ENERGY EFFICIENT DOMESTIC VENTILATION SYSTEMS FOR ACHIEVING
ACCEPTABLE INDOOR AIR QUALITY

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ENERGY IMPROVEMENT KITS:- FIELD RESULTS

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SYNOPSIS

25 different but representative dwellings from the Birmingham Local Authority housing stock have been monitored before and after energy retrofitting. All dwellings received measures aimed at reducing air infiltration.
The paper presents the findings of these field trials as a set of case studies encompassing both fabric and infiltration measures. In addition the infiltration measures are commented upon in more detail. The results are as much, if not more, pragmatic than scientific and emphasise the importance of technology transfer, i.e. implementation. The diverse nature of U.K. housing (especially local authority stock), user influences, and relatively low quality of current U.K. building practice all combine to markedly affect prediction of costs/benefits.
E.I.K. evidence suggests that simple E.C.Ms. are successful but that more sophisticated combinations tend to under-achieve. Where it is possible to identify ventilation changes in several cases this is impaired by increased use of windows and/or permanent ventilation. Nevertheless reduction of between 0.3 and 0.6 ac/hr. appear typical where such effects are not operating.

1. INTRODUCTION

The E.I.K. Project - a joint venture by The Birmingham City Housing Dept. and The Dept. of the Environment ; has recently been completed (1) (2) (3). Primarily concerned with the thermal upgrading of existing local authority housing stock (which accounts for around 10% of all U.K. energy consumption) the project was carried out in 2 phases:-
- a random 4% survey of the existing Birmingham stock
- monitored field trials (before and after) of energy retrofits to 25 representative dwellings.

The decision to include field trials in the E.I.K. project reflected the objectives and methodology of the Better Insulated Homes Programme of the Department of the Environment which commenced in 1974. Within its main objectives (4) important secondary aims were recognised, e.g. to 'explore' construction feedback, to assess real energy savings, etc.
The survey data was subjected to thermal analysis and eventually the 25 dwellings used in the field trials were selected (on criteria of associated technical and occupancy preferences).
Table 1 illustrates the dwellings together with the energy conservation measures. They are assigned an 'E.I.K. Number' (1 to 25) which is used throughout this paper.
Monitoring had 4 principal aspects:-
Energy use. Fortnightly reading of separate meters to heating, hot water, lighting and power

Temperature. 4 to 6 room temperatures were measured at half-hour intervals.
Behavioural aspects. The occupants have been interviewed to identify household characteristics, and use of appliances/spaces/windows.
Practicalities. For the exercise to be of direct benefit to others then operational factors also require evaluation, e.g. design, construction, management, costs, savings, etc.
Useful energy (fortnightly) is compared to temperatures differences to yield Empirical Design Heat Loss (EDHL) rates. These vary with time due to changes in ventilation rates. The variations and mean values, however, are a measure of the insulation standard of the building shell and comparisons of 'before' and 'after' (retrofitting) values facilitates an assessment of the performance of energy conservation measures (ECMS). Comparisons of EDHLs with PDHLs (Predicted Design Heat Loss rates) is a further aid to performance assessment (e.g. by identifying gross under-achievement of an ECM).
This method of analysis is similar to the proposed 'Energy Signatures' of Norlen (5) and the "Overall Coefficients of Heat Transfer" of Sonderegger (6). The principal advantage is its applicability to data from differing time periods. Additionally it can be used to model standardised annual energy consumptions and savings and hence economic viability of ECMs (normalising for changes in internal temperature if desired).

2. ENERGY CONSERVATION MEASURES (ECMs)

2.1 General

A wide range of measures were considered (within an overall budget limit of £1,000 per dwelling - 1979) ranging from simple draught exclusion, roof insulation, etc. to comprehensive improvement packages involving solid wall insulation, heating system changes, etc. Strategically, improvements were seen to fall into three categories:-

First-aid. First line of defence work such as draught exclusion, system maintenance, roof and hot water tank insulation.

Optimum. A range of measures suited to individual houses and intended to represent the maximum that could be judged as cost-effective. This may include cavity wall insulation, additional roof insulation, more thorough draught exclusion, etc.

