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A Practical Study of Retrofit Airtightening Old Houses For Energy Efficiency

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A Practical Study of Retrofit Airtightening Old Houses for Energy Efficiency

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1 Summary

This project set out to measure the effectiveness of weatherstripping old houses. It formed part of a programme to reduce dust mite populations in a group of Wellington City Council rental houses by generally improving moisture control performance. This required the buildings to be insulated and to be improved in airtightness to an air leakage rate of 7 ac/h at 50 Pa. Houses reaching this level were to be fitted with heat recovery ventilation systems supplementing existing ventilation with an additional 0.75 ac/h of fresh air.

The initial airtightness of the 15 houses in this study ranged from 12.6 to 23.7 ac/h at 50 Pa. By successively closing obvious leakage openings in the envelope with masking tape, and re-measuring the airtightness of the complete building, a schedule of retrofit steps, and an airtightness target, were established for each building. The largest and most practical improvements resulted from tightening openable windows and external doors, and caulking leakage openings in internal linings (mostly inside cupboards). The practical airtightness targets ranged from 6.1 to 14.7 ac/h at 50 Pa and were often short of the ideal 7 ac/h at 50 Pa.

The task of more permanently airtightening the houses was offered to two building contractors. In a pilot trial on one house, 83% of the target airtightness was achieved using standard carpentry practices of resetting windows and doors, and caulking leakage openings in the interior lining with a sealant. A second contractor, using mostly foam strip materials on doors and opening windows, achieved an average 25 % of the airtightening expected in a further 7 houses. Overall, the program has shown that relatively large (about 50%) improvements to the airtightness of weatherboard homes constructed in the 1950's are achievable, but that the trade skills of the operator are the controlling factor in achieving useful weatherstripping.

2. The airtightness of houses in New Zealand

The air leakage characteristics of houses can be measured with a blower door, as illustrated in Figure 1. This device lowers the indoor air pressure slightly with a fan that extracts air at a measured flow rate from the building. The airtightness result that is most often quoted is the air leakage rate at an international standard pressure difference of 50 Pa, expressed as volume air changes per hour (ac/h). Typically, these air leakage rates are around 20 times the infiltration rate driven by normal wind and stack pressures. They are a property of the building that can be compared to building code requirements for house air leakage performance if they exist, or compared with buildings of different types, age or location around the world.

The airtightness of houses has never been consciously engineered to meet a particular target in any code or standard in New Zealand. Instead, the airtightness that has been achieved is a result of a number of construction and material properties that include the airtightness of window and door joinery and the finished standard of internal linings. Surveys [1, 2 and 3] have shown that the age and shape of houses has a significant bearing on airtightness. Most of the data available in New Zealand relates to houses built after 1960. For these, 93% had airtightness results between 5-16 ac/h at 50 Pa. For a small group of 6 houses built prior to 1960 [1] the airtightness results were in the range 16 to 24 ac/h at 50 Pa showing that houses with strip interior lining (match lining, wall panelling, and tongue and groove flooring) tended to be less airtight than more recent houses lined with sheet materials (particleboard flooring and paper-sheathed gypsum plasterboard walls and ceilings). The use of down-lights with ventilation openings to the roof space may be in the process of reversing this trend, but detailed studies have shown that the interior lining has more control over building airtightness than external claddings. It is therefore not surprising that building materials which reduce the number of joints (and hence air leakage sites) lead to more airtight construction. A comparison between houses built before and after 1960 is given in Figure 2.

