / ΔT = 3.2°C	95.1
	DHW	75 l / ΔT = 39°C	12.5
			107.7
Air	removal dwelling	fluctuating	-46.0
	supply dwelling	fluctuating	41.1
	fresh air	fluctuating	-12.3
	exhaust flue gases	fluctuating	47.0
			29.8
		Total:	**137.5**

Ventilation rates and Indoor Air Quality

The air tightness of the dwellings in which the ventilation measurements took place was measured according to the Dutch standard NEN 2686 "Airpermeability of buildings. Method of measurement". There are no differences in the building envelopes of the retrofitted apartments with a MFA and the non-retrofitted apartments with collective heating. The air leakage flow by a pressure difference of 10 Pa (NEN 2686) is 43 dm^3/s for the non-retrofitted apartments (n_{50} = 1.71) and 45 dm^3/s for the retrofitted apartments (n_{50} = 1.80). There is no significant difference in air tightness for the retrofitted and non-retrofitted apartments.

In the non-retrofitted apartments (natural supply and PSV) the average ventilation rates are 37.8 dm^3/s for the living room and 6.1 dm^3/s for the bedrooms. The continuous constant tracer gas measurements show very strong variations of air flows from 0 up to about 300 dm^3/s.

In the retrofitted apartments (balanced ventilation) the average ventilation rates are 15.3 dm^3/s for the living room and 9.4 dm^3/s for the bedrooms.

Table 2: Measured indoor air quality parameters and ventilation rates (PSV and MFA)

	non- retrofitted (natural supply + PSV)			**retrofitted (balanced ventilation by MFA)**			
	Living room	**kitchen**	**bedrooms**	**living room**	**kitchen**	**bedrooms**	**guidelines**
CO_2 (mg/m^3)	1863	2406	2621	1527	1610	1338	1800
CO (mg/m^3)	3.1	4.2	3.1	2.4	2.6	2.3	10 (8h)
TVOC ref. CH_4 (mg/m^3)	5.0	5.3	5.2	2.8	2.4	2.3	(3)
NO_2 ($\mu g/m^3$)		135			25		150 (24h)
Airflow const.tracergas method (dm^3/s)	37.8		6.1	15.3		9.4	-
Air flow PFT (dm^3/s)	31.3 (total dwelling, heating season)			55.1 (total dwelling, heating season)			-
RH (%)	34	36	36	40	42	41	30 - 70

Constant tracer gas measurements show that the air flows have much less variation and are rather constant in time. Although the average total air flow in the retrofitted apartments is smaller than in the non-retrofitted apartments the quality of ventilation is much better. Figure 4 shows that the ventilation pattern differs completely. In the non-retrofitted apartments the ventilation (and indoor air quality) is much more influenced by occupants behaviour and weather conditions. Occupants use more window airing and window ventilation causing great variations in air flows. Variations in air flows in the retrofitted apartments are mainly caused by occupants switching the fans (low/high) and the opening and closing of inner doors.