Rehabilitation. Older properties will at some stage be due for renovation and it is more cost-effective to include energy conservation measures during such work when only the marginal or extra cost is entered onto the cost-benefit analysis.

This strategy, in response to detailed information about each dwelling e.g. condition, energy systems, defects, complaints, led to the E.C.Ms. in table I.

2.2 Air Infiltration Reduction

A variety of measures were employed to reduce/eliminate the most obvious sources of air leakage.

- Windows were generally weatherstripped by the application of a silicone rubber sealant.
- Doors and loft hatches predominantly had nylon brush seals fixed to the jamb. Letter boxes received nylon brush closers.

(these two items were carried out by a specialist contractor - all other air infiltration measures were carried out by a general contractor).
The cost of these weatherstripping items ranged from £1.74 to £2.02 per metre run.

In general these measures proved relatively trouble free although several instances were noted of paintwork being 'pulled away' when the masking sellotape was removed. A few windows which did not have a rebated opening joint were difficult to retrofit and attempts to form a 'lip' from silicone rubber were aesthetically inadequate.

Brush weatherstripping of sash windows was troublesome and would be difficult to judge as adequate both on aesthetic or performance criteria. Indeed since it was installed in one instance after having 'freed' windows sealed by many coats of paint - the air leakage may have been increased. Occasionally brush weatherstripping of doors detached itself from the jamb due to inadequate fixing (short pins).

- Air brick - permanent ventilators in the external wall were generally 'redundant' by current standards and practice (and certainly contributed substantially to air leakage). These were replaced by conventional bricks. Where required for gas appliances adequate permanent ventilation in accordance with West Midlands Gas guidelines was either left or installed where previously omitted. The cost of this item was approx. £3 per brick and not surprisingly proved to be trouble free.
  The above items constituted a basic air infiltration ECM package which all dwellings received. Occasionally other items were implemented, e.g.

- unused flues were specified to be sealed. The intention was to seal it from room air whilst maintaining the void ventilated to outside. This current practice is an achievable preference with flues on external walls/but is not generally possible for fully internal flues which were simply boarded over in the room 'fire place' but with a large (approx. 0.075 m^2) permanent ventilator. This, of course, would have a much reduced, if any, effect on air leakage via the flue.

- suspended timber floors were covered with hardboard and caulk sealed to the skirting board. This measure proved relatively trouble free although in one instance differential movement caused upward bowing of the hardboard. The cost of this measure was £3 per m^2.

- Louvre windows were replaced (2 cases) by casement windows (at a cost of £83 and £109). The work was generally satisfactory.

- External porches were constructed in 2 cases - once where the main entrance opened directly onto the main living (and heated) space and once where an existing canopy and associated structure lent themselves to the addition of a fully enclosed porch. This work was completed at a cost of £655 and £511 respectively and generated no difficulty.

These and other ECM's are summarised in table II.

Although £/ U is a relative index of theoretical cost efficiency it should be modified by any knowledge of temperature differences across the ECM. For example the difference between the highest and lowest average temperatures recorded in the 'before' period are:-

	T(internal)	T(internal) - T(external)
warmest living room	23.0°C	17.4°C
coolest living room	15.0°C	9.3°C
warmest bed room	19.6°C	14.0° C
coolest bed room	10.5°C	5.0° C
warmest whole house	21.3°C	15.7°C
coolest whole house	12.6°C	7.1°C

These variations in Ti - Te introduce, approximately, a 2:1 variation on theoretical payback periods for measures to living rooms/whole houses and 3:1 for measures to bedrooms. This 'noise' can mask an otherwise 'clear' signal.

2.3 Practical Feedback

Before looking at some of the quantifiable 'benefits' arising from the ECMs it is worth noting some less measurable effects.

- A point which applied to all ECMs but in particular to air infiltration reduction measures concerned the nature of the original fabric. In simple terms it is not worth applying a retrofit to a base component which is inappropriate in terms of design and/or condition to receive it. For example, several timber frame windows and doors were in such a condition that even the adaptable silicone rubber technique could not accommodate the large and irregular gaps around ill fitting and distorted openings.

