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Preliminary results of the WHO Frankfurt housing intervention project

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ABSTRACT

Thermal insulation of buildings is widely recognized for its economic benefits due to decreased energy costs and since residences are major consumers of energy, it is also considered an appropriate tool for reducing greenhouse emissions and mitigating climate change. Yet, little information exists on the potential health effects of thermal insulation, which is often accompanied by a decrease of air exchange rates in air-tight and highly insulated buildings.

The WHO housing and health programme therefore implemented a health-monitoring project in cooperation with a large housing agency based in Germany. The project collected data in spring 2006 before renovation work, and re-contacted all households in spring 2007 after renovation was carried out. In parallel, a control group of dwellings without interventions was used to collect additional data to identify changes caused by building rehabilitation in the intervention group. The main objective was to assess the impact of thermal insulation changes on indoor environments, and evaluate potential effects on residents' health.

Drawing from 131 insulated and 104 non-insulated dwellings (with data for 220 and 155 residents, respectively), the project's preliminary results indicate that thermal insulation had a strongly positive impact on thermal conditions and thermal comfort as perceived by the residents, and decreased relative humidity in renovated dwellings. Results for direct effects on the occurrence of mould in renovated dwellings were weak, but indicated the major role of humidity levels and air exchange for adequate indoor climate. Direct associations of thermal insulation with health effects were also weak and limited to smaller prevalence differences of respiratory diseases and cold. Additional effects of the refurbishment were increased satisfaction and living conditions as perceived by residents, and a clear reduction of noise exposure.

In conclusion, the first results indicate that renovation activities and insulation are not in conflict with the health of residents and have the potential to improve health-related living conditions and thermal comfort if the rehabilitation work is done professionally and considers the need for adequate air exchange.

Keywords

CONTENTS

1. Introduction

Thermal insulation of buildings is widely recognized for its economic benefits due to decreased energy costs and since residences are major consumers of energy, it is also considered an appropriate tool for reducing greenhouse emissions and mitigating climate change. Yet little information exists on the potential health effects of thermal insulation, which is often accompanied by a decrease of air exchange rates in air-tight and highly insulated buildings.

The WHO Housing and Health Programme therefore implemented a health-monitoring project in cooperation with a housing agency based in Frankfurt, Germany that administers more than 50 000 dwellings in the city. The agency renovates over 1000 dwellings each year. The project aimed to assess potential health impacts of improved thermal insulation. Key objectives were to assess the impact of thermal insulation changes on indoor environments, and evaluate potential effects on residents' health.

The first wave of data collection was carried out in February and March 2006. Housing data was collected from 374 households and more than 600 residents were interviewed on related health effects during this period. A first report on the 2006 baseline study findings is available at (http://www.euro.who.int/Document/NOH/Frankfurt_proj_1stData.pdf). From 21 February to 18 March 2007, the second phase of the intervention study "Housing and Health" was conducted in Frankfurt. Of all households that had been visited in 2006, 235 were successfully recontacted.

**Figure 1. Overview of surveys and participating households by group**
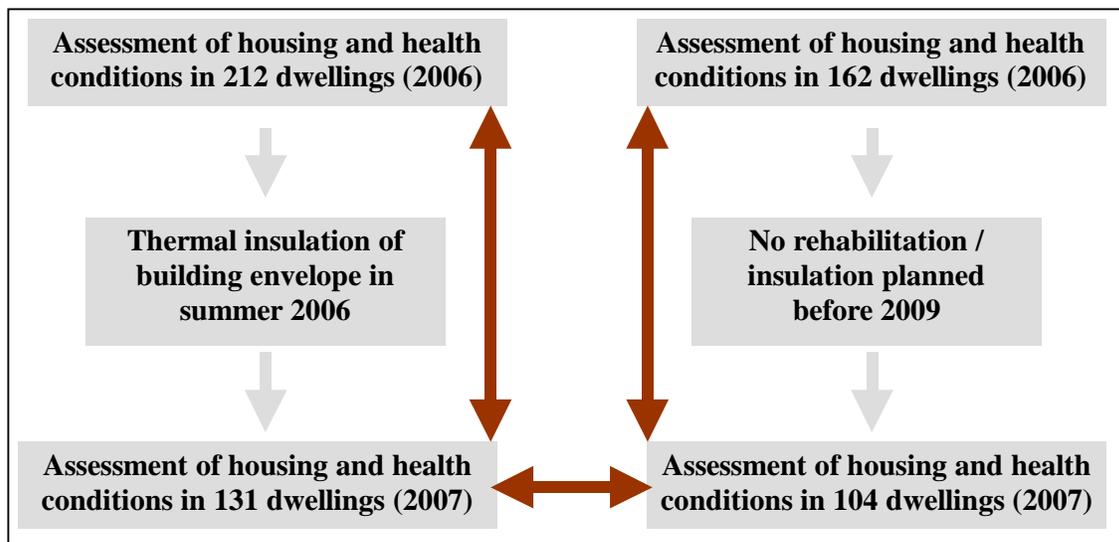
2. Participation and refusal rates

Of the 374 dwellings surveyed in the 2006 baseline study, 23 (6.1% of total sample) had to be excluded in 2007 as the residents had moved out during the past year. Of the remaining 351 households (the active sample), a total of 55 (15.7%) could not be reached during the survey, by either telephone or personal visits. Sixty-one households (17.4% of active sample) refused to participate in the follow-up study for various reasons, as follows:

- no interest in cooperation   40.0%
- not in good health   11.4%
- no time for interview   16.3%
- frustrated about housing company/refurbishment   11.4%
- on holiday   4.9%.

Thus, a total of 235 (62.8% of the total household sample, 66.9% of the active household sample) were interviewed.

Figure 2. Sample participation
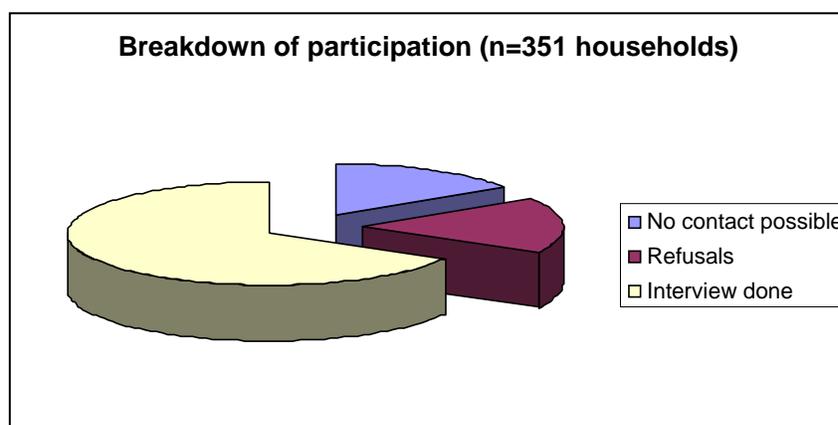
Of these 235 households, 391 of the 485 residents provided health information, compared to 610 people interviewed in 2006 (64% successfully recontacted).

For comparative analysis of information given in 2006 and 2007, the data sets of the individual residents and dwellings were checked for consistency. In case of wrong people filling out the health questionnaire in 2007 (who had not provided health data in 2006) or unexplainable differences of key characteristics (age, gender, size), individual health data sets were excluded. From the 391 surveyed residents, 375 matching cases were identified in the 235 dwellings.

The interviews were conducted by 10 interviewers working in five teams of two people, and included a visit to the dwelling, administration of a face-to-face questionnaire on the housing conditions, an inspection carried out by the survey team and the provision of self-administered health questionnaires for each resident who provided health data in 2006. Some basic exposure measurements on indoor temperature as well as wall temperature and humidity were taken by the interview teams in all dwellings. More detailed measurements on indoor temperature and relative humidity, volatile organic compounds (VOCs) and house dust were undertaken in dwellings in which those measurements had been applied the year before. In a total of 130 dwellings, a data logger was installed, which measured the temperature and relative humidity for six days,

compared to 189 dwellings in the 2006 baseline study. VOC measurements were undertaken in 38 dwellings, and dust samples were done in 105 dwellings. In addition, all residents that had volunteered in 2006 to participate in health measurements – peak flow meter (PFM) and NO measurements in exhaled air – were asked to repeat the same measurements, leading to collection of peak flow data for 271 people and NO for 123 people.

Table 1 below presents the overview of data collected in 2006 and 2007, and how many matching cases could be identified for both years. Due to survey team errors or health measurements of individuals who could not be found in the 2006 survey, the number of matched sets is somewhat reduced.

Table 1. Overview of baseline and follow-up survey data, and matched cases for analysis (valid measurements only)

2006	2007	Matched data sets
374 dwellings/households	235 (-37.2)	235
610 individuals	391 (-35.9%)	375
189 data logger measurements (RH and °C)	130 (-31.2%)	124
216 NO-measurements	122 (-43.5%)	117
442 PFM-measurements	267 (-39.6%)	263
38 VOC-measurements	24 (-42%)	22
170 dust samples	105 (-38.2%)	102

The analysis results presented in this document are based on the matched data sets, i.e. on exclusively those cases for which data was available for both 2006 and 2007.

3. Population characteristics

The surveyed population of the matched data set takes into account all those inhabitants who filled out health questionnaires in 2006 and 2007 (n=375) and relates to housing information from 235 dwellings. However, not all 375 residents answered every question, so the number of cases may still differ for various questions (same for housing data). The population surveyed ranged from 1 to 97 years of age, with an average of 46 years. Women are slightly more numerous in 2007 then in 2006 (55% of the sample in 2006, 58% in 2007). Therefore, the proportion of men has slightly decreased from 45% of the sample in 2006 to 42% in 2007. The population can be split up into three relevant age groups (fig. 3): children and teenagers up to 17 years old, adults (18 to 64 years old) and seniors (65 and above). Only 13% of the surveyed population were children and teenagers (2006, 13%), while 60% were adults younger than 65 years of age (2006, 64%) and 27% were seniors (2006, 23%).

Figure 3. Age groups
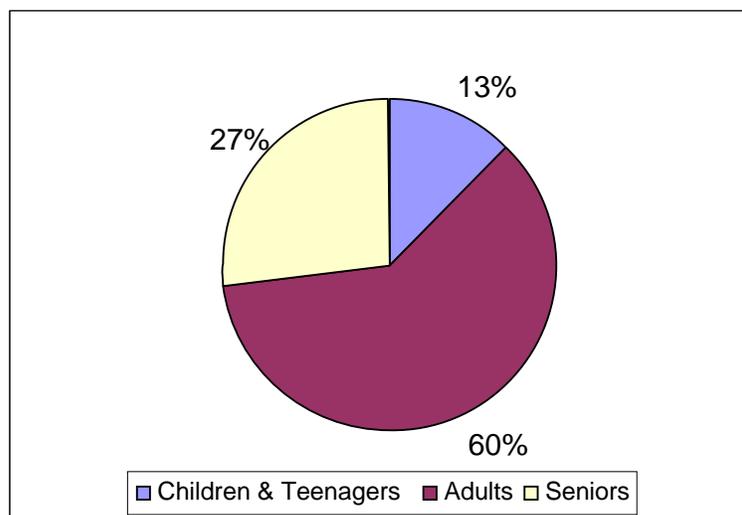
4. Dwelling characteristics and renovation measures

The buildings that were selected for the project are located in different neighbourhoods of Frankfurt and belong to the three administrative sections of the housing agency called service centres. The highest number of dwellings in the sample was in the Service Centre Nord area. In general, there is no relevant difference between the coverage of the three areas in relation to intervention and control groups.

Figure 4. Distribution by service centre areas
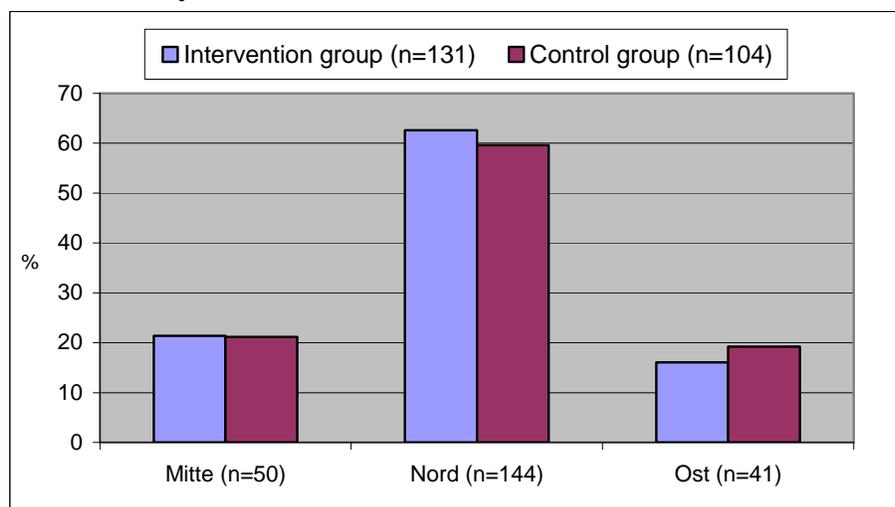
The selected buildings are all of a similar type (multifamily apartment buildings) but differ in age, size and height. Little variation is found in the coverage of dwellings by intervention or control groups. As Figure 5 shows, the main housing types either had up to six dwellings per staircase (usually two-storey buildings), or were larger buildings with four or more dwellings per floor over several floors.

Figure 5. Distribution of dwellings by building size
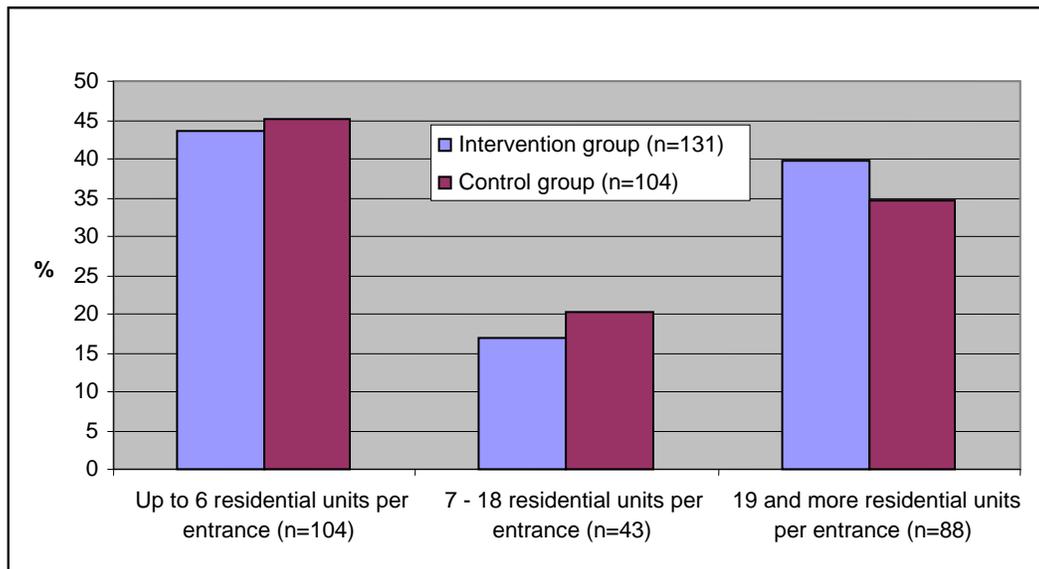
The distribution of floor levels shows that the majority of the households surveyed did not live higher than four floors up.