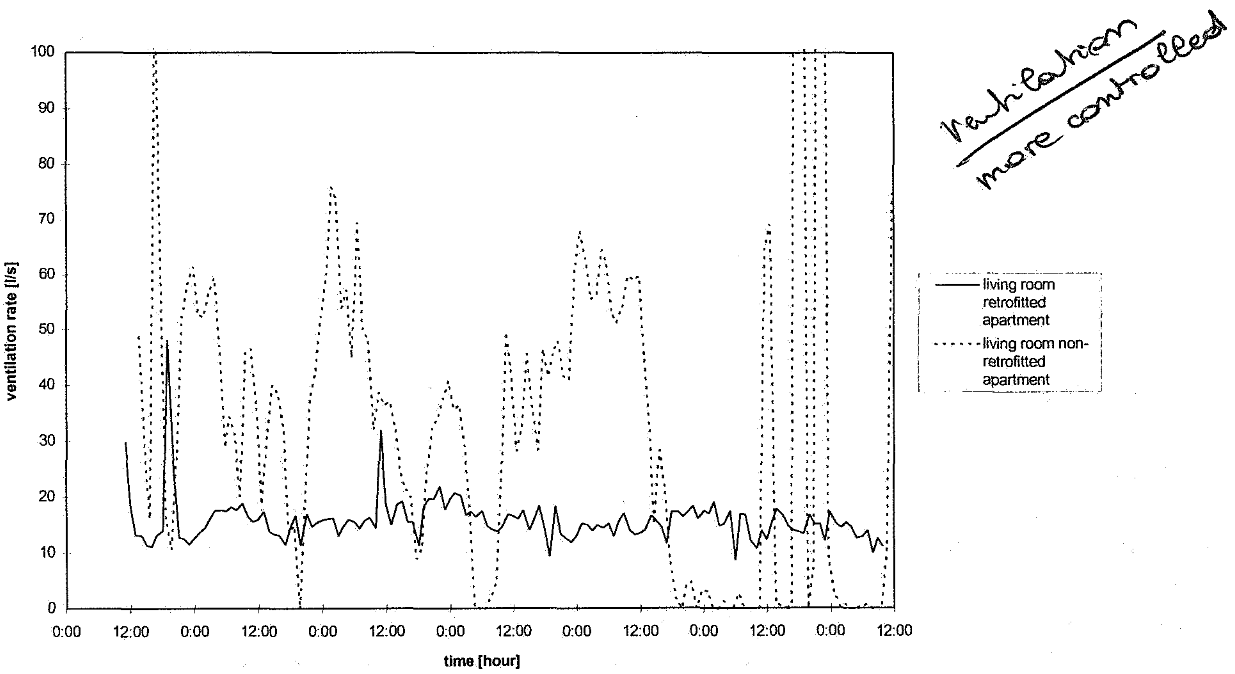

Figure 4. Ventilation rates (dm^3/s) living room in a non-retrofitted and retrofitted apartment

In the non-retrofitted apartments the average CO_2 concentration exceeds the hygienic guideline level of 1800 mg/m^3 . The average CO and NO_2 levels did not exceed the guideline levels. However, in one apartment a peak value occurred of 78 mg/m^3 during 15 minutes in the kitchen. This level means a serious health risk. The main reason for these levels and the peak values are the unvented hot water appliances in combination with the lack of possibilities for controlling the ventilation exhaust. In the retrofitted situation all measured concentrations of indoor air quality parameters show a significant decrease for average levels as well as for peak levels. Source removal and improved ventilation show results in better indoor air quality.
Figure 5 shows CO levels in a non-retrofitted kitchen with PSV and an unvented hot water appliance and a retrofitted kitchen with mechanical extraction.
The ventilation rates measured by PFT and constant tracer gas method will be further analysed and linked with the air tightness measurements and the occupants survey on the use of ventilation and airing provisions in IEA-Annex 27: "Evaluation and demonstration of domestic ventilation systems" (2).