- Several occupants were such profligate users of windows that measures to these had little effect and as is illustrated in Section 5. Of more concern than this continued user influence are those cases where it is believed that the potential benefit of reduced infiltration was mitigated by increased window use. There appear to be 2 principal reasons for this:-

a) an increase in condensation on window glass. This was particularly severe in 2 dwellings(6 and 10). In both cases the occupants had started to produce their domestic hot water via saucepans on the gas stove as a means of reducing their electric water heating bill. In short - an illustration of the complex interactions which can markedly influence energy consumption and conservation.

b) a reduced heat loss and unchanged heating system (in most dwellings room gas radiant/convectors) occasionally led to high room temperatures with a related increase in window use patterns.

Both a) and b) produce the same effect - a by-passing of the energy saving from reduced infiltration.

- In one case (15) increased condensation not only promoted increased window opening but was of great concern occurring as it did on non-glass elem ents with consequent mould growth. There was no clear user influence. This case undoubtedly provides sustenance to those who argue that draught proofing of dwellings should not be carried out by local authorities.

- There were a few instances where ventilation rates appear to have been influenced by by-passes either remaining after or introduced by retrofitting. For example, permanent ventilators for the provision of combustian air, opening up of sealed flues ....).

3. IMPACT OF ECMs.

This section briefly summarises the measured effects of all the ECMs and section 4 attempts to extract information directly pertinent to the air infiltration measures. 'Benefits' are discussed under headings:-

- Envelope Heat Loss
- Temperature
- Fuel use
- Costs/Benefits

3.1 <u>Envelope Heat Loss</u>

Two forms of Design Heat Loss (DHL - W/^{o}C) are used:-

- P.D.H.L. Predicted D.H.L - (steady state assuming one airchange per hour before retrofitting and 0.75 ac/hr. afterwards).

- E.D.H.L. Empirical D.H.L. (Derived from energy used to produce a temperature difference (one per fortnight).

Figures 1, 2 and 3 illustrate the findings. Briefly these are:-

- since E.D.H.L. is a measure of the <u>observed energy</u> efficiency of a building envelope then changes in E.D.H.L. are a measure of the <u>achieved</u> increase in the envelopes resistance to heat loss. Since not all dwellings can be monitored most studies will be restricted to P.D.H.L. values and, consequently, it is of some interest to note the correspondence between Predicted and Empirical values. It is apparent that a consistent 'non-agreement' exists of the 'Before' and 'After' group. Taken as a sample of 50 this is not insignificant and the correllations are:-

- Before E.D.H.L. = 0.76 P.D.H.L. + 37.3(W/^{o}C) (r = 0.82)
  After E.D.H.L. = 0.79 P.D.H.L. + 29.8(W/^{o}C) (r = 0.81)

The mismatch is not surprising in the context of the many inherent assumptions. The consistency is, however, re-assuring since it is relative rather than absolute values which are of greatest concern in a retrofit programme.

Of as much, if not more, importance than the regression equations is the observation that those cases deviating substantially from 1:1 agreement are those where defects etc. capable of explaining the errors were known to occur.

- mean values are:-

Heat Loss W/^{o}C

	Empirical	Predicted	E/P
Before	227	248	0.92
After	177	184	0.96
Change	50	64	0.78
(% change	22	26	0.85)

- the mean values suggest better agreement than the regression equations.

- agreement improves slightly as envelope heat loss is reduced.

- Although E/P at O.92 and O.96 may appear an acceptable average for design purposes (i.e. sizing of heating systems) an E/P of O.78 for the 'savings effect' is perhaps more significant since this is the basis for estimating energy savings and hence payback periods etc. A figure of O.78 is better than the O.67 reported by Norlen (9). Although 'reasonable' mean agreements and 'correlations' exist there is considerable scatter and the mean value is of little comfort to an individual case (e.g. dwelling 8).