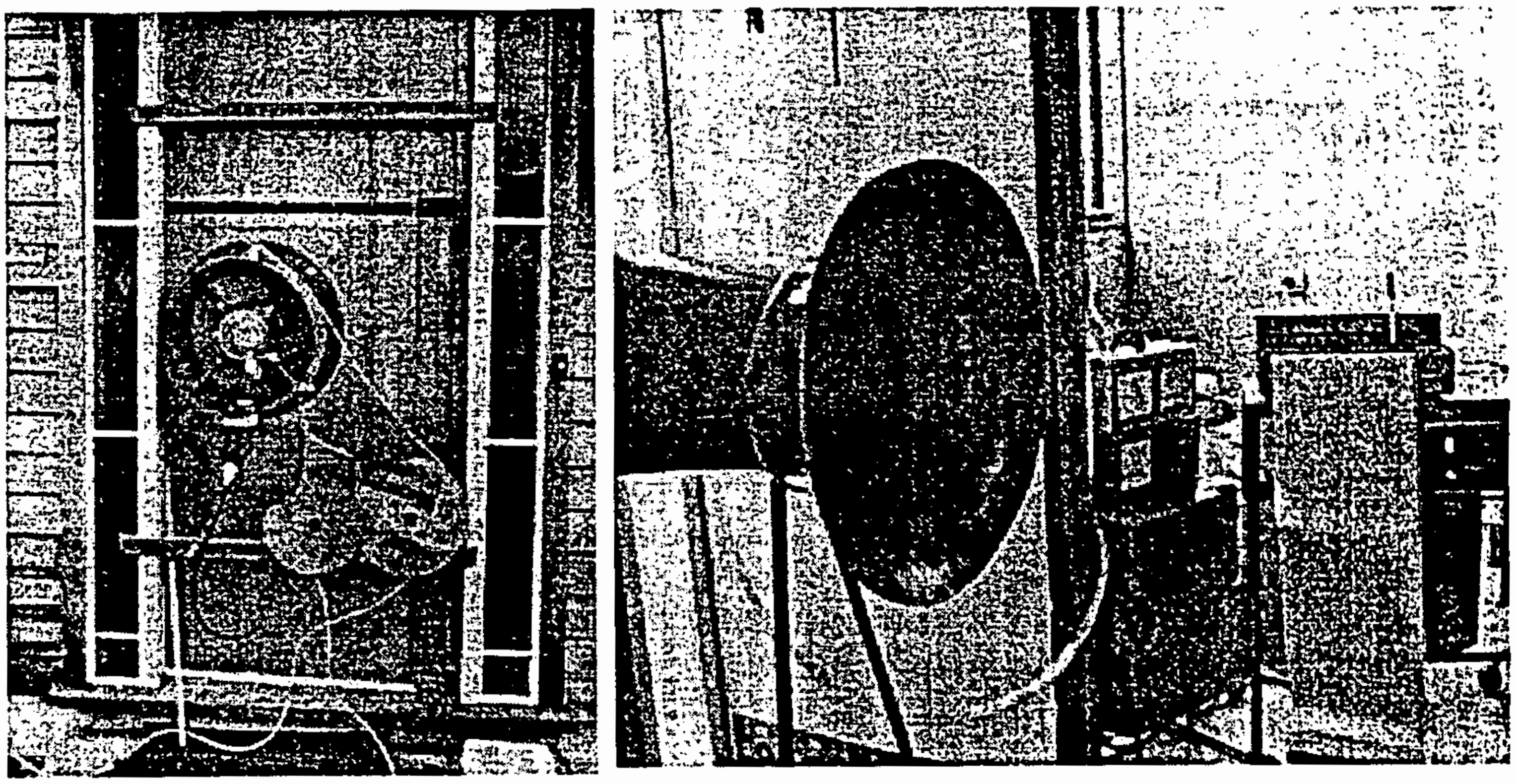

Figure 1: Blower door and associated instrumentation for measuring building airtightness