Figure 6. Distribution of dwellings by floor level
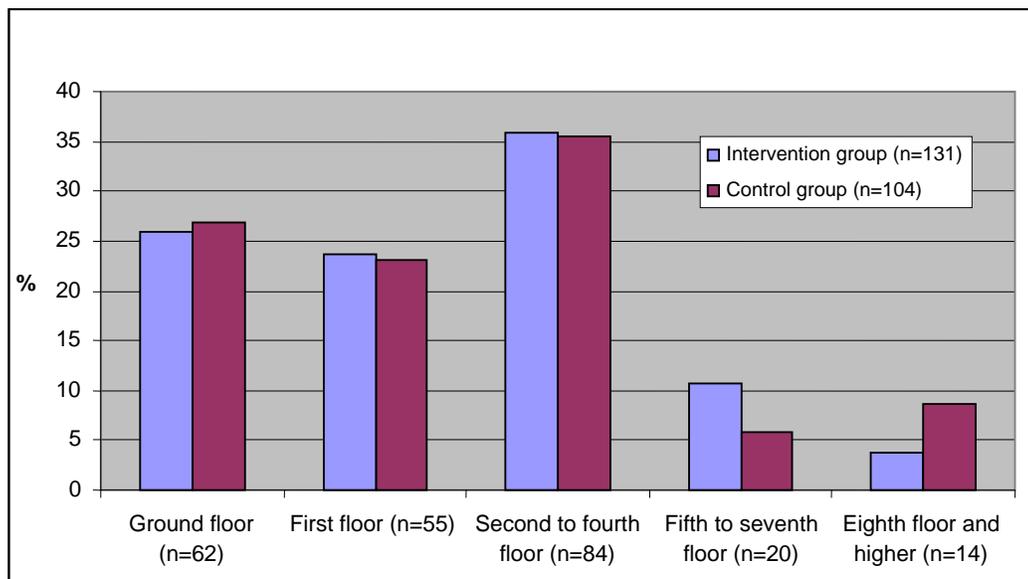
Finally, the traffic exposure was assessed. Figure 7 indicates that the renovated buildings were closer to trafficked roads than the control group buildings. This could be because the housing agency aims at renovating buildings on the outside line of neighbourhoods first, so that the outside appearance is improved and the maintenance action is visible to the public. In any case, this data needs to be considered when looking into the effect of noise exposure.

Figure 7. Distribution of dwellings by traffic exposure
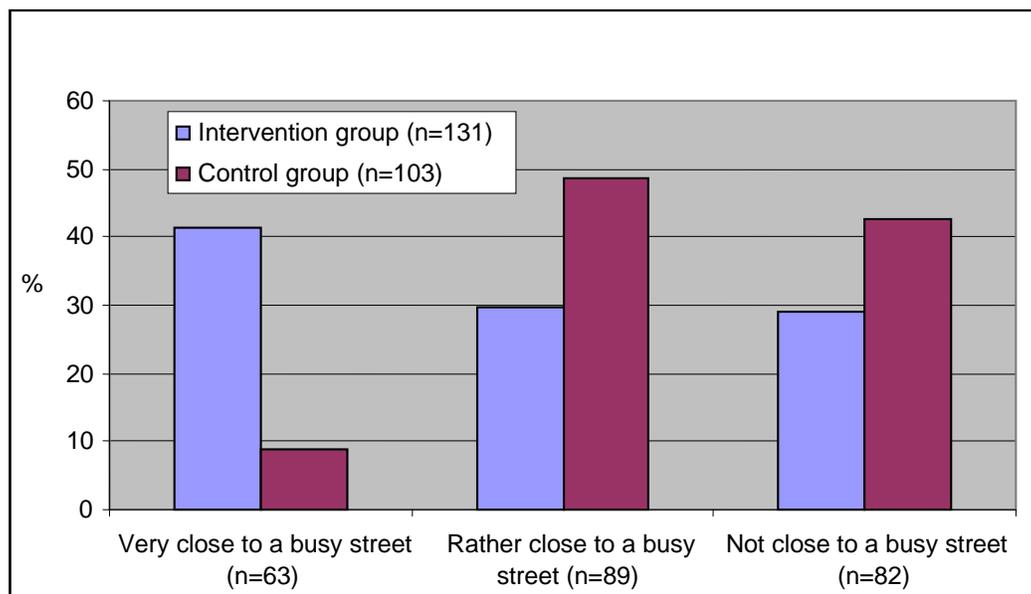
The local housing agency carried out the following refurbishment activities between the first and the second surveys:
- thermal insulation of all building facades
- thermal insulation of the roof/ceiling of highest dwelling
- thermal insulation of basement/floor of lowest dwelling
- installation of energy-efficient windows where replacements were necessary
- installation of new heating systems in buildings with substandard systems.

Table 2. Renovation activities

| Intervention	Intervention group (56%) of surveyed dwellings)	Control group* (44%) surveyed dwellings)
New windows in all rooms	29%	1.9%
New windows in some rooms	33.6%	3.8%
Change of heating system	32.1%	1%
Insulation of façade	86.3%	0%
Insulation of basement ceiling	**64.9%	0%
Insulation of building roof	**51.9%	0%
New dwelling door	18.3%	0%

*In some dwellings, the housing company made only necessary changes to obsolete components (windows, etc.).
**These results are affected by various households in the same building reporting that their roof had been repaired. In total, only 19.7% of all surveyed dwellings are located right under the roof.

The pictures below show two typical housing types which were part of the survey. The pictures to the left show the buildings before, the pictures to the right show them after rehabilitation.

Additional renovation projects without significance for thermal comfort were painting of staircases, installation of intercom systems, new power and water supply systems, improvement of outside spaces/greenery and other repairs as required. However, these renovations are not part of the survey and their impact will not be looked at, although they may improve the general quality of the dwelling significantly.

5. The challenge of "local climate change"

A word of caution is necessary at this stage, as the survey suffered from unfortunate weather conditions during the two data collection periods. In February–March 2006, when the baseline survey was undertaken, Frankfurt experienced uncommonly low temperatures. The average daytime outdoor temperature measured by survey teams was 4.3ºC, with a low of -2.4°C and a high of 13°C. Survey teams had to do their work during one week with piles of snow in the neighbourhoods and even some impact on the public transport system. During the survey in February–March 2007, there was no trace of winter at all. Over the three survey weeks, an average daytime outdoor temperature of 12.3°C was measured by survey teams, with a low of 5.2°C and a high of 27.1°C).

Therefore, it is important to bear in mind that these temperature differences during the field work may affect the results. All findings presented in the following pages have to be put into perspective, as the 2007 survey period was considerably milder than the 2006 period and this may devalue the impact of renovation work and thermal insulation. However, questions asking for assessments of thermal comfort, thermal insulation, satisfaction with heating system etc. were put in such a way that they covered the last three months (health questions) or referred to the winter in general. Thus, those assessments should represent the overall assessment for the whole winter period, which also includes the colder periods.

6. Overall expectations for and effects of refurbishment

Expectations

Before the housing interventions were undertaken, there were no differences between living conditions in dwellings of the intervention and control groups. The results of the baseline survey in 2006 showed that these comparable conditions were also reflected by the almost similar assessment of repair needs, which were seen as a priority by 51% and 52% of households in the control and intervention groups, respectively.

Figure 8. Assessment of need for repair by households
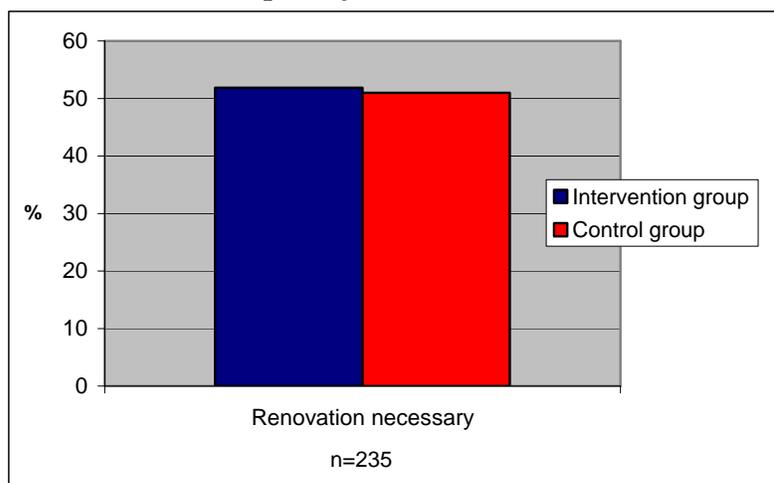
Still, the need for renovation is not evenly spread throughout the housing stock. It is obvious that households that had reported problems with cold had more urgent need of repairs and renovations than others.

Figure 9. Impact of problems with cold on perception of renovation need
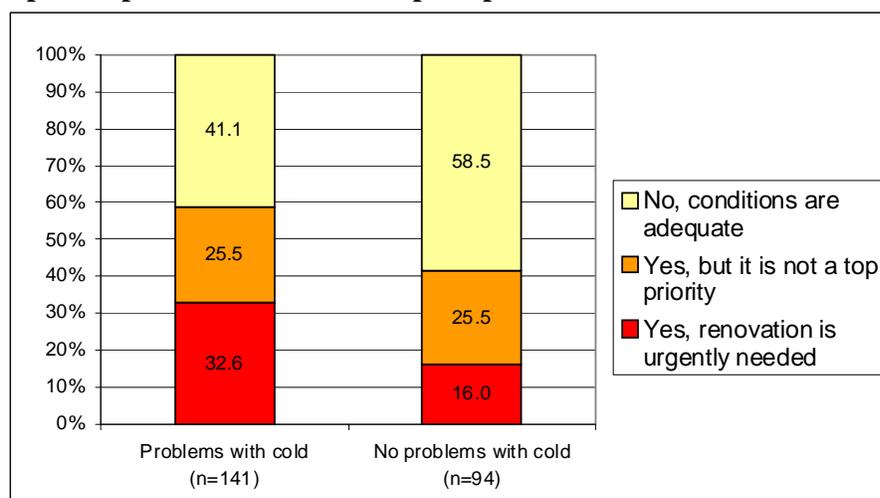
Half of households that considered renovation expected that it would lead to a significant reduction of heating costs. This is almost double the 27% and 28% of households that considered renovations not urgent or unnecessary. These data indicate that cold indoor temperatures are a

substantial factor for households in requesting renovations, which they think will lead to improvements.

General effects of renovations

In the follow-up survey after the renovation work, the residents of the renovated dwellings strongly considered the implemented interventions as changing their general living conditions (fig. 10) – this is partially due to the improved thermal insulation, but is also to other renovation measures in and around the buildings that are irrelevant to health consequences of thermal insulation.

Figure 10. Living condition changes by dwelling group
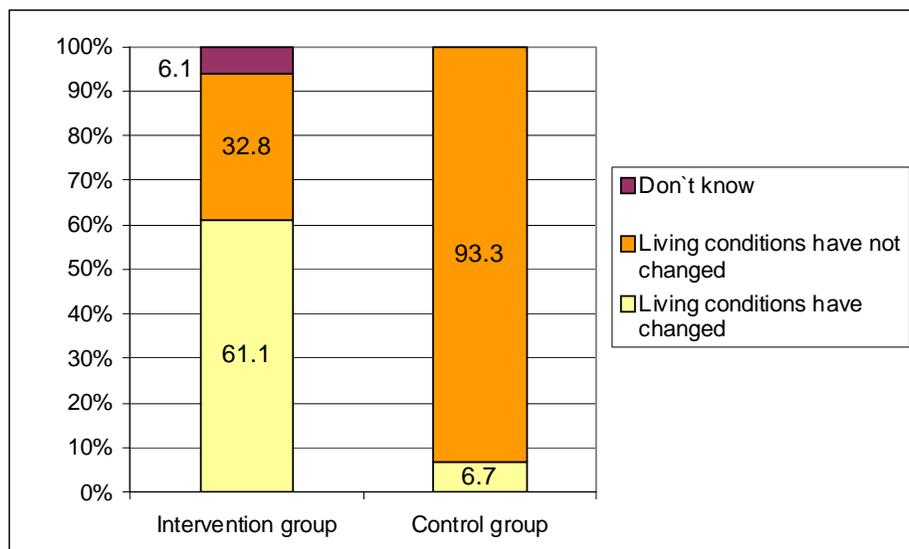
Still, despite the strong acknowledgment that the renovation work changed residential conditions, the residents' satisfaction with their dwelling changed little. In total, households in buildings designated for renovation were more dissatisfied with their living conditions than households in the control dwellings, but this pattern did not change after renovation: there was almost no increase in dwelling satisfaction for households in renovated buildings. More detailed analyses of the characteristics of these households and their complaints would be relevant.

**Figure 11. Dwelling satisfaction before and after housing renovation**
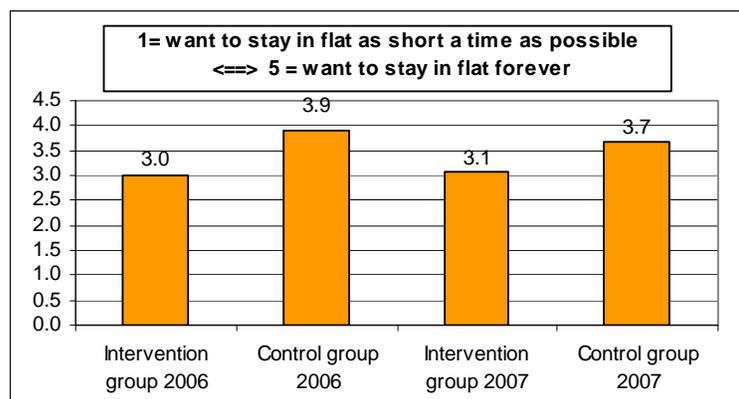
Specific effects of renovations

The thermal insulation was judged better than it had been in 2006 by 76% intervention group households, whereas 86% of control group members, as expected, reported no changes in satisfaction. However, this assessment may be moot, since the winter of 2007 was much warmer than that of 2006, and it is impossible to know the extent to which the weather, as opposed to the insulation, shaped opinions.

Figure 12. Evaluation of thermal insulation
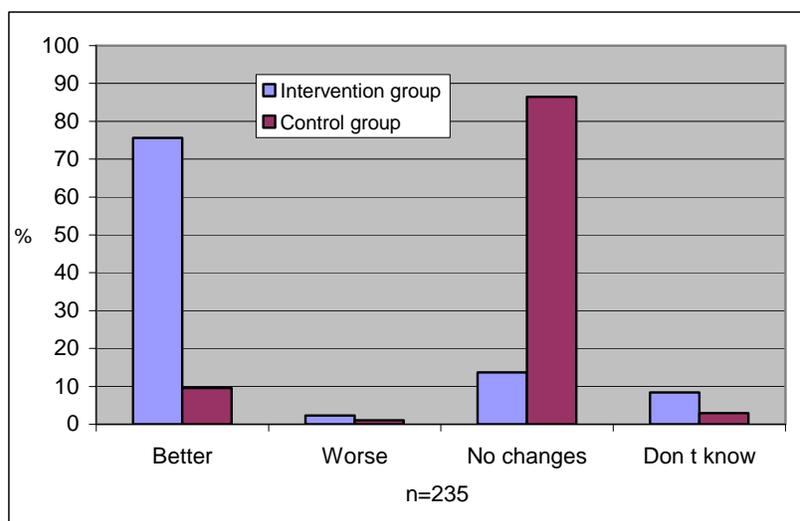
In the figure below, the ranking on a scale from 1 (very dissatisfied) to 5 (highly satisfied) shows that the majority of household representatives from the intervention group (77%) are satisfied with the thermal insulation; contrary to 30% of household representatives from the control group. Again, it is difficult to identify to what extent this assessment is based on the experience of cold in winter 2007, or the knowledge of having received thermal insulation.