3.2 Temperatures

Of interest is the way in which the distribution of internal temperatures is altered since this is indicative of the influence of control, use, cooling curve, etc. on the temperature condition of the house. In many cases it appears that a rise in average temperatures results primarily from increased temperatures during periods of non-heating (slower cooling). In this event such a rise cannot be prevented and it is idle to speculate as to whether it is fortuitous (lack of thermostatic control) or deliberate (occupants explicit objective).

Figure 4 indicates no significant correspondence between the rise in internal temperature and the change in envelope heat loss (E.D.H.L.) stimulating this rise. However, there are some trends, for example, there are a group of points significantly higher than the others and these can all be traced to specific causes, e.g. inadequate control on heating appliances (1 and 4), large proportion of largely uncontrolled free or casual heat gains (21, 25, 23), user preference (4), low 'before' temperatures (19) etc. Similarly although the average temperature rise for the whole group was O.9°C it was only O.5°C for the warmer thermostatically controlled centrally heated dwellings but 1.1°C for the rest (largely gas fires without thermostatic control).

A summary of mean temperature related data is:-

		Before	After	Change
(Te)	..	6.1	6.7	+ O.6
(Ti) °C	..	16.5	17.4	+ O.9
(Ti - Te) °C	..	10.4	10.7	+ O.3
Savings offset (%)		-	-	10.4%

3.3 Fuel Use

It is difficult to summarise fuel use in such a diverse range of case studies but the following is indicative of the nature of energy usage. The figures refer to delivered energy per average fortnight in the heating season (for similar external conditions).

		Purchased: Direct Space Heating		Purchased: Indirect eg. Lighting, Cooking, DHW etc.		Free: People + Solar		Total	
		mean	range	mean	range	mean	range	mean	range
Before	kwhrs	516	70-998	281	104-687	251	139-376	1048	417-1604
	%	49	17-66	27	14-45	24	13-45	100	
After	kwhrs	474	48-871	251	97-576	177	106-285	903	346-1396
	%	52	14-66	28	15-49	20	10-44	100	

3.4 Costs v Benefits

Costs:- are taken as the capital cost of the ECMs based upon quotations made in 1980 but monies paid in 1981. In addition to the variability that differential inflation of costs and benefits introduces into the cost benefit ratios it is sometimes forgotten that there exists a considerable 'error' in building costs. This error is obviously self correcting in large samples but this may not be the case in these limited trials. Certain costs revealed themselves to be highly dwelling sensitive (e.g. double glazing, external wall insulation) yielding widely varying unit costs. Some items were charged on a measured basis (e.g. cavity fill) and in several instances the contractor's measurement did not exactly concur with a measurement of the area to be treated. It is the judgement of the City Building Finance Department (who administered the contracts) that the building costs charged were 'typical of the time'. (80/81 'turn of the year').

Benefits:- are expressed in terms of delivered (i.e. purchased) energy and the cash value of such energy savings. This energy is valued at 1980/81 prices namely: gas 0.72p/kwhr, electricity 4.22p/kwhr (off peak 2.33p/kwhr), solid fuel 1.77p/kwhr. Since monitoring did not proceed for a complete year both before and after improvements it has been necessary to model annual energy savings from measured data over approximately 18 weeks before, and 30 weeks after, improvements.

Method 1. Uses measured EDHLs normalised for temperature differences to provide an estimate of annual energy savings. This is a favourable estimate since it places an 'energy value' on any temperature rises.

Method 2. Uses the measured difference in purchased energy to produce an estimate of an annual saving. Temperature rises will have an adverse effect on this estimate of the benefit. However, it is a more 'honest' estimate of cash savings.

Mean Costs and Benefits are:-

Insulation	..	£529
Heating	...	£ 68
Infiltration	..	£183
Capital Cost	..	£780 per dwelling

	Fuel saving (kwhrs)	Fuel value (£ p. a.)	Simple Payback period (yrs)
Method 1	3605	31.50	24.8
Method 2	2532	26.20	29.8 *

(* excludes 4 cases of clearly anomalous behaviour).