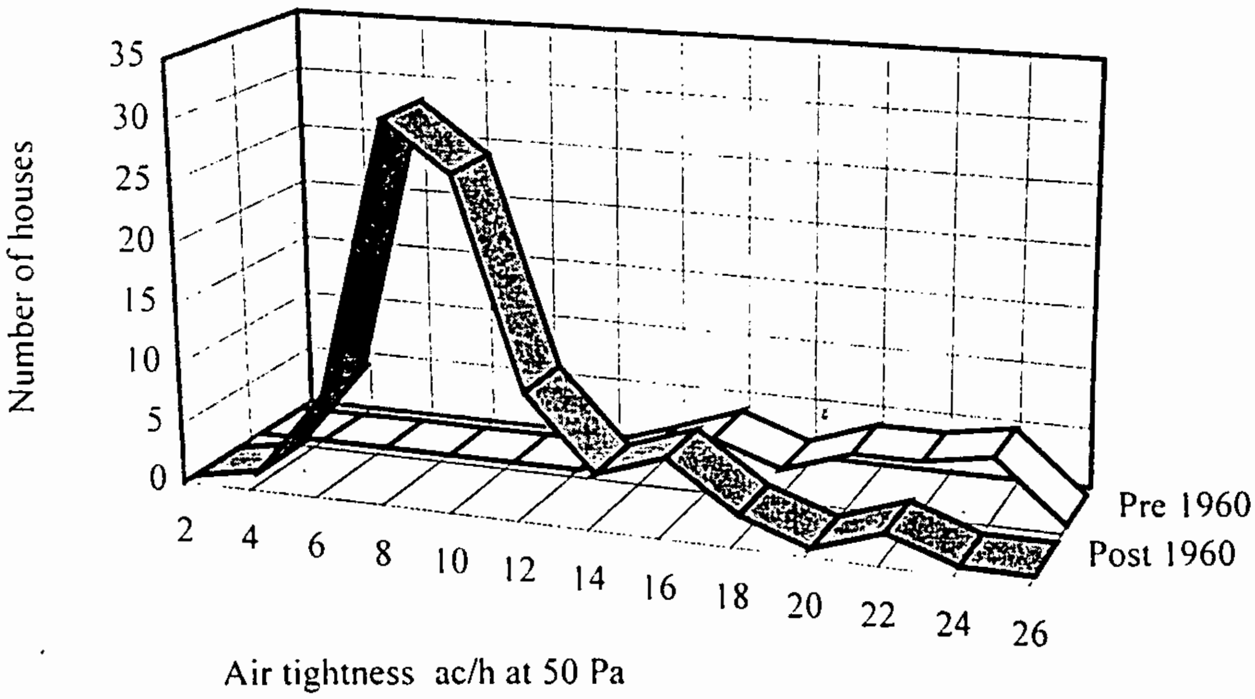

Figure 2: Histogram of house airtightness by age

3. Energy efficiency and air quality implications

Ventilation is both an energy efficiency and an indoor air quality issue. This means that any attempt to airtighten old houses for energy efficiency reasons will need to consider how far this can be taken before conflicting with indoor air quality and moisture control requirements. The average infiltration rate expected in houses with an airtightness of 20 ac/h at 50 Pa is about 1 ac/h in a sheltered suburban setting. While the energy implications of this in an uninsulated house are small, where insulation levels have been brought up to current building code requirements, 1.0 ac/h of infiltration heat loss could be as much as 40% of total envelope heat losses. If the airtightness of such a building were upgraded to 10 ac/h at 50 Pa then the infiltration (about 0.5 ac/h) heat loss could be reduced to a more acceptable 25% proportion. In this study, it was intended that 10 houses be upgraded to an airtightness level of 7 ac/h at 50 Pa, and that the reduced infiltration rate be supplemented by a further 0.75 ac/h of fresh air delivered by a heat recovery ventilation system.

Ventilation helps dilute a wide range of indoor contaminants. In recognition of this, New Zealand has adopted the ASHRAE Standard 62-1989 *Ventilation for acceptable indoor air quality* [4] as NZS 4303 [5]. This provides a guide to the ventilation required for a wide range of building end-uses to meet accepted indoor air quality criteria. For residential buildings, the background levels of ventilation given in NZS 4303 can be interpreted as a house-wide average ventilation rate of 0.5 ac/h by area weighting the different requirements for services and occupied areas. Higher ventilation rates will be necessary to remove steam from kitchen and bathroom areas but this intermittent need can be satisfied either mechanically or by opening windows. The infiltration rates in the houses upgraded to 7 ac/h at 50 Pa in this study would generally be less than 0.5 ac/h but an additional 0.75 ac/h of fresh air was to be supplied mechanically.

4. Initial airtightness results

A sample of 30 houses built in the 1950's for rental accommodation by the Wellington City Council was selected to trial measures designed to reduce dust mite populations. It has been recognised that dust mites thrive in the moist environments in New Zealand houses [6] and that generally raising the energy efficiency of the building with insulation, energy efficient ventilation and increasing indoor temperatures might reduce dust mite populations and provide a healthier environment for asthmatics. The complete project has involved a number of research groups and funding sources and has objectives that are much wider that the airtightness retrofit programme described in this paper.