Figure 13. Satisfaction with thermal insulation

Figure 14. Change in perception of cold
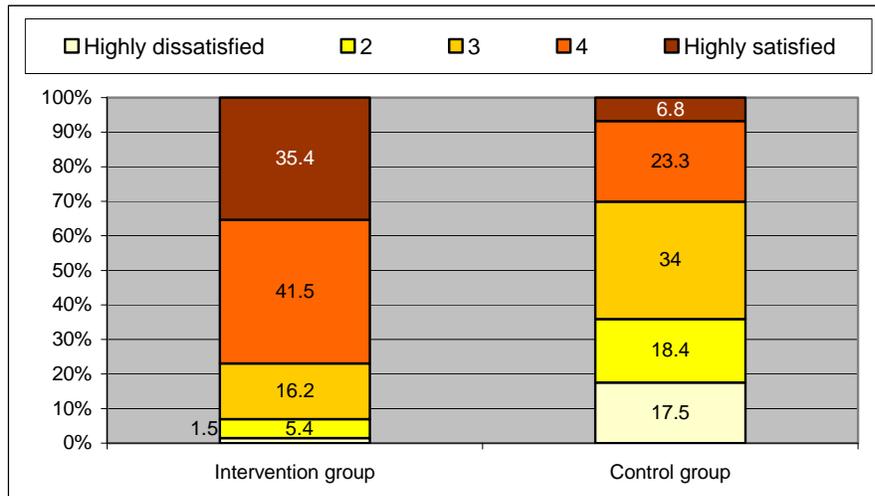
The results of the thermal insulation installation are clearly reflected by the figures below, showing that the perception of cold indoor temperatures in 2007 is much lower for intervention group dwellings than for control group dwellings (see figure 14).
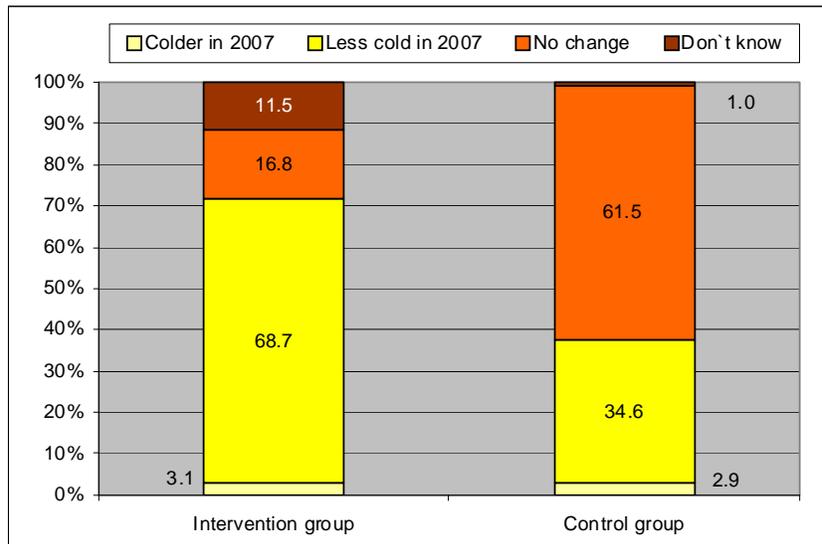
In 2006, 25% of all households stated that they had never felt cold during the previous winter, whereas 75% felt cold to different degrees. There are only minor differences between control and intervention dwellings, and in general all answer options except "permanent" perception of cold are strongly represented. The data for 2007, however, tell a different story. There are two main findings: first, there is a general trend towards decreased cold perception in both groups (consistent decline from "never" cold to "permanent" cold). It is most likely that this is due to the mild winter in 2007. Second, there is an additional decrease of cold perception for dwellings of the intervention group that seems to be independent of the general, temperature-related trend. The difference becomes especially visible in the extreme categories ("often" and "permanent").

Figure 15. Frequency of perceived cold in winter 2006
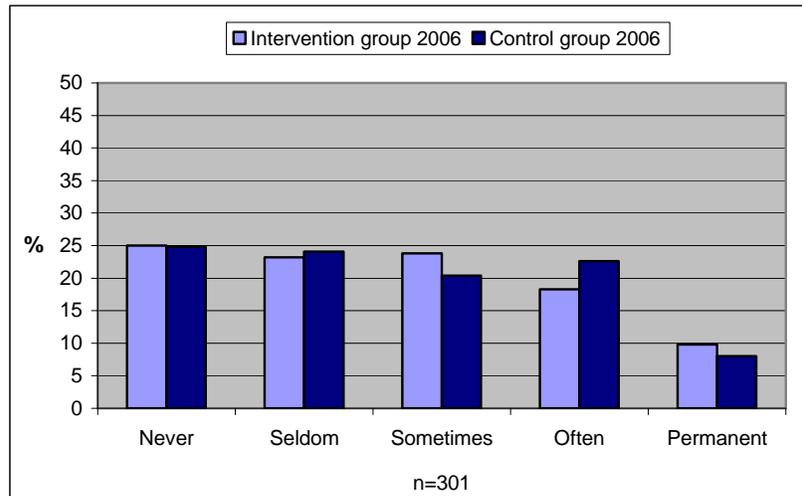
Figure 16. Frequency of perceived cold in winter 2007
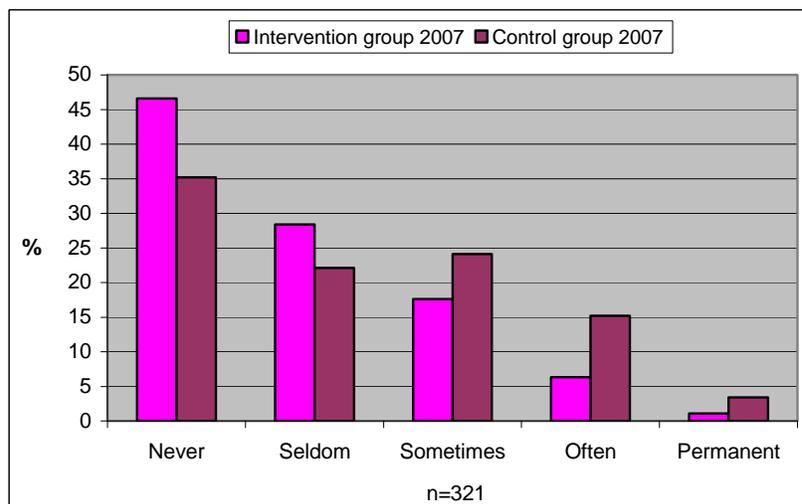
While there are marked differences for the perception of cold, less obvious results have been found for the occurrence of draughts, as well as for problems with humidity and mould. The figures below indicate that the findings may be somewhat conflicting – as in the case of draughts and mould, where intervention group households have reported both an increase and decrease of the problem that were higher than those of the control groups – or not really strong (e.g., dampness) (fig.s 17–19).

Figure 17. Problems with draughts

n=234
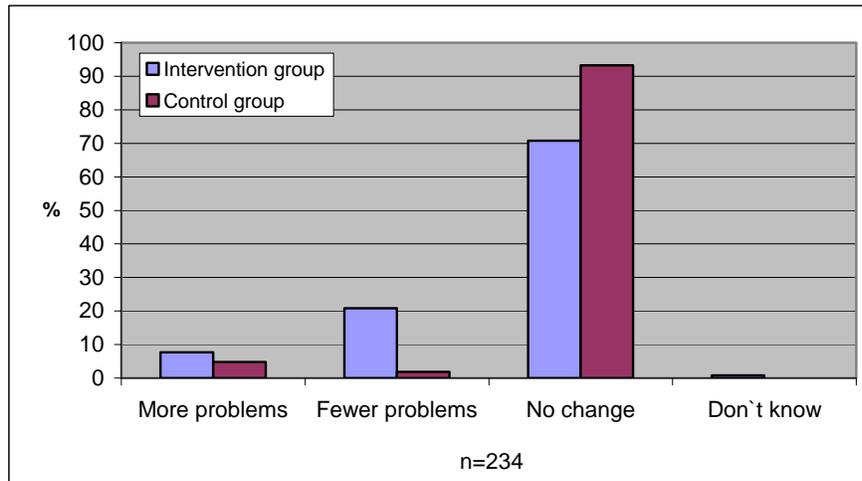
Figure 18. Problems with dampness or condensation

n=235
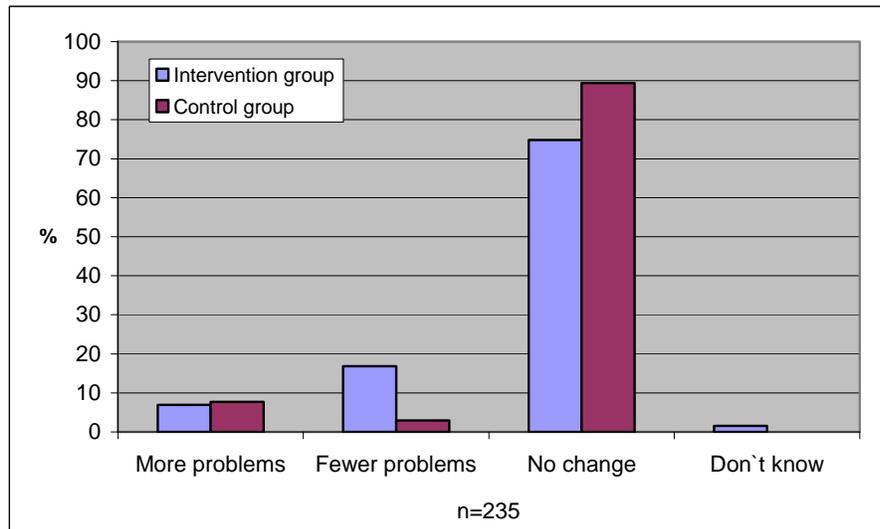
Figure 19. Problems with mould growth

n=235
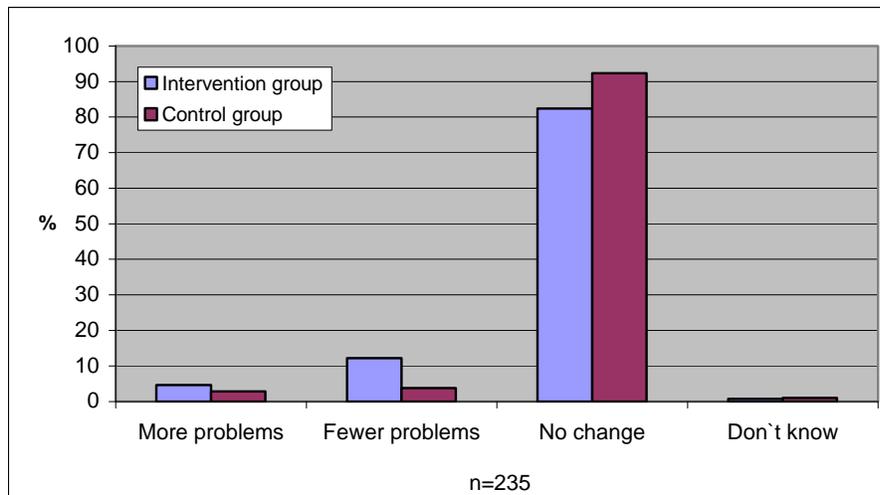
In conclusion, the effects of the intervention appear to be mostly limited to the perception of cold, unsurprisingly, since that is the most direct indicator of thermal comfort. The other aspects (draughts, dampness, mould) depend much less on the temperature and are affected by other factors to a much higher degree. In addition, they are harder to assess and – in the case of mould – may only lead to measurable changes after some time.

Ventilation changes

Specific attention was paid to ventilation behaviour as the most appropriate way to provide adequate air exchange for tight buildings after renovation. Significantly more households in intervention group dwellings reported that they had been informed on how to provide adequate ventilation (considered necessary in heavily insulated buildings) via windows. Still, the number is much lower than it should be and shows a large potential for improvement by the housing agency.

Figure 20. Information on adequate ventilation behaviour by group
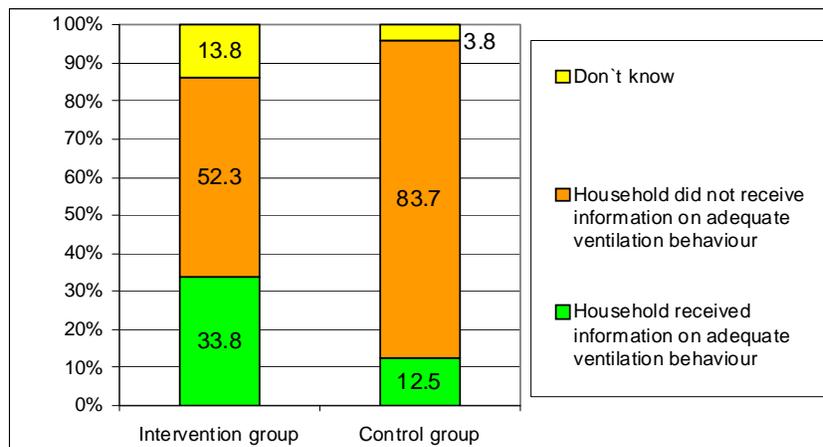
The least satisfying result is that the information on adequate ventilation behaviour is obviously not effecting any change: compared to the baseline survey before renovation work, there is very little change in ventilation behaviour by households that received the information, and it is only slightly better than for those households that did not receive the advice.

Figure 21. Ventilation behaviour by information provided
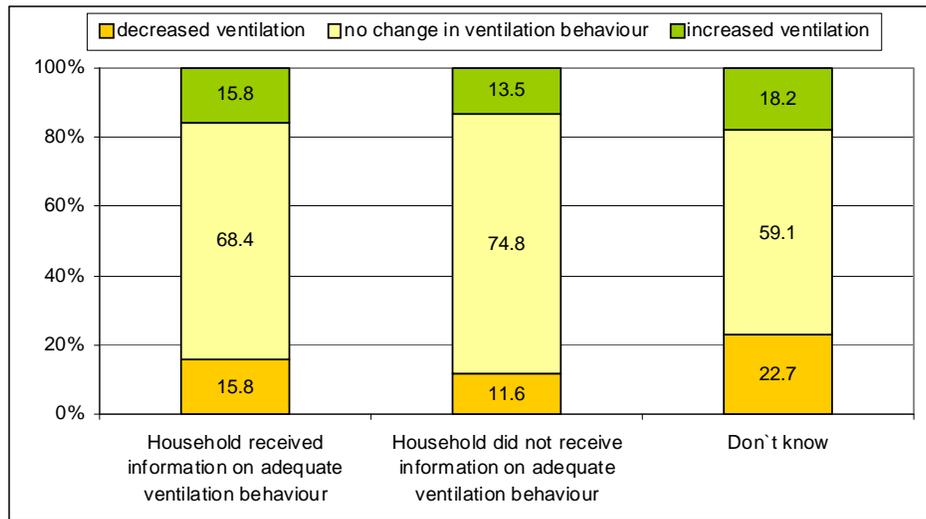
7. Noise

In 2006, 23.1% of the surveyed population reported frequent or permanent noise disturbance, with no difference between control and intervention groups. Residents who stated they were never disturbed by noise were slightly more numerous in the intervention group.