Figure 5 (a) and (b) relates the estimates of energy saving by Methods 1 and 2 to capital costs. Of interest is the apparent division between a group of simple cheap retrofits for which returns are high and a group of more complex and expensive retrofits for which returns are disappointingly low. The figure implies a 'break point' at around £500, below this there is a strong relationship between capital cost and reduced EDHL but above this the slope is markedly reduced. It seems that the relatively simple (cheap) measures perform 'reliably' but then when more complex, sophisticated (expensive) measures are implemented (especially in combination with other ECMS) then under achievement severely limits the cost benefit ratio. This phenomenon has been reported elsewhere, e.g. Swedish Council for Building Research (8) who reported good returns for ECMs when implemented individually but unexplained under-performance when ECMs were combined. This may be related to the point that the expensive retrofit packages are likely to be very sensitive to the condition of the base structure and/or any defects in installation.

4. SUMMARY OF FIELD WORK

a) The study was very much one of 25 separate case studies and as such any generalisations cannot be made with statistical confidence.

b) The form of monitoring, although simple, has proved effective. EDHL has been useful and the development of this along the lines of 'Energy Signatures' is seen as a valuable diagnostic aid.

c) E.C.M. selection was approached by the design team in a relatively structured manner so as to evolve retrofit packages 'suited' to the dwelling compatible with a national programme of upgrading. However, there were many instances where on-site fine details influenced these selections - primarily in one of 3 ways:-

- to make an ECM more expensive than expected from unit costs.
- to make an ECM virtually impossible in realistically practical terms.
- to suggest an ECM by virtue of simplicity.

These influences injected 'noise' into an originally 'tidy' strategy such that the final set of packages appears to be more 'ad hoc'.

d) The successful implementation of an ECM is very dependent upon its level of sophistication, the condition or suitability of the base structure, the skill/experience of operatives. If one or more of these is 'suspect' then difficulties are likely to be generated.

e) Predicted and Empirical estimates of heat loss agree reasonably well although the former tends to be higher. The agreement between predicted and empirical estimates of the changes to heat loss is less satisfactory. The empirical estimate is, on average, 78% of the predicted but with a range of 30 to 279 %. A great majority of those with a correspondence of less than the average are associated with retrofits including external insulation and double glazing.

f) Temperature changes induced by the retrofits were encouragingly small. Much of the temperature rise was associated with slower cooling and cannot be regarded as 'avoidable'.

g) Ventilation appears throughout this study, as others, as an area where insufficient data was calculable in relation to the known significance to the energy balance.

Pressurisation tests on 5 houses (carried out by British Gas) proved illuminating both in terms of the value of this technique and the results it provided. (See Section 5).

h) Empirical estimates of fuel saving agreed well with that which could have been predicted at design stages using for example the model of McNair (7). This average agreement is encouraging although within the sample there were 5 cases with savings less than 50% and 5 cases with more than 150% of the predicted. Most of these can be satisfactorily explained but the argument that on average a retrofit package will produce a stated saving will be of little consolation to those who 'under achieve' and a pleasant surprise to those who 'overachieve'. It is then important to refine expectations of 'achievement'. - the fact that almost 50% of this field study deviated so far from prediction must be regarded as unacceptable.

5. VENTILATION EFFECTS

This section reflects upon those findings capable of providing some insight into the division of reduced envelope heat loss between fabric and ventilation effects.

5.1 Empirical Estimates of Ventilation Rates

In theory it might be possible to arrive at an estimate of ventilation rates from

$$\text{E.D.H.L.} = \text{P.F.H.L.} + \text{E.V.H.L.}$$

and

$$\text{F.V.H.L.} = \text{E.V.R.} \ (0.33 \text{ Vol.}).$$

where E.D.H.L. = Empirical Design Heat Loss (W/^{o}C)
P.F.H.L. = Predicted Fabric Heat Loss (W/^{o}C) (conduction)
E.V.H.L. = Empirical Ventilation Heat loss (W/^{o}C).
E.V.R. = Empirical Ventilation Rate (ac/hr)
Vol. = Volume of dwelling (m^3).

Thus, EVR is 'available' for fortnightly periods both during the 'before' and 'after' monitoring periods.