The houses were split into three groups of 10. One group was kept unchanged as a control. A second group (category B) was insulated to ECNZ Medallion levels [7] (ceiling R=3, wall R=1.5, and floor R=2). The third group (category A) was further upgraded with airtightness improvements and a heat recovery ventilation system. Of the modified houses, 15 were airtightness tested in their original state and the results of these measurements are presented in Table 1. Here the airtightness is presented as an air leakage rate at 50 Pa in ac/h (volume air changes per hour) and as l/s m^2 (l/s per m^2 of envelope area). Initial airtightness results ranged from 12.6 to 23.7 ac/h at 50 Pa and generally coincided with earlier results for houses in this age group of 14 to 24 ac/h at 50 Pa [1]. The 15 houses were a similar size (only two outside the floor area range 79 to 99 m^2) and were basically of the same construction (weatherboards walls, suspended timber strip-lined floors and pitched metal roofs).

House Number	Category	Floor area m^2	Volume m^3	Air leakage rate at 50 Pa ac/h	Air leakage rate at 50 Pa l/s m^2
1	B	54	132	23.0	4.54
2	A	90	220	22.8	4.76
3	A	99	220	19.3	3.83
4	B	79	194	23.7	4.95
5	B	96	235	21.7	4.34
6	A	95	233	22.6	4.71
7	A	85	209	15.6	3.10
8	A	74	181	19.5	3.69
9	A	93	228	17.8	4.14
10	B	82	201	13.8	2.91
11	A	94	230	21.1	4.53
12	A	83	284	14.6	2.90
13	B	54	135	13.5	2.71
14	B	91	223	12.6	2.73
15	B	82	201	15.4	3.21

Table 1: Initial airtightness results for 15 houses

5. Retrofit airtightening a single house

The first attempt to catalogue the leakage openings in a house and identify those most easily upgraded was carried out in house 3. After the initial airtightness was measured, the most obvious and accessible leakage openings were temporarily blocked with masking tape. Re-measuring the building airtightness then gave a measure of the effectiveness of this step.

It was noted that many of the windows fitted poorly as a result of building movement and missing catches so the first temporary upgrade involved taping all the opening window joints. This improved the airtightness from 19.3 to 13.3 ac/h at 50 Pa (a 30% improvement). Eliminating leaks around a poorly fitting door further reduced the air leakage rate to 12.2 ac/h at 50 Pa (a further 6% improvement). The next most obvious leakage openings were detected as draughts while the building was being depressurised by the airtightness fan. These were located inside cupboard areas where the interior lining was often incomplete. Scotia and lining details were often less well finished in these areas. By eliminating the more obvious lining defects in cupboards and between wall linings and window frames, a further improvement to 10.9 ac/h at 50 Pa (7%) in the building airtightness was achieved. Other leakage openings were identified but considered to be either too small or impractical to correct. While the building was under fan depressurisation, carpets were seen to float above floor level, indicating air leaks through the floor. Retrofit air tightening of these areas would have involved removing floor coverings which would have been considered if these were due to be replaced.

After removing all the temporary measures, written instructions were given to a building contractor to carry out the permanent retrofit. In house 3 the contractor refitted the windows and replaced missing catches. Often this involved repositioning hinges and catches. Wall lining defects were dealt with using a sealant. Re-measuring the building airtightness showed that 80% of the target airtightness improvement had been achieved. Further attention to interior lining details and blocking the large under-floor openings around waste pipes made a further 6% improvement in the building airtightness. The trial upgrade process, and the two retrofit steps, are illustrated in Figure 3.