Figure 22. Reported noise disturbance in dwellings
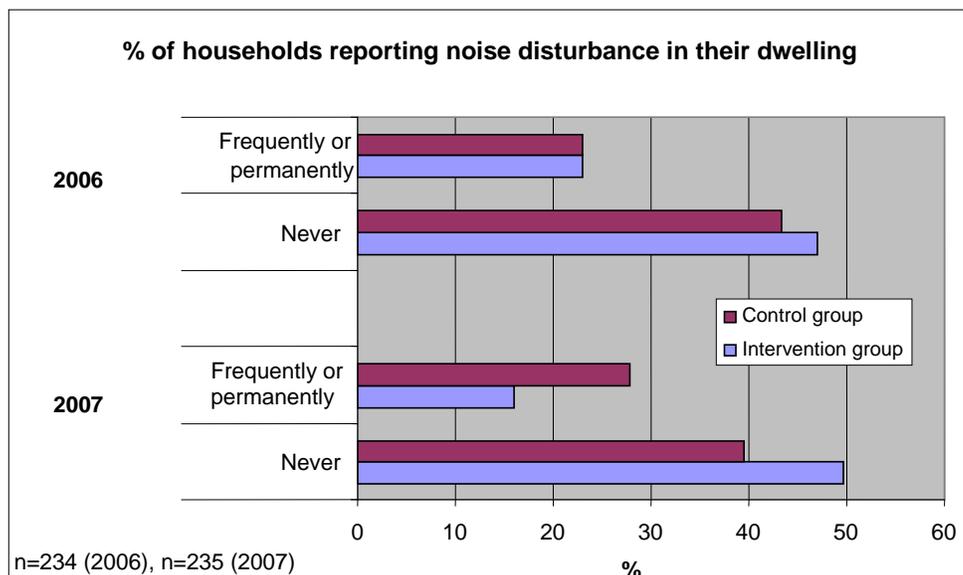
For 2007 the number of households stating that they are often or permanently disturbed by noise is considerably higher in the control group than in the intervention group. Corresponding to these findings, households where renovations had been done reported no disturbance at all by noise more often. Thus, the results suggest that thermal insulation may also have a positive effect on noise disturbance. More detailed analyses are required to confirm such a hypothesis.

Noise is perceived as a frequent disturbance by more than 20% of all surveyed households in both years, and is considered the reason for sleeping problems by around 20% of the residents as well – it remains to be analysed if the 20% are the same people. In any case, the data shows that before the renovation, more sleeping problems due to noise were reported by residents of intervention group dwellings, while after renovation more residents in the control group reported such problems. As intervention group dwellings tend to be closer to busy roads, this change may also indicate that reduction of noise exposure is a potential result of the renovation.

Figure 23. Sleep disturbance by noise during past four weeks, 2006
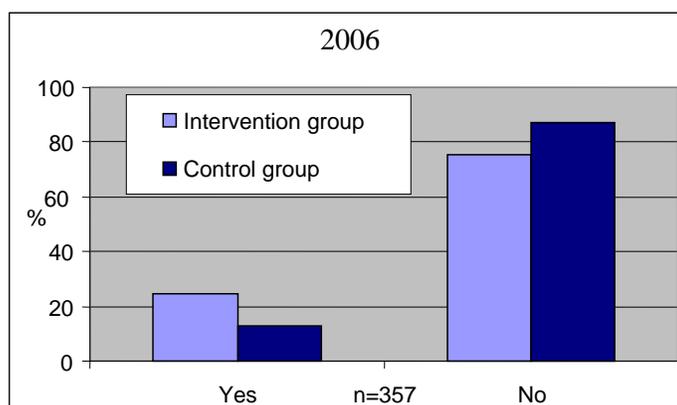
Figure 24. Sleep disturbance by noise during past four weeks, 2007
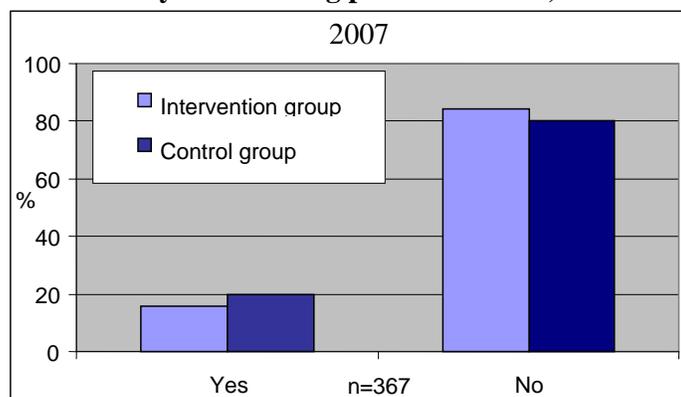
8. Temperature, humidity and comfort

In order to dig deeper into the issue of thermal comfort, the survey included an inspection of the sample dwellings that in many cases (n=128) could be combined with temperature and humidity measurements over a period of six days. Data were collected at five-minute intervals in one room (living room or equivalent) with a HOBO data logger. Fifty-seven per cent (73 dwellings) of the 128 dwellings were from the 2006 intervention group and the remaining 55 dwellings (43%) were from the control group.

Temperature

The collected data show a high proportion of dwellings with an average temperature below 21.5°C in 2006, with intervention group dwellings being slightly more often perceived as cold (fig. 25). In 2007 (fig. 26), the number of dwellings with an average temperature lower than 21.5°C decreased, but the strongest reduction took place in the intervention group.

Figure 25. Average dwelling temperature, 2006
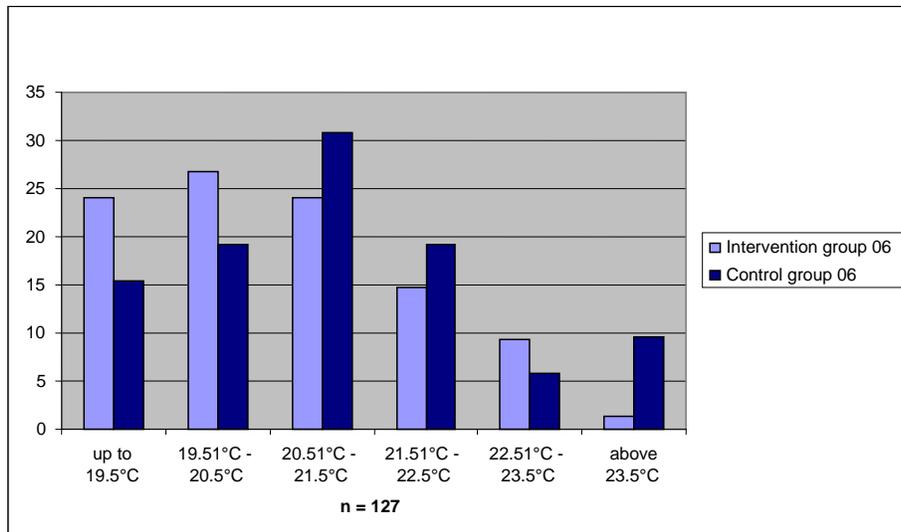
Figure 26. Average dwelling temperature, 2007
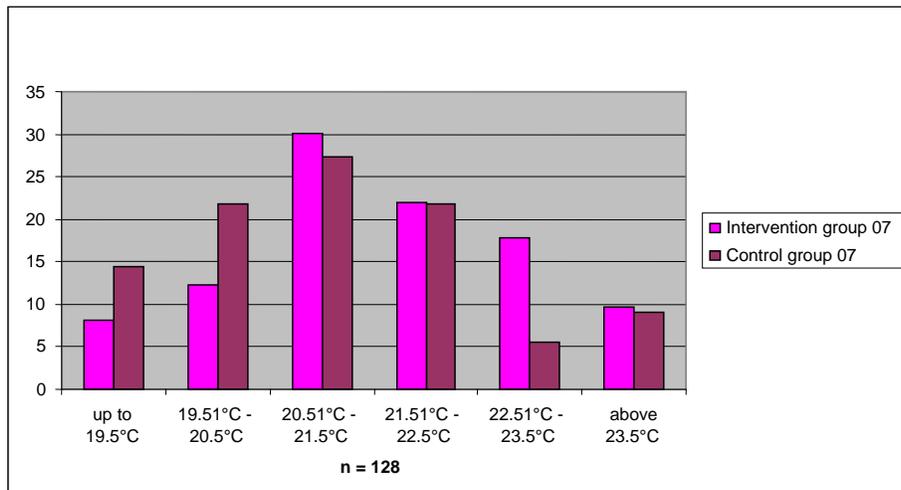
The relatively high temperatures of the winter in 2007 have to be taken into consideration when interpreting these measurements. To better assess the results, the data was used to calculate the change of temperature categories of each individual dwelling. The six temperature categories as shown above were used to identify dwellings that jumped up one or more categories, fell into lower categories or remained within the same category as in 2006. Although this approach does not show the level of indoor temperatures, it indicates the effect of changes between 2006 and 2007.

Figure 27 shows that there are marked differences between control and intervention dwellings: while 25% of the intervention dwellings increased by two or three categories, this is only the case for 5% of the control group dwellings. That the peak for control group is in the category "no change" while the peak for the intervention group is in "jump of one category" suggests that there is an additional effect of the renovation work on the measured and objective indoor temperatures, somewhere between one or two temperature categories, i.e. 1–2°C.

Figure 27. Change of average temperature in 2007
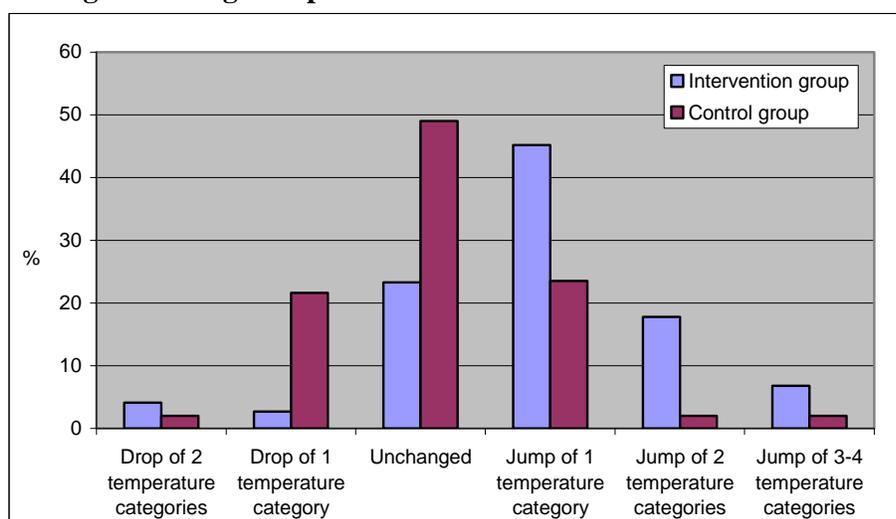
Using the median temperature instead of the average gives similar results. All dwellings were warmer in 2007, but this increase is almost three times stronger for the insulated dwellings (0.85°C increase versus 0.29°C increase for control group dwellings). Assuming that the 0.29°C of increase in control dwellings relates to the warmer climate in 2007, an increase of 0.56°C can be explained by the insulation campaign. It may be expected that during colder weather, when homes are heated more, the difference between the two groups could be significantly more than this half degree. Comparing the data by year shows that intervention dwellings were around 0.3°C colder than the control group dwellings before the intervention, but 0.3°C warmer after the intervention.

Table 3. Change of median temperature 2006–2007 (n=124)

	2006	**2007**	**Difference**
Intervention group	20.62	21.47	0.85
Control group	20.90	21.19	0.29
Difference	0.28	-0.28	

These findings correspond rather well with the perceived indoor temperature of the surveyed population. During the cold winter of 2006 almost the same proportion of control (57.7%) and intervention (61.8%) households reported low indoor temperatures. In 2007, 38.5% of the control group and 17.6% of intervention group did so (fig. 28). Such a high difference between dwellings with new thermal insulation and those without is presumably not only the result of

higher winter temperatures, which should affect both groups equally. Thus, the results indicate that there may be an independent effect of the insulation, apart from the milder weather.

Figure 28. Households reporting low indoor temperature
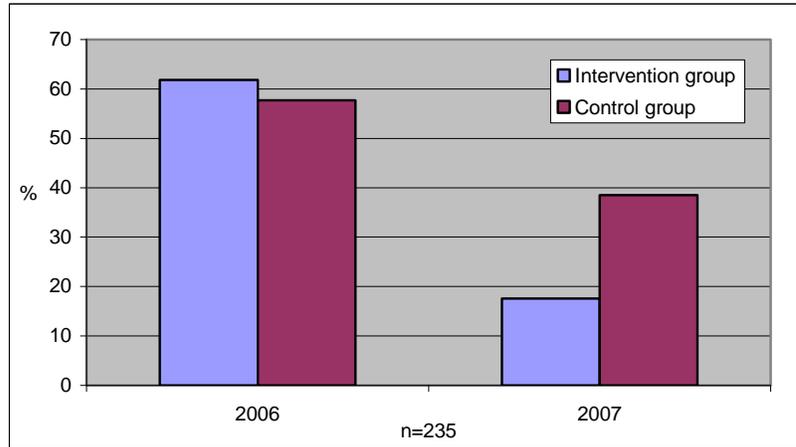
Quite a few dwellings actually became colder in 2007, despite the warmer weather and the reduced perception of cold in the households. As the figure below shows, the percentage of dwellings with reduced indoor temperatures is much lower in intervention dwellings, which may be explained by the better insulation. The fact that the indoor temperatures went down in the warmer spring of 2007 is difficult to explain. One reason could be that in spring 2006, the households were heated quite substantially due to the very cold weather, while in 2007 some households may have not used the heating system.

Figure 29. Change of median indoor temperature between 2006 and 2007
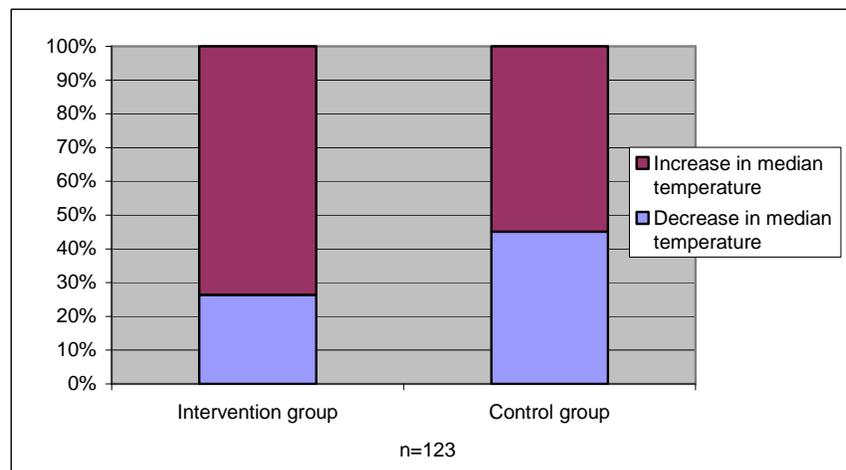
Humidity

Compared to the results on temperature, relative humidity levels in the surveyed dwellings do not show a very clear pattern. In 2007, for most of the dwellings the average relative humidity was measured in the range of 30–50%, with a trend towards increased humidity levels from 2006 (Fig.s 30, 31). This trend is probably related to the temperature difference, as relative humidity

tends to be inversely correlated to temperature. It is very difficult to derive a finding that would go beyond this general trend. However, the comparison shows that control group dwellings are more affected by increased relative humidity levels.