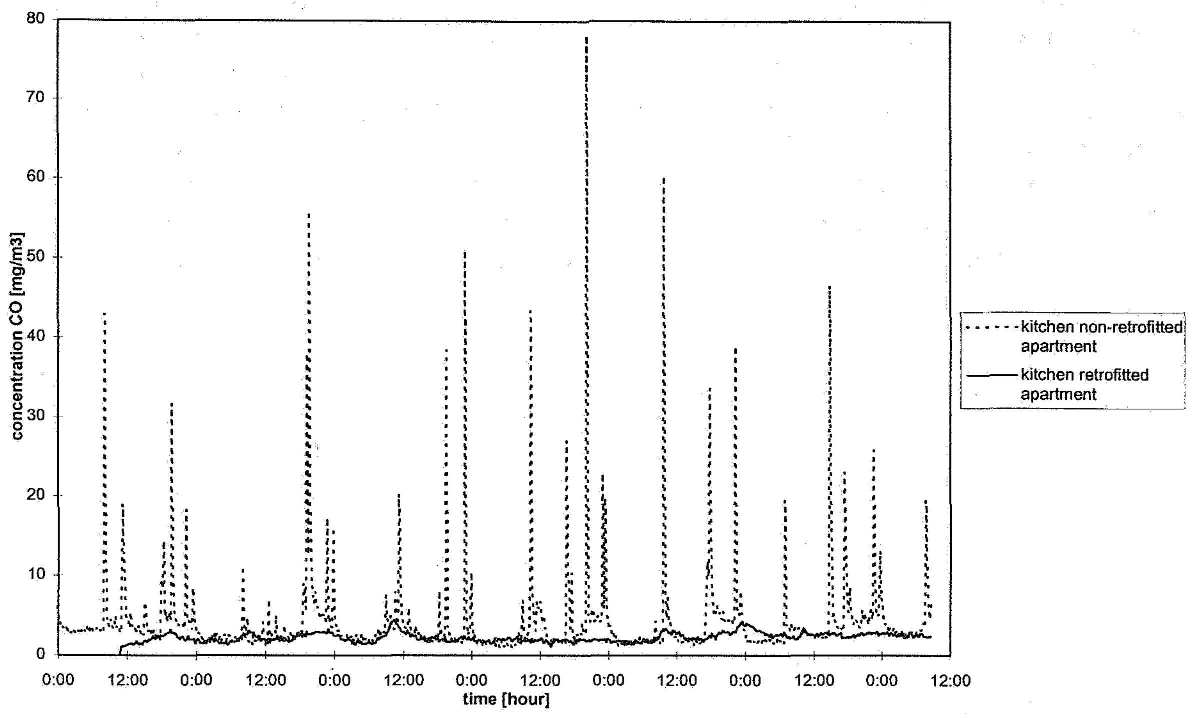

Figure 5. CO levels (mg/m^3) in a retrofitted and non-retrofitted kitchen

Occupants survey

The objective of the survey is to get general insight in the retrofitting as a process and the functioning and acceptance of the multi-functional appliances (MFA). For several reasons an oral survey was chosen. The response was 75 % out of 72 addresses.

Information and arguments provided by the housing corporation:

The housing corporation Heerlerbaan provided clear and understandable information. The arguments used such as individual temperature control, energy saving and improved ventilation were accepted by 75% of the occupants.

Appointments and realisation of the retrofitting:

Most appointments were carried out correctly. 20% Felt tied at home during the activities. Noise and dust caused inconvenience to 30 % of the occupants. A few damages due to the activities were reported; they were mostly repaired by the housing corporation. In some apartments earlier improvements made by the occupants, like an additional cooker hood in the kitchen, were removed with permission of the occupants.

Distribution of the costs:

There is no raise in rent or in service costs calculated for heating and ventilation investments done by the housing corporation. A small raise in rent, equal to the rent calculated by the local utilities (MEGA) for a similar DHW appliance, is made for the DHW system. This raise is accepted by 65%. After retrofitting occupants are now individual financial responsible for their energy consumption. The general opinion is that this is a more fair system than before.

Functioning and acceptance of the multi-functional appliances:

Based on the first the occupants appreciate the individual space heating system, the temperature control in different rooms and the increased fresh air rate in the bedroom. All occupants with more experience (a full winter season included) are very positive. A minority of the occupants has problems with the control of the MFA and low temperature level in the bathroom. The location and size of the radiators installed is judged positively. The MFA is installed in a cupboard in the hall. This solution means that this space is not available anymore for storage. This solution is reported as negative but necessary by most of the occupants. For this reason, additional storage capacity is installed by the housing corporation. The DHW system before retrofitting caused smell and very poor indoor air quality (NO_2, TVOC, CO). All occupants appreciate the comfort of the DHW system but the waiting time to get hot water is too long (a common problem with these kind of so called "combi-boilers"). Complaints of natural ventilation system before retrofitting concerned cooking smells and condensation. After retrofitting these complaints are far less and occupants report a significant increase of fresh air and improved indoor air quality. There is no univocal information on occupants with allergic sensitivities and their experiences. There are few negative reactions on the location of installed ducts. The size and finish of the ducts are reported positively. The fan is judged positively by most occupants. A few occupants report a great or, in contradiction, others a too small air capacity. Noise caused by the fan is reported by most occupants, especially at night. Half of the occupants wonder if the ventilator can be turned off for certain periods of time, for example at night and during the period of vacation or other absence. The general opinion is that the amount of draught has not changed; 15% of the occupants notice an increase in the amount of draught. This minority names several different rooms with draught, it is not clear where this draught is located exactly.

CONCLUSIONS

- During the demonstration between October 1996 and May 1997 no major occurred concerning the functioning and performance of the multi-functional appliances.
- Gas use for space heating decreased by 48 % compared to the adjacent similar blocks, only by retrofitting the heating system.
- Gas use for DHW increased. This problem is not inherent to MFA's but due to an increase in comfort of hot water supply in relation to small water heaters like unvented "geysers". As a result of this conclusion further experiments are going on in this project on measures to limit the hot water use without influencing the comfort.
- Although in retrofitted apartments average ventilation rates decreased, due to better control, the quality of the ventilation improved, resulting in better indoor air quality. Measurements of indoor air quality parameters show a significant decrease of concentrations CO, CO_2, NO_2 and TVOC.
- Electricity use of MFA's was about 130 kWh (20 %) higher than expected. In the next generation MFA's DC fans will be applied, decreasing electricity use with 50 %, and high efficiency heat recovery (laminar cross-flow heat exchangers) with an efficiency > 90 %.

ACKNOWLEDGEMENTS

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