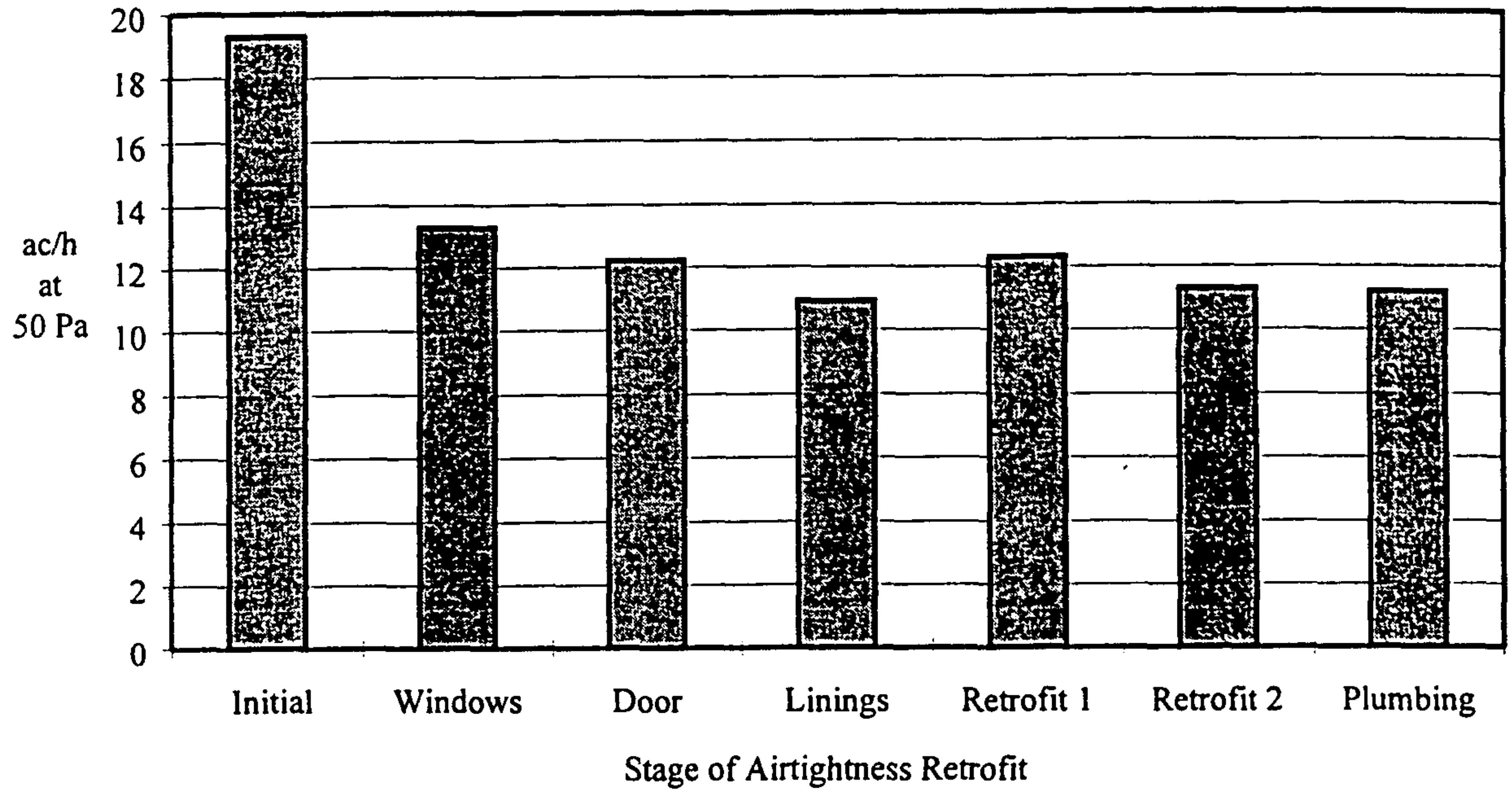

Figure 3: The airtightness of house 3 showing the temporary improvements and retrofit stages

6. Airtightness targets for 15 houses

The airtightness of a further 14 houses was measured and the effect of temporary upgrades in the following areas determined:

1 Joints around opening windows
2 Defects in internal linings (inside cupboards and between window frames and wall linings)
3 Openings around waste pipes under baths and sinks

The average effectiveness of these steps is given in Figure 4, expressed as a percentage of the initial airtightness result. The average airtightness improvement was 54%.