Figure 30. Average humidity in dwellings 2006
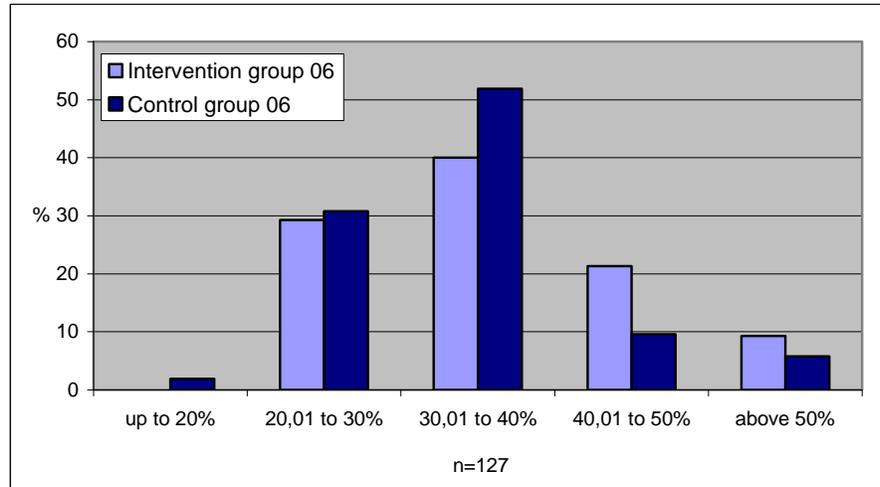
Figure 31. Average humidity in dwellings 2007
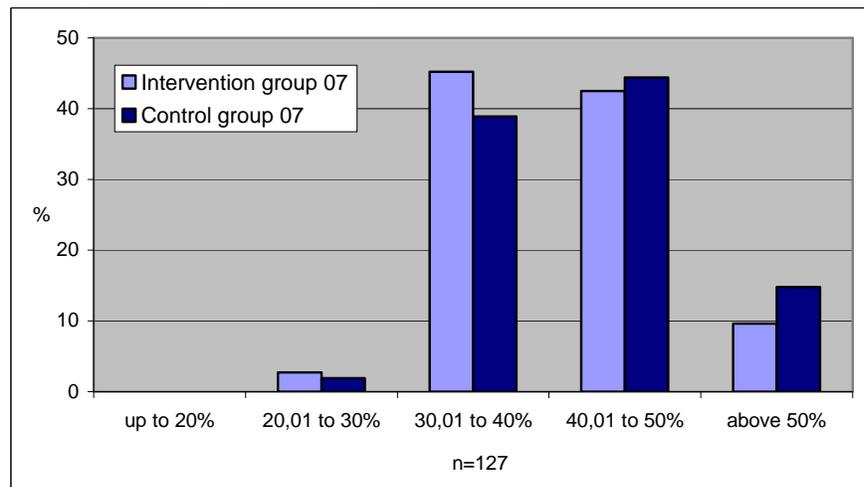
All other conditions being equal, relative humidity levels will be higher in colder dwellings (the control group) than in warmer dwellings (the intervention group). Therefore, the results could be attributed to renovation measurements directly, but seem rather to follow the indoor temperature.

The degree and direction of change in humidity categories were calculated as they were for temperature. The figure below also indicates that the differences between the groups are not as large within individual categories as they were for temperature. However, there is a clear trend of intervention group dwellings dropping or remaining in the same category, while control group dwellings more frequently show a jump. This suggests that the intervention may have had a positive impact on the reduction of dampness in indoor air, probably based on the higher temperature.

Figure 32. Change of average humidity levels
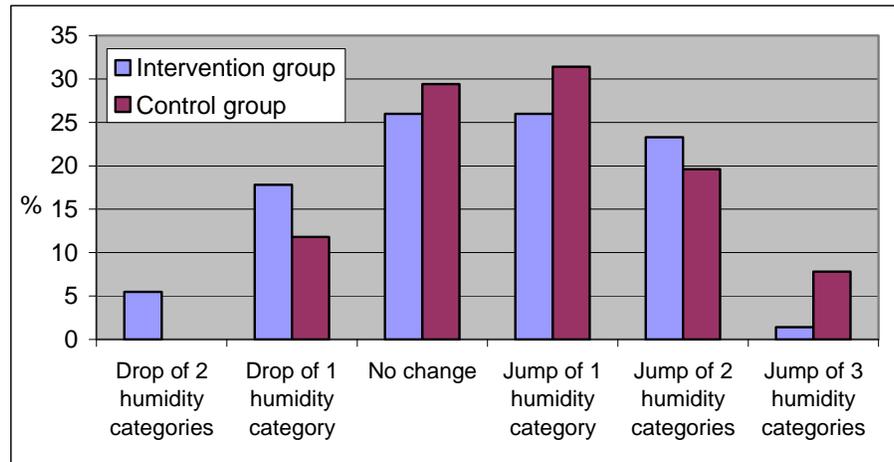
The results for median relative humidity also show an increase for both groups that is probably associated with the increased temperature/humidity levels of the outdoor air. The differences between the groups are marginal, but suggest that intervention dwellings had a slightly smaller increase in relative humidity (Table 4, Fig. 33). The results therefore are similar to the results for average values above.

Table 4. Differences of median relative humidity levels (n=124)

	2006	2007	Difference
Intervention group	34.56%	40.70%	6.14%
Control group	33.84%	41.18%	7.34%
Difference	-0.72%	0.48%	

Figure 33. Change in median relative humidity
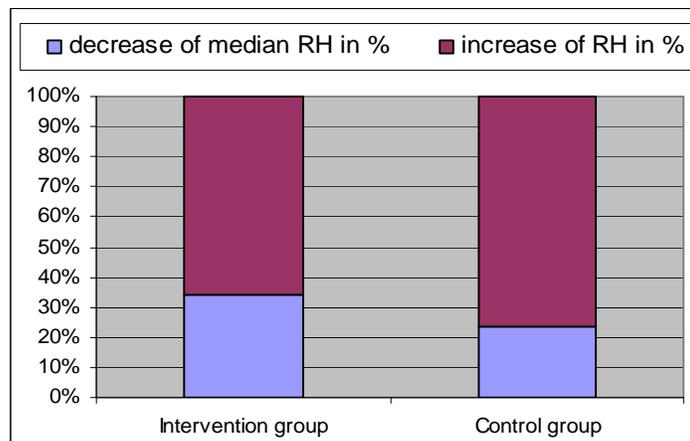
9. Wall temperature and humidity

Survey teams conducted measurements of living room and bedroom wall temperatures and humidity as part of the dwelling inspection. Bedrooms tend to be less heated, so climate changes may have a stronger impact. The number of measurements differs as they were only conducted when the head of the household agreed and the wall surface was accessible. In both rooms, the minimum and maximum temperature of one outside-facing wall and one internal wall were recorded. The humidity was measured at the coldest spot on these walls.

Wall temperature

The data show that the intervention dwellings were much warmer in 2007. For both rooms, the temperature difference between inside and outside facing walls was strongly reduced in intervention dwellings after thermal insulation as well (see Table 5). The warmer weather probably explains why the difference also decreased in control dwellings.

Table 5. Temperature change* on inside and outside facing walls in C°

	Living room walls			Bedroom walls		
	inside	outside	difference	inside	outside	difference
2006 Intervention	19.0	16.6	2.4	17.5	14.2	3.3
2007 Intervention	19.8	18.8	1	18.8	17.3	1.5
Difference	0.8	2.3	--	1.3	3.1	--
2006 Control	19.5	17.3	2.2	18.3	15.1	3.2
2007 Control	19.3	17.3	2	18	15.9	2.2
Difference	-0.2	0	--	-0.3	0.8	--
Increase by insulation	1	2.3		1.6	2.4	

*Temperature measured on the inside of these walls, measurement data given are means of the minimum temperatures

The intervention brought about an increase of 2.25°C in living rooms and 3.1°C in bedrooms on outside-facing walls that were insulated. In the control group, there was no change in outside wall temperature for living rooms, and an increase of 0.75°C for bedrooms, probably due to the warmer weather. If this temperature increase is subtracted from the increase of 3.1°C for the intervention group, there is still a 2.35°C increase due to the thermal insulation measures. Inside walls also benefited from the insulation, but obviously less so than outside walls.

By looking closer into the differences of outside-facing and internal living room walls, it can be observed that although the differences between inside and outside walls are much higher in 2006 than in 2007, there is little difference when comparing dwellings of the intervention and the control group in 2006. In 82.7% of all dwellings, the outside-facing wall of the living room is at least 1°C cooler than the living room inside wall, and there is a clear trend that the largest group of dwellings in both groups had a difference of more than 3°C.

Figure 34. Difference of outdoor and indoor wall temperatures in living rooms, 2006
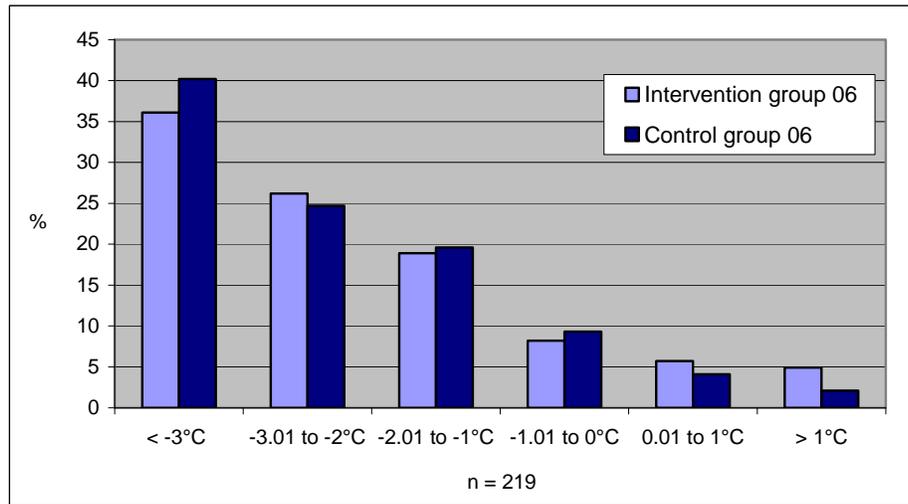
The results show that due to the warmer weather during in 2007, the differences between internal and outside-facing walls were less, with a normal distribution with most cases in the middle of the figure.

Figure 35. Difference of outdoor and indoor wall temperatures in living rooms, 2007
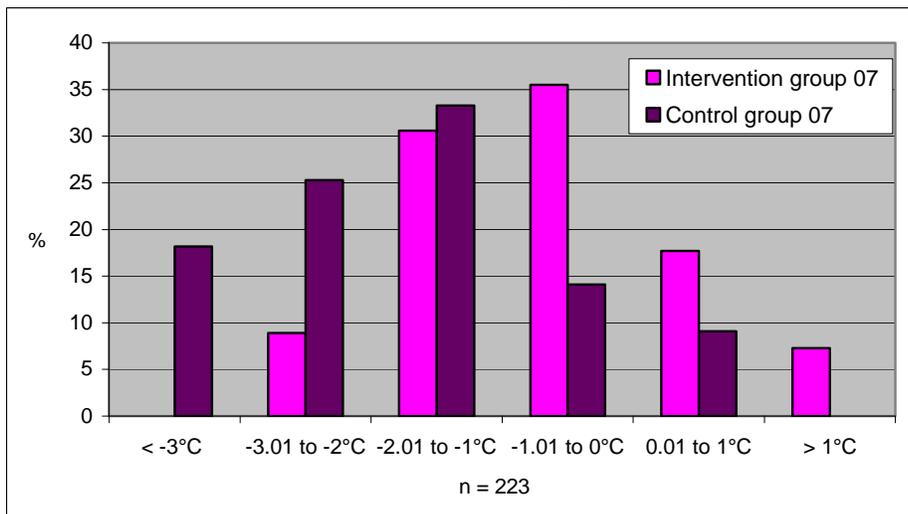
Chart 35 also shows that the proportion of dwellings of the control group is considerable higher in the groups of negative temperature differences above 1°C. Thus, despite the effects of a milder winter in 2007, an impact of the renovations on the wall temperatures is recognizable. Intervention group dwellings show a reduced temperature difference between the walls, which will lead to a perception of more comfortable indoor temperatures.

Corresponding patterns can be found by looking at average temperatures and differences of outside-facing and internal bedroom walls. However, the average temperature in bedrooms tends to be lower so that the pattern is repeated but also shifted to colder conditions. For example, in 2006 the proportion of dwellings with a temperature difference of more than 3°C between outside-facing and internal bedroom walls was at 48% compared to 38% in living rooms. In 2007, there were – despite the warmer weather – still 37% of all dwellings with a difference of at

least 2°C for bedrooms, while this was the case for only 25% of the living rooms. Still, the main result for bed rooms is that – similar to living rooms – the renovated dwellings seem to have a reduced temperature difference between the bedroom walls that cannot just be explained by the weather (fig.s 36, 37).

Figure 36. Difference of outdoor and indoor wall temperatures in bedrooms, 2006
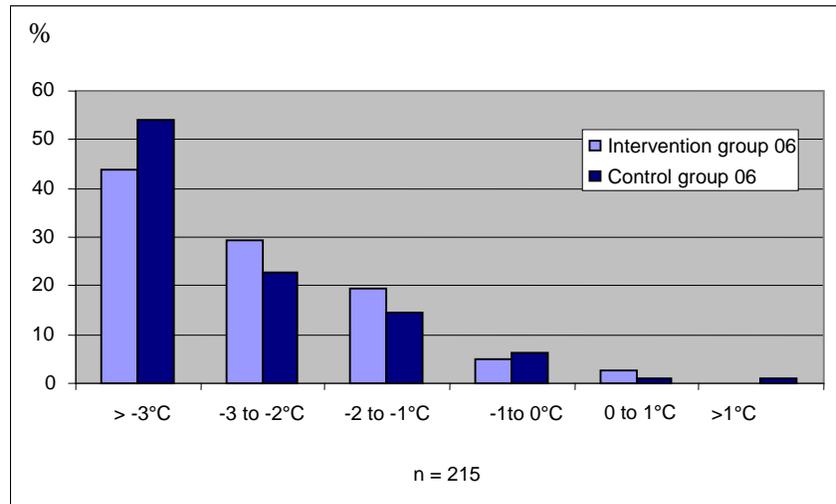

Figure 37. Difference between outside and inside wall temperature in bedrooms, 2007
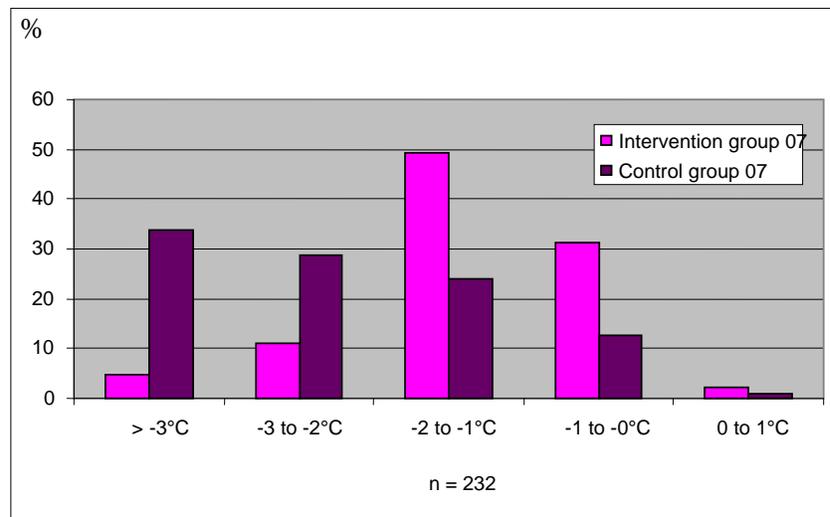
Wall humidity

As for the relative humidity measurements in the living rooms over a period of six days, the results for measured wall humidity are less strong. Still, it can be said that measurements of average wall humidity show a slight increase from 2006 to 2007.