There is generally a relationship between EDHL (and hence EVR) with external temperature which substantiates theories of increased window use as this rises (10). There are insufficient data points to confirm whether there is an external temperature below which window use is negligible (viz. stable E.D.H.L and E.V.R.).

Given an original E.D.H.L (E.V.R.) vTex relationship then after retrofitting it is expected that the greatest reduction will occur at low values of Tex (and E.D.H.L/E.V.R.) since this relates to windows being closed and hence both insulation and air infiltration reduction measures are operating. However, at higher values of Tex (and E.D.H.L/E.V.R.) although fabric measures are still operative air infiltration reduction measures are 'by-passed' by window use. In fact fewer than 20% of the dwellings conform to this idealised behaviour, the remainder producing either an equal decrease at all temperatures or (limited window use, or increased window use at lower temperatures?) a greater decrease at low values (increased window use at higher temperatures?)

Although these and other discrepancies in the E.D.H.L/E.V.R data can be adequately explained by reference to the detailed knowledge of use and other influences in these field trial dwellings, the reverse is not true. These difficulties are further compounded by inaccuracies in P.F.H.L. As referred to in section 3 the field trials identified under-achievement associated with external wall insulation and double glazing and this reflects itself in the derived E.V.Rs for these dwellings. The average E.V.Rs before and after improvements is 0.92 and 0.71 ac/hr respectively (14 dwellings) when the 'under-achievers are excluded from the sample.

Figure 6 illustrates some of the effects referred to above:-

Fig. 6a) Dwelling No. 3. No Fabric E.C.Ms. E.V.R. reduced from 1.7 to 1.0 ac/hr. The only other dwelling without fabric measures was a flat (No. 22) which showed an E.V.R. reduction of 1.3 to 1.0. ac/hr.

Fig. 6b) Dwelling No. 15. Referred to in Section 3 where an increase in condensation led to increased window use. E.V.R. increased from 0.4 to 0.5 ac/hr. These low values are compatible with a single storey terraced dwelling.

Fig. 6c) Dwelling No. 10. Representative of dwellings where permanent ventilation (windows or fixed units) inhibits reductions in E.V.R. due to air infiltration measures. E.V.R. is 1.3 before and 1.2 afterwards. (Users have some windows open all the time).

Fig. 6d) Dwelling No. 17 'Over achievement' due to greater reduction in ventilation than predicted. A first floor flat with heating of two rooms. The removal of permanent vents and weatherstripping has greatly reduced the amount of adventitious infiltration. The relationship with windspeed indicates the influence of the permanent vents to heated spaces. E.V.R. was reduced by 0.6 ac/hr.

5.2 Predicted Infiltration Rates

5 dwellings (Nos. 2,5,10,13 and 19) were subjected to pressurisation tests (before and after improvement) by staff of the Watson House Research and Development Division of the British Gas Corporation. Their findings (Table III) suggest that the E.C.Ms (cavity fill, vent sealing, draughtstripping) have produced leakage reductions of around 55% (flues sealed) in 4 of the 5 dwellings, with approximately 15% attributable to vent sealing. Dwelling No. 13 showed a much lower reduction commensurate with it being originally relatively 'tight'.

In addition to these measurements the leakage v pressure difference curves have been used together with climatic and envelope data to input into the predictive model of the Lawrence Berkeley Laboratory. (11).

These predicted infiltration and empirical ventilation rates (E.V.R.) are:-

Dwelling	2		5		10		13		19	
	B	A	B	A	B	A	B	A	B	A
Average infiltration rate predicted by LBL model (11)	2.5	0.5	1.2	0.4	1.1	0.7	0.8	0.8	1.6	0.6
Empirical ventilation rate.	1.1	0.8	1.2	0.9	1.8	1.6	1.3	1.3	1.5	0.9

(all ac/hr)

Figure 7 illustrates the fortnightly variations. It is expected that the predictions concur with the lower values of E.V.R. (i.e. windows closed). This is seen to be approximately the case although there are clear exceptions notably dwelling 2 where the very high leakage before