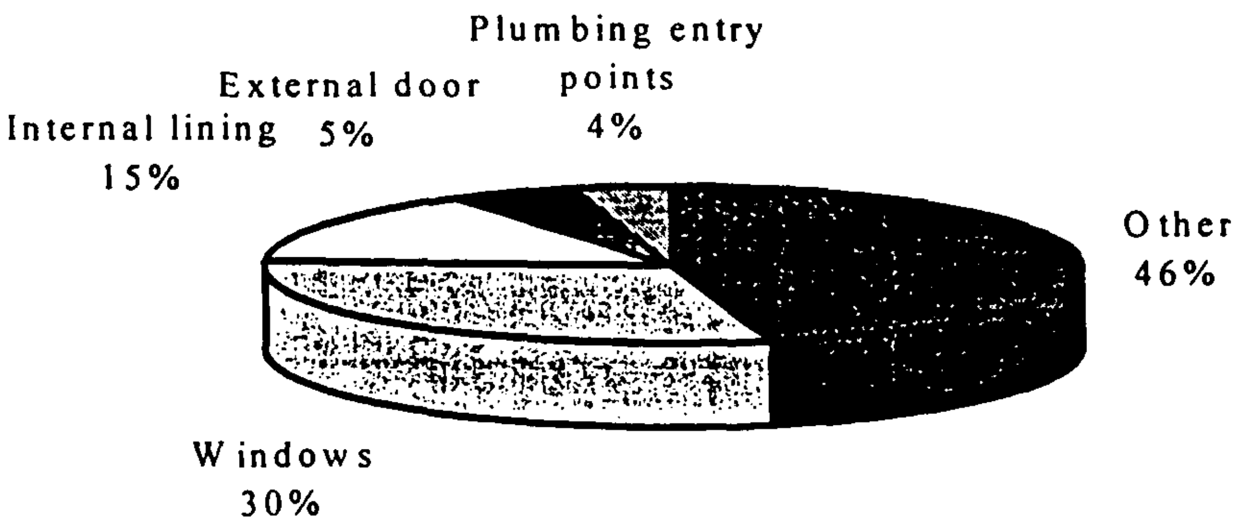

Figure 4: Average temporary airtightness improvements achieved in 15 houses. The residual air leakage is shown as "other"

The average improvement in the airtightness of 15 houses was a reduction of 18.5 to 9.0 ac/h at 50 Pa. This is a 50% improvement, but the final airtightness level generally fell a little short of the 7 ac/h at 50 Pa specification for Medallion 2000 houses equipped with mechanical heat recovery ventilation. It would have been possible to make further improvements (for example by sealing openings under floor coverings) but the measures needed would be costly and invasive.

The airtightness results for sequentially upgrading 15 houses using the same steps applied to house 3 is illustrated in Figure 5:

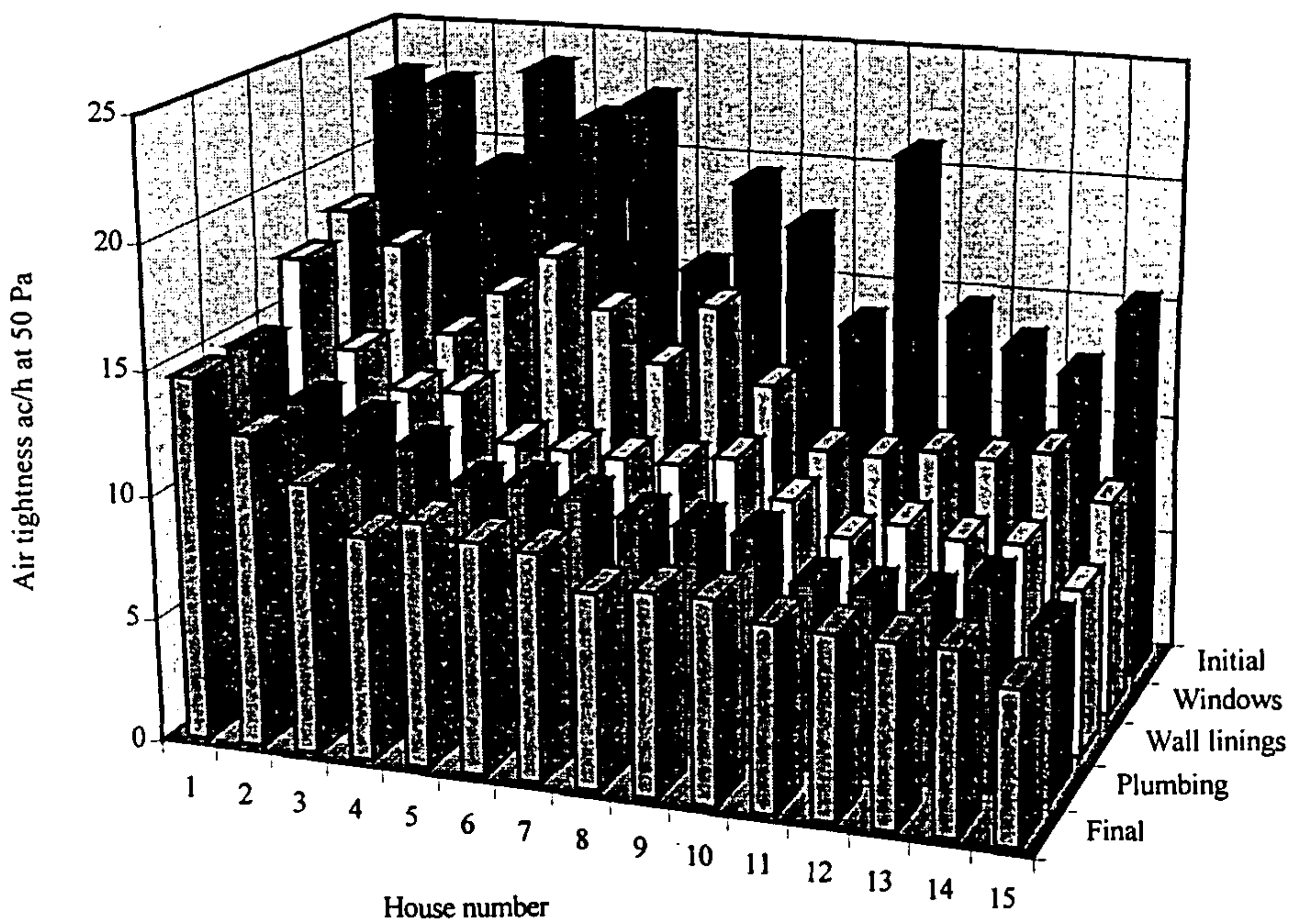

Figure 5: Four stages of temporary airtightening 15 pre 1950's houses

7. Effectiveness of airtightness retrofits

Following a reasonably successful retrofit airtightening of house 3, where 80% of the target improvements were achieved, a further 7 houses were upgraded. This time a second contractor was issued with the lists of jobs to be carried out in each house. Where a carpentry approach that involved re-setting windows was taken on house 3, this time a less expensive method of fitting commercial draught-sealing materials to opening joints was followed. Sponge-seal materials were fitted to the opening joints around windows where this was consistent with the window pulling up on the catches. The same approach was used for doors, along with sealants for indoor lining details.

The commercial retrofit air tightening of this group of 7 houses achieved 25% of the gains expected. Figure 6 shows the initial, target and post-retrofit airtightness for these houses, as well as for house 3. The second approach achieved little of the gains that were shown could be achieved in house 3. One of the main reasons was thought to be the difficulty of applying foam air seals to window openings. Often the foam strip was observed to tighten part of the opening joint, at the expense of the window not pulling up as far on the catch. This problem has been discussed in an earlier analysis of available draught-sealing materials [8]. Clearly the question of installed quality needs further thought in connection with foam seals in window and door openings.