Table 6. Average wall humidity

	Living room		Bed room	
	indoor wall	outdoor wall	indoor wall	outdoor wall
2006	0.31	0.38	0.33	0.43
2007	0.42	0.46	0.43	0.49

Wall humidity levels were classified into three groups. Walls with a humidity level of 0.0 to 0.6 are considered as dry wall, those from 0.7 to 0.9 are within a transition range and levels of 1 and above are defined as potentially humid walls. For outside-facing walls in living rooms, an increase of humid walls is identified for 2007 but no clear difference between control and intervention group can be detected. For internal walls, no wall was identified as potentially humid in 2006 or 2007 in either group (fig.s 38, 39).

**Figure 38. Humidity of outdoor living room walls, 2006**
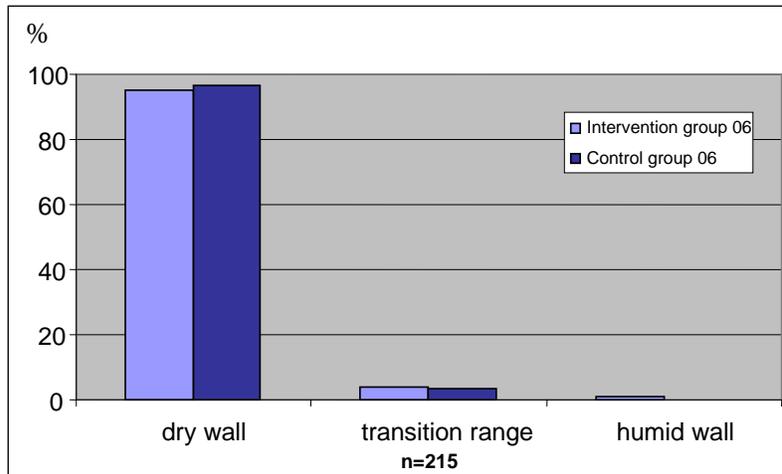
Figure 39. Humidity of outdoor living room walls, 2007
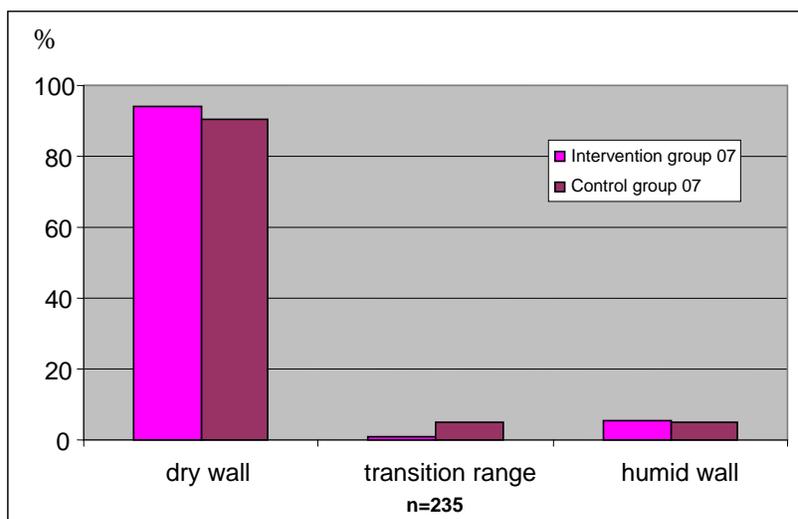
Thus, the humidity of the living room walls does not seem to provide any useful indicator to assess the effectiveness of thermal renovation as a damp and mould mitigation strategy under the given weather conditions, which are, of course subject to change.

For bedrooms, the results for outside walls show that in 2006, around 90% of all bedroom outside walls were categorized as dry, with no differences between the groups. In 2007, however, for all intervention group dwellings the bedroom outside walls were categorized as dry while around 8% of the respective walls in the control group were in the transition range (fig.s 40, 41). It therefore seems that the warmer weather lead to dry walls for insulated dwellings, but not necessarily for uninsulated dwellings. For inside bedroom walls, however, no relevant differences were found.

Figure 40. Humidity of outdoor bedroom wall, 2006
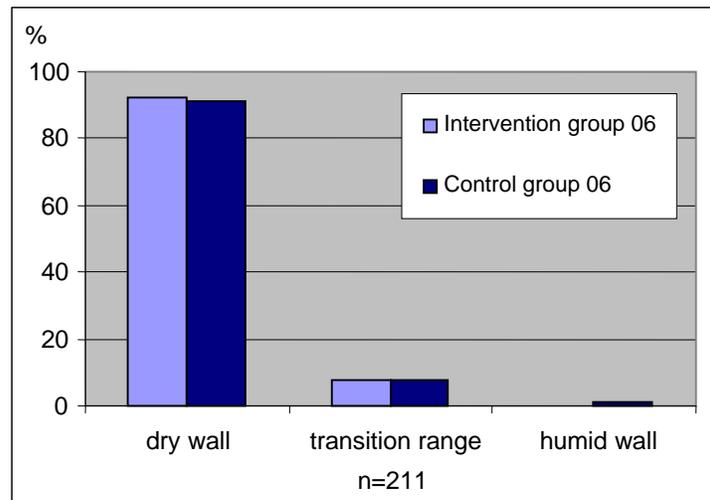
Figure 41. Humidity of outdoor bedroom wall, 2007
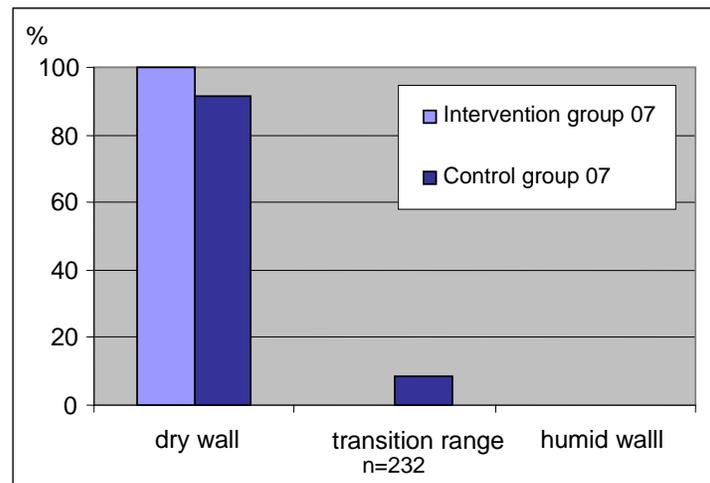
10. Temperature–humidity interaction

It is known that the relative humidity level of air follows the temperature, as air can absorb more vapour in warm conditions. The indoor temperature – as well as wall temperatures – therefore play a substantial role for dampness and condensation. The results for the interaction between temperature and relative humidity show different performances for the control and intervention group dwellings.

Figure 42. Median relative humidity in relation to median temperature, intervention group
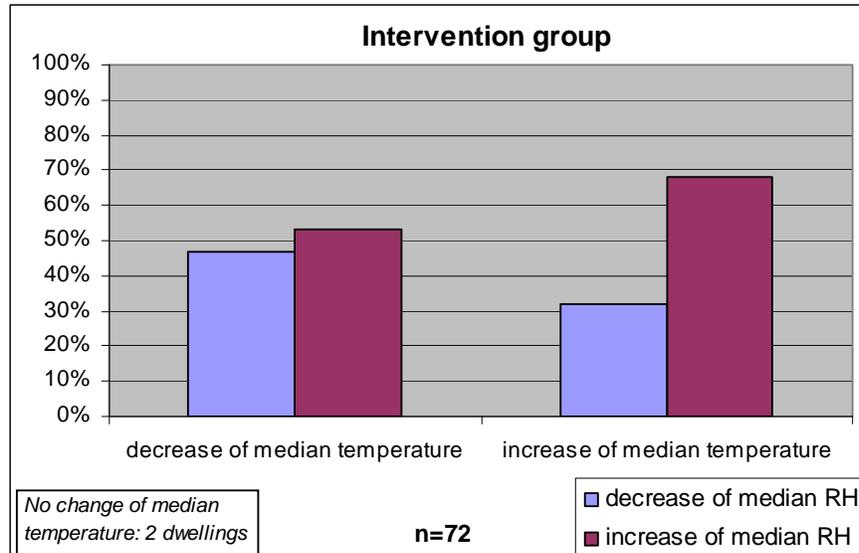
Figure 43. Median relative humidity in relation to median temperature, control group
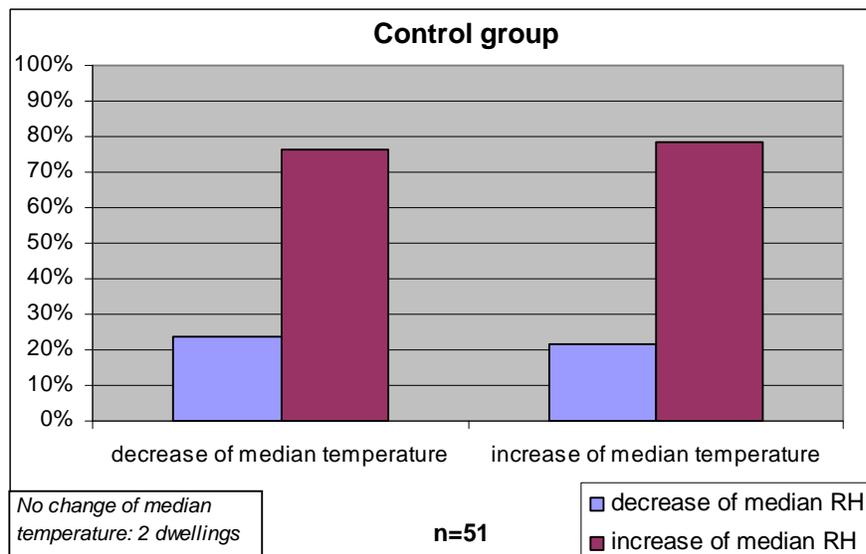
In the control group, there is always an increase of humidity irrespective of whether the indoor temperature goes up or down. In the intervention group, a decrease of indoor temperature in comparison to the year before the intervention does not have any effect on humidity levels, while an increase of humidity is observed in dwellings with higher temperature than in the year before.

It is difficult to provide a reason for this; the increased temperature could be considered an indicator of a lack of ventilation, which then may explain the increased humidity. A full overview of the results of the measurements is provided below.

Table 7. Overview of the results of the measurements

| All dwellings	lower median RH	higher median RH
Lower median temperature	33.3%	66.7%
Higher median temperature	28.4%	71.6%
Lower temperature	lower median RH	higher median RH
Intervention group	47.1%	52.9%
Control group	32.1%	67.9%
Higher temperature	lower median RH	higher median RH
Intervention group	23.8%	76.2%
Control group	21.4%	78.6%

Temperature, relative humidity and visible mould

The data suggest that the intervention has had little impact on visible mould. It could be that no large impact would result from the interventions; it could be that it takes a longer time for effects to occur (the follow-up study was undertaken a few months after the interventions), and it could be that the weather differences between the 2006 and 2007 surveys affected the results negatively. However, from the data itself it is only possible to state that more than 80% of the surveyed dwellings did not show a change in mould status, and such changes as did occur were decreases of mould rather than increases. Nevertheless, the rate of decreasing mould is higher for intervention group dwellings.

Figure 44. Change of mould occurrence
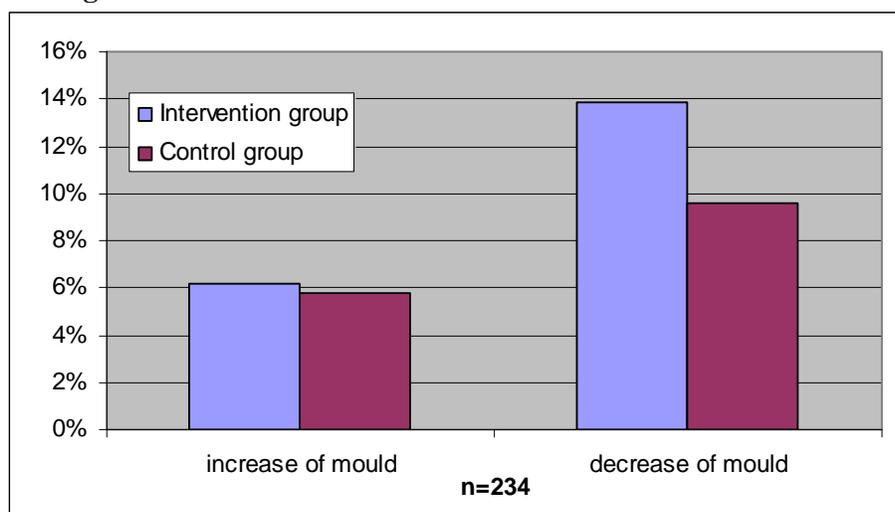
More detailed analyses are difficult as the number of dwellings with sufficient data is low – especially for the dwellings with lower temperature – and does not allow drawing valid conclusions. However, it is interesting to note the differences between the groups and the fact

that despite decreasing temperatures, none of the control dwellings had higher mould levels (Table 8). It can be assumed that ventilation and air exchange may play a role as there is no clear pattern to identify in the data.

Table 8. Change of median temperature and mould

Change in median temperature	less mould	no change	more mould
Lower median temperature	7.9%	89.5%	2.6%
Higher median temperature	11.3%	81.3%	7.5%
by dwelling group			
Lower median temperature	less mould	no change	more mould
Intervention group (n=17)	11.8%	82.4%	5.9%
Control group (n=21)	4.8%	95.2%	0.0%
Higher median temperature	less mould	no change	more mould
Intervention group (n=52)	9.6%	82.7%	7.7%
Control group (n=28)	14.3%	78.6%	7.1%

Although the temperature is important for the occurrence of mould, the key factor is the presence of moisture. Therefore, the impact of humidity levels on mould was analysed similarly to temperature. The results below suggest that an increase in humidity may be associated with both an increase and decrease in mould (suggesting that other factors in the dwelling may be decisive), while for the decrease of humidity levels, there is a clear result showing a reduction in visible mould.

Figure 45. Mould occurrence and change of median relative humidity
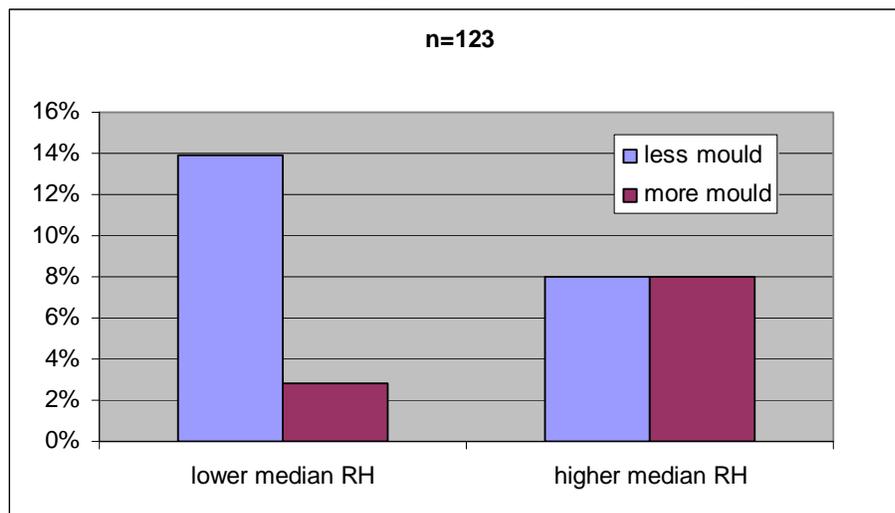
It is noteworthy that higher humidity leads to a strong increase in mould in the intervention dwellings, while this is not the case for control dwellings. Likewise, lower humidity is associated with a strong reduction in visible mould that is not apparent in control dwellings (Table 9). The results could thus be interpreted to mean that irrespective of the cause of humidity, well-insulated dwellings may react more sensitively to humidity changes than less well-insulated dwellings, and that mould can be a frequent consequence when humidity rises in well-insulated buildings.

Table 9. Relation of change of median RH and mould

	less mould	no change	more mould
Lower RH	13.9%	83.3%	2.8%
Higher RH	8.0%	83.9%	8.0%
by dwelling group			
Lower RH	less mould	no change	more mould
Intervention group (n=24)	16.7%	83.3%	0.0%
Control group (n=12)	8.3%	83.3%	8.3%
Higher RH	less mould	no change	more mould
Intervention group (n=48)	6.3%	81.3%	12.5%
Control group (n=39)	10.3%	87.2%	2.6%

Hygrothermal categories

Four hygrothermal categories were developed for considering the effects of heat and humidity. Almost half of all dwellings for which measured data were available belong to the group with both rising temperatures and humidity levels. However, there are some differences between the dwelling groups: while 23.6% of the intervention dwellings showed higher indoor temperatures with lower humidity, this was true of only 11.8% of control dwellings. Likewise, the percentage of higher humidity with lower indoor temperatures was much higher in control dwellings (33.3%) than in intervention dwellings (15.3%).

Figure 46. Hydrothermal categories by dwelling group
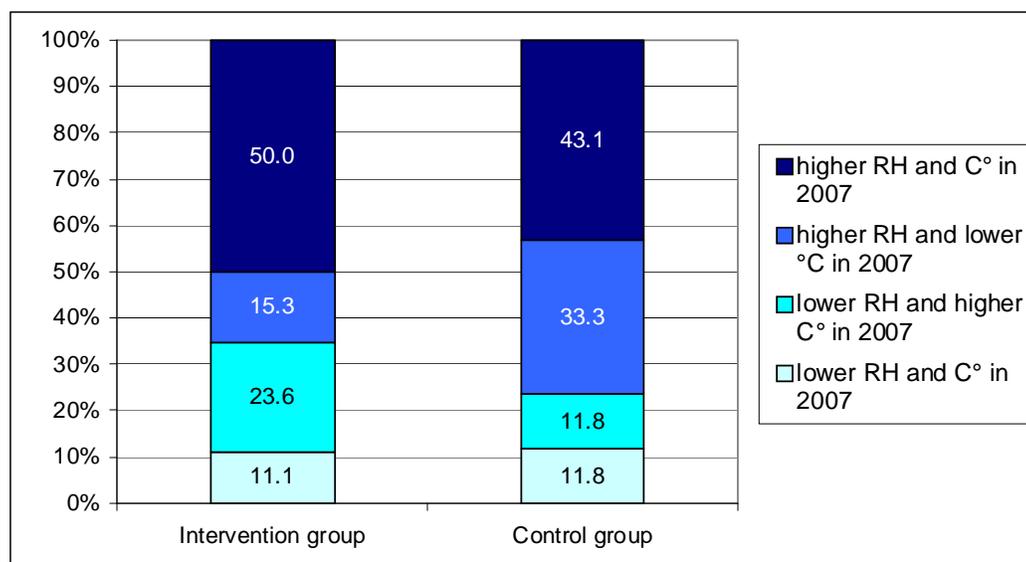
As a next step, the hygrothermal categories were looked at for their relation to mould occurrence. As the figure below shows, the variation is not that high but it is obvious that only dwellings with reduced humidity and temperature levels did not show any increase of mould, and had the strongest decreases. The highest increase of mould was found for dwellings that were warmer

and more humid in 2007. The results of Figure 47 are striking, as reduced temperatures are considered a risk factor for condensation and mould growth, but they can also indicate that the moisture balance is more relevant for damp and mould occurrence than the indoor temperature.

Figure 47. Hygrothermal categories and mould
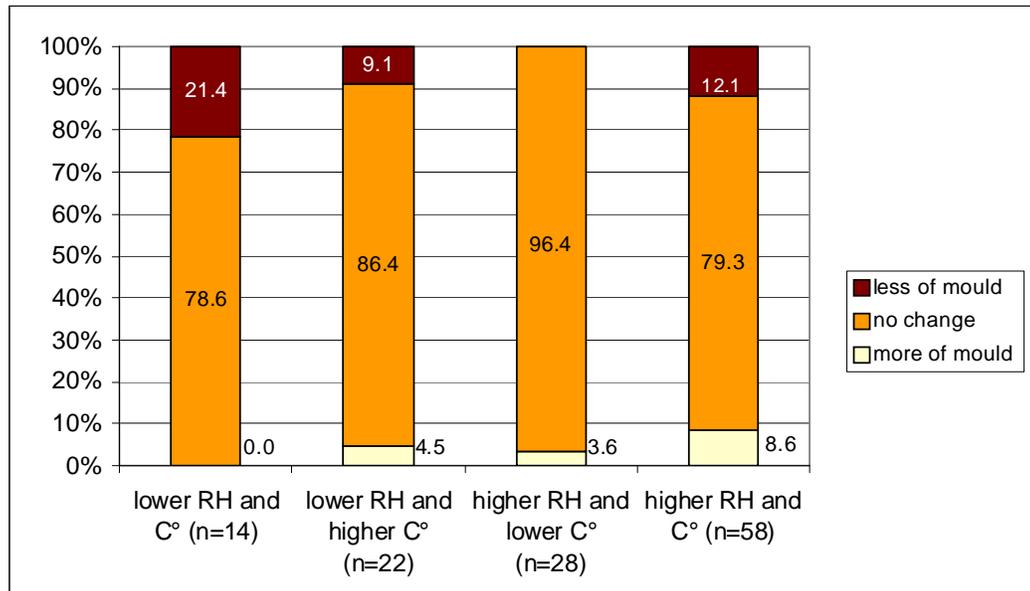
11. Health status changes

The sampled population was asked to self-evaluate their health status. Of the 2007 population, 67.3% evaluated their health as good or very good (2006: 64.8%), with the health improvement being mainly accounted for by less healthy people from 2006 not participating in the 2007 study. Comparing the data from 2006 and 2007 in both groups, about 70% of participants did not indicate a change in health status. However, a higher number of the surveyed population in renovated dwellings evaluated their health as better in 2007 than in 2006, and deterioration of health status is reported more often by control group members.

Figure 48. Change of health perception in 2007
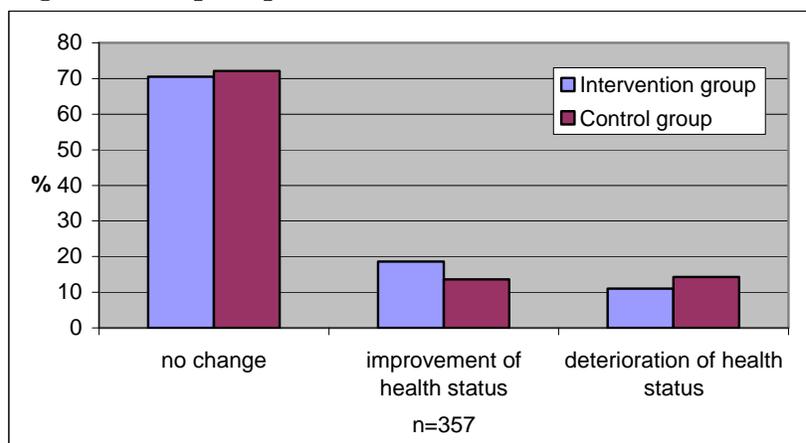
To what extent the loss of individuals between the 2006 and the 2007 survey may have affected these results has not been analysed, as it is quite possible that people with bad health show a different degree of residential mobility than those with good health. Also, there may have been more mobility in the intervention dwelling group, as it was affected by renovation and rent adjustments, which may have lead to the moving out of poorer households which often have lower health status as well. In any case, the differences definitely seem too modest to suggest that the renovation itself has triggered a direct health improvement. Still, possible pathways – especially affecting mental health – will have to be explored after making sure to what extent other factors may play a role.

Looking into the mental health effects of housing renovation is difficult, as there are two possible hypotheses: mental health decline due to the inconveniences of the renovation work or mental health improve as a result of the improved living conditions. While the first may be expected during or shortly after the work, the second would be expected in the mid- or long-term. As the follow-up survey was undertaken a few months after the insulation work was finished (in a few buildings, some other renovations were still ongoing), it is difficult to say to what extent the first or the second outcome is more likely.

The data below show that in general, the prevalence of depression (measured from four self-reported phenomena: sleep disturbance, loss of appetite, lack of motivation/interest and lack of self-esteem) decreased somewhat in both groups. However, it is obvious that the prevalence of strong depression trends has increased. It is therefore difficult to attribute these results to the renovation work, and more detailed analyses are needed, taking into consideration the age of the residents.

Figure 49. Depression trends by dwelling group
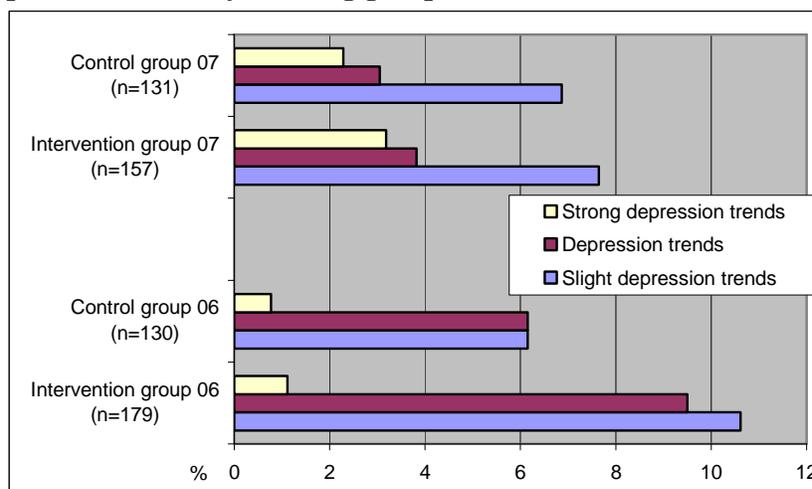
The residents were also been asked about chronic and acute diseases (for a reporting period over the previous three months, the winter season). A selection of four reported diseases and the proportion of their occurrence in 2006 and 2007 is shown in the figure below.

Figure 50. Reported diseases during last three months
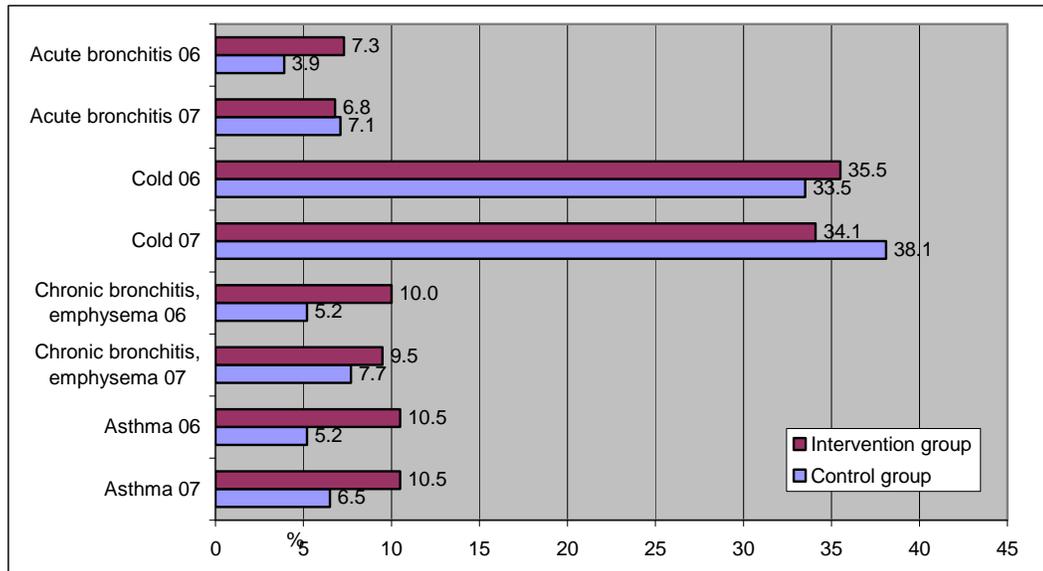
Only small changes can be identified within each group for the reported diseases. Within the control group a slight increase for all the shown diseases can be observed – the highest for colds, which were reported by 33.5% of the control group in 2006 compared to 38.1% in 2007. The occurrence of these four diseases among intervention group inhabitants either did not change or decreased slightly.

It is also possible to compare individuals and their health changes between 2006 and 2007, looking at persons that reported having had cold, asthma symptoms or acute bronchitis in 2006 but not in 2007 (decrease), or vice versa (increase). In this case, the data provide a rather similar picture.

Table 10. Change in disease prevalence in residents after the housing interventions

	Common cold		Asthma		Acute bronchitis	
	Decrease	Increase	Decrease	Increase	Decrease	Increase
Intervention group (n=220)	20.0%	18.6%	3.6%	3.6%	5.9%	5.5%
Control group (n=155)	11.6%	16.1%	1.3%	2.6%	3.9%	7.1%

These data suggest that in all three cases, there is almost equal increase and decrease of disease prevalence for the intervention group, while there is more increase than decrease in the control group. Also, it is obvious that there is more variation in health status in the intervention group than in the control group, where the percentage of residents with changing health status is smaller. Only detailed analyses will be able to establish potential associations between disease prevalence and housing factors. However, looking at the total number of cases available for each of the diseases, it seems unlikely that solid evidence can be derived.