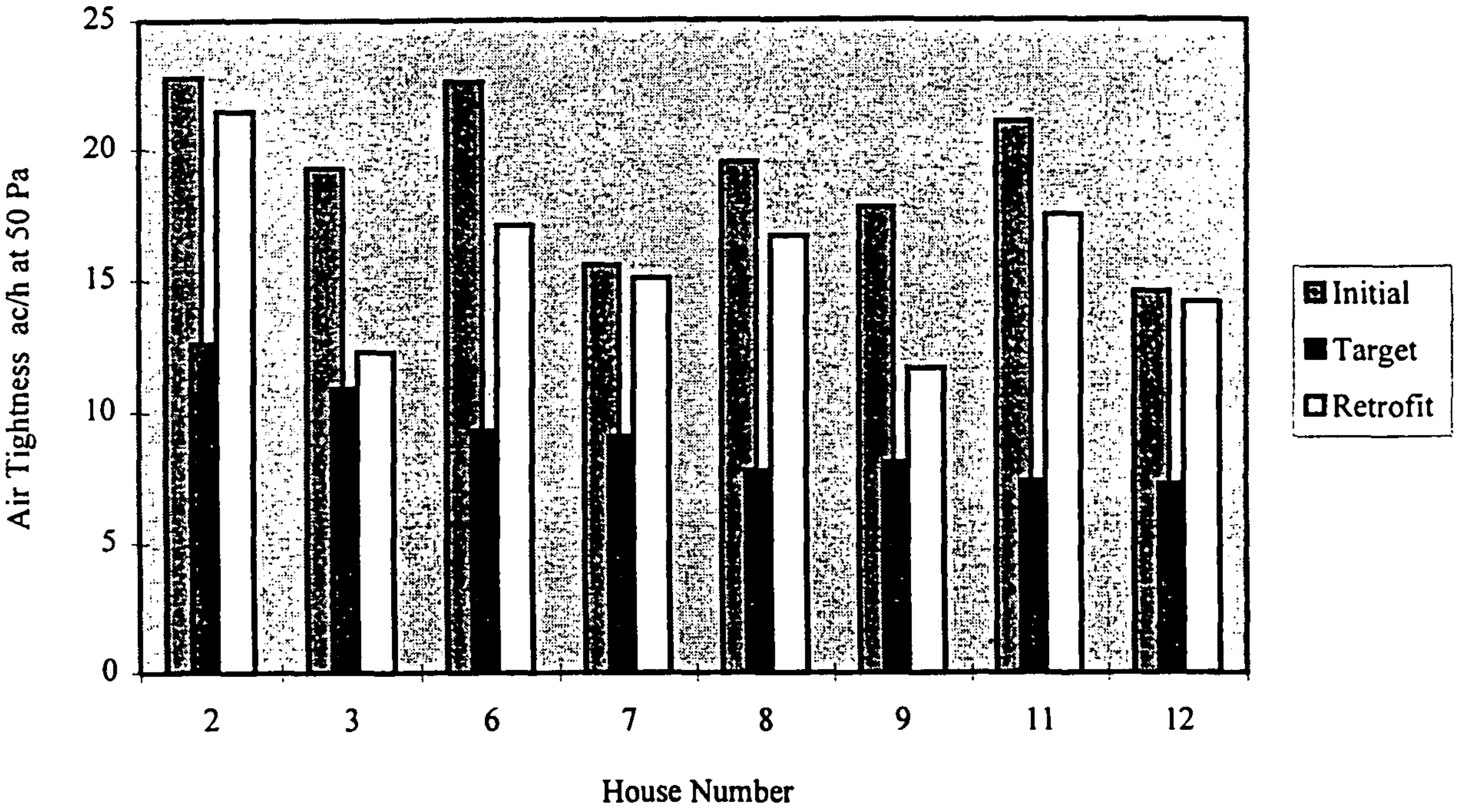

Figure 6: Airtightness of houses before and after retrofit compared with airtightness levels achieved with temporary upgrades

8. Conclusions

This study set out to improve the airtightness of 8 houses built in Wellington in the 1950's. Initially, the potential for practical airtightness upgrades was measured in a larger sample of 15 houses, using the method of fan depressurisation to help locate leakage openings in the envelope and to measure the effect of any temporary masking of these openings. This set an airtightness target for each house along with a list of remedial actions to be carried out by a building contractor. Follow-up airtightness tests after the retrofit work had been completed were used to gauge the success of this step. The following observations are important:

- The initial airtightness of 15 houses built in the 1950's was 12.6 to 23.7 ac/h at 50 Pa. This result was similar to earlier measurements of 6 pre-1960's houses.

- Using temporary measures it was possible to improve the average building airtightness by 50%. This was achieved by masking leakage openings around windows, doors and internal linings (particularly inside cupboards and between window frames and linings).

- More permanent retrofits were carried out in 8 houses by contractors. In a pilot trial on one house, 83% of the target airtightness was achieved using standard carpentry practices of re-setting windows and doors, and caulking leakage openings in the interior lining with a sealant. A second contractor, using mostly foam strip materials on doors and opening windows, achieved an average 25 % of the airtightening expected in a further 7 houses.

Overall, the program has shown that relatively large (about 50%) improvements to the airtightness of weatherboard homes constructed in the 1950's are both achievable and justified from an energy efficiency point of view, but that it is not clear how to effectively implement these gains.

9. Acknowledgments

This work was funded by the Building Research Levy and by ECNZ who supported the dust mite research project. We acknowledge the assistance of ECNZ and the Wellington City Council for their assistance in gaining access to the buildings involved. The building occupiers are also acknowledged for their patience in allowing this work to proceed.

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