The responses for acute respiratory diseases show a similar pattern to those above. Fewer people in the control group reported not having any respiratory disease during the winter of 2007 than in the previous winter, while no change was observed for the intervention group. The results, as shown on the following figure, represent mere indications based on a small sample size, but should be followed in up in more detail.

Figure 51. Acute respiratory diseases during last three months, 2006
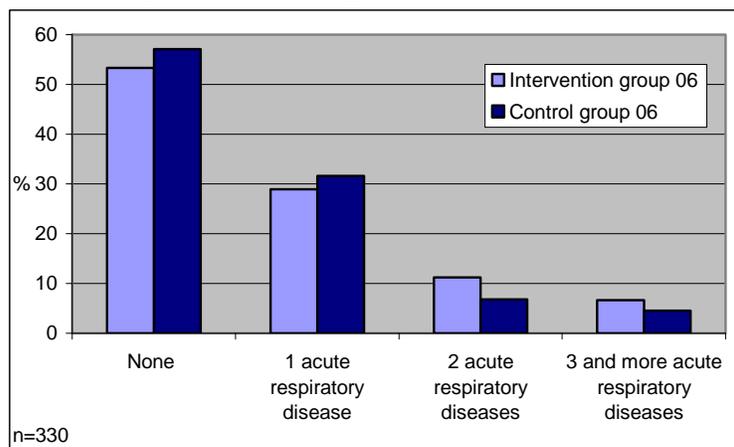
Figure 52. Acute respiratory diseases during last three months, 2007
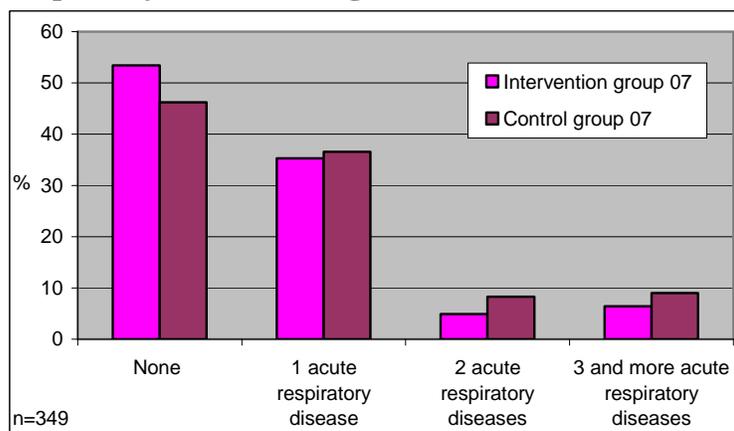
Asthma was mentioned as a problem by 8.3% (n=31) of residents in 2006 and 8.8% (n=33) in 2007. The proportion of asthmatic intervention group respondents reporting attacks during the previous three months increased from 39.1% in 2006 to 50% in 2007. Asthmatic control group respondents reporting attacks during the previous three months decreased from 25% in 2006 to 10% in 2007.

Figure 53. Asthma attacks during previous three months, 2006
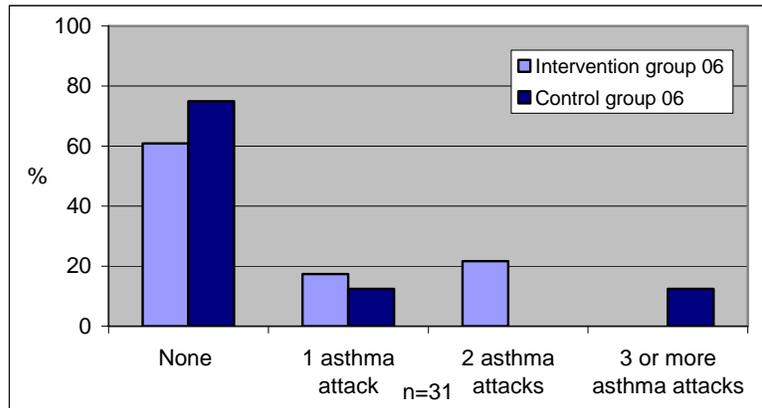
Figure 54. Asthma attacks during previous three months, 2007
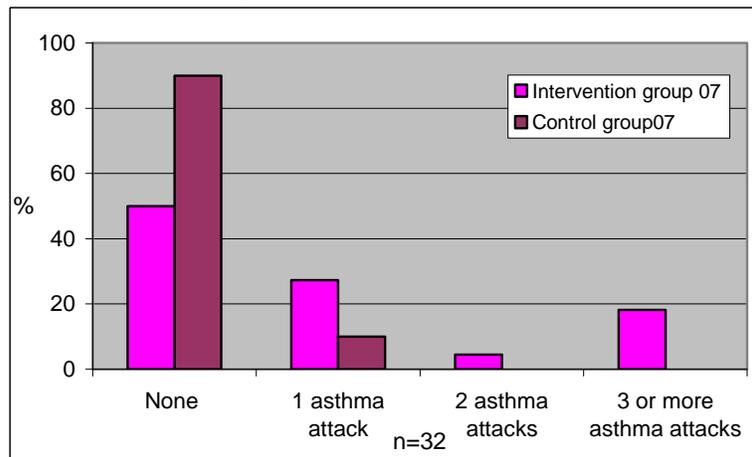
These results may indicate that while the number of asthma patients did not show large differences between 2006 and 2007, the renovation had some impact on those who already had asthma. Again, it must be noted that this result is based on a very small number of cases, but should such a result be confirmed by larger studies it could have very high public health relevance and would call for immediate action.

For the measurements of NO in exhaled air, used as an indicator for respiratory allergic reactions, it was impossible to detect any impact of the interventions. A total of 117 residents agreed to make the NO measurement in both studies. As the figure below (figure 55) shows, there is almost no variation between the two dwelling groups.

Figure 55. Changes in NO in exhaled air by dwelling group
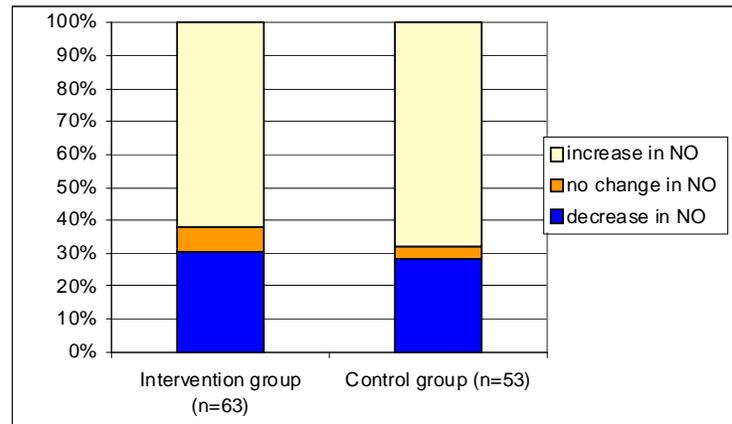
Also, no clear impact on NO was found for the different variations of mould occurrence (NB – low case numbers are strongly affecting the interpretation). Again, more detailed analyses are necessary.

Figure 56. Change of NO measured in exhaled air in relation to mould occurrence
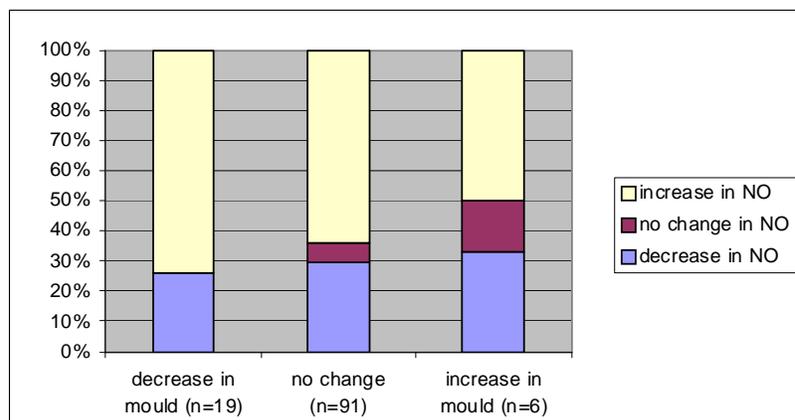
Finally, the number of sick days during the previous three months is a crude indicator of general health status. Although the sick days of intervention and control groups do show some differences, it is difficult to derive a trend or overall result as the differences are too diverse. More detailed analyses and especially some age adjustment would be necessary to be able to reach any useful conclusions. Nonetheless, at a first glance the results on sick days do not seem to be promising.

Figure 57. Sick days in the previous three months, 2006
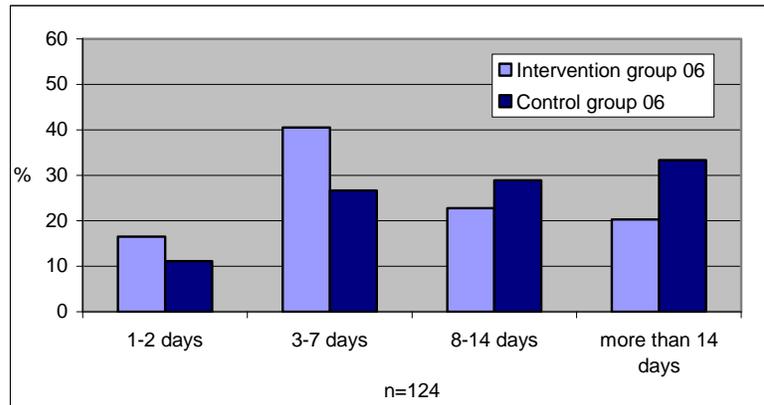
Figure 58. Sick days in the previous three months, 2007
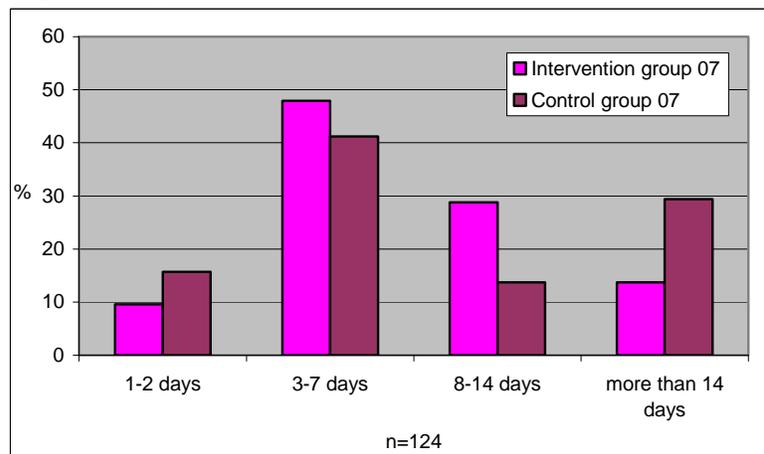
12. Preliminary conclusions

The analyses presented in this document are far from exhaustive and are based exclusively on bivariate statistics. Their relevance is therefore limited and the reported findings need to be confirmed and validated by in-depth and – to the extent possible - multivariate statistical procedures, for which the data will be publicly accessible (see chapter 13).

However, the preliminary findings presented in this paper do allow a series of preliminary conclusions and indications:

- The perceived exposure to noise has been reduced by the insulation measures, which was mostly visible in the reduction of severely exposed households.
- The thermal insulation measures that were applied have shown positive effects on the perceived quality of thermal insulation and resulted in significant changes to indoor thermal comfort. The perception of cold was strongly reduced in intervention dwellings.
- Measured indoor temperatures objectively indicated the positive impact on thermal conditions, showing a significantly higher rate of warmer dwellings within the intervention group. This result was found for individual temperature categories as well as for average and median indoor temperature.

- For relative humidity, the intervention group dwellings showed a somewhat stronger decrease than the control group dwellings, however, the magnitude of this difference was much less expressed than it was for temperature.
- The impact of the relative humidity level seemed to be stronger in insulated dwellings: while an increase of humidity was associated with an increase of mould prevalence, a decrease of humidity was associated with a decrease of mould prevalence. This trend was not visible for the control group dwellings.
- Generally speaking, the realization of housing renewal and thermal insulation seemed to not have a directly measurable negative impact on the health status of the residents in this study. The identified variations were rather modest and tended to indicate limited health improvements rather than health deterioration. However, the role of age and climate conditions in the two survey years needs to be analysed in more detail.
- Asthma represented an exception as it indicated a slight increase of attacks in asthmatic residents for the intervention dwellings which theoretically could be associated with the increased building tightness and reduced air exchange. This finding is to be validated further as well.

These first findings would suggest three main conclusions, indicating that
- ⇨ thermal insulation measures have the expected positive impact on indoor temperatures and thermal comfort;
- ⇨ insulated dwellings may be more sensible to indoor humidity changes which in turn would enhance the relevance of ventilation and air exchange in order to reduce accumulation of indoor pollutants and mould growth; and
- ⇨ health constraints may be restricted to diseases such as asthma which make the individual person more vulnerable to the indoor conditions and contamination.

The fact that asthmatic persons were the only group to show negative consequences in relation to the housing renewal work is interesting and – should such findings be replicated – most relevant for further public health follow up. However, in general terms, housing interventions focusing on thermal insulation measures seem to pose little direct and short-term health threat to the residents, provided they do account for the need of adequate air exchange measures and are undertaken properly.

13. Further data analysis and public access to data

Next to the data use by WHO, the data of the Frankfurt study is available to all interested researchers and institutions. After receiving the data, analysis will be done independently by the interested institutions and researchers. However, the ownership of the data set remains with the WHO Regional Office for Europe. WHO will exert a minimum level of coordination to streamline analysis teams working on similar hypotheses and to maintain information exchange between research groups. Independent publications may be made by the research and analysis teams with due reference to the data source.

Interested parties can request further information from the WHO European Centre for Environment and Health, Bonn (e-mail: info@ecehbonn.euro.who.int) and should apply for access to the data set with a first set of hypotheses to be analysed.

For data based on measurements sponsored by external institutions (dust, NO in exhaled air, VOC), access has to be given by the respective institutions.

Thermal insulation of buildings is widely recognized for its economic benefits due to decreased energy costs and considered an appropriate tool for reducing greenhouse emissions and mitigating climate change. Yet, little information exists on the potential health effects of thermal insulation.

Addressing this gap, the WHO housing and health programme implemented a health-monitoring project in cooperation with a housing agency based in Germany. The main objective was to assess the impact of thermal insulation changes on indoor environments, and evaluate potential effects on residents' health. The project collected data in spring 2006 before renovation work, and re-contacted all households in spring 2007 after renovation was carried out. In parallel, a control group of dwellings without interventions was used to collect additional data.

Drawing from 131 insulated and 104 non-insulated dwellings (with data for 220 and 155 residents, respectively), the project's preliminary results indicate that thermal insulation had a strongly positive impact on thermal conditions and thermal comfort as perceived by the residents, and decreased relative humidity in renovated dwellings. Results for direct effects on the occurrence of mould in renovated dwellings were weak, but indicated the major role of humidity levels and air exchange for adequate indoor climate. Direct associations of thermal insulation with health effects were also weak and limited to small prevalence differences of respiratory diseases and cold. Additional effects of the refurbishment were increased satisfaction and living conditions as perceived by residents, and a clear reduction of noise exposure.

In conclusion, the first results indicate that renovation activities and insulation are not in conflict with the health of residents and have the potential to improve health-related living conditions and thermal comfort if the rehabilitation work is done professionally and considers the need for adequate air exchange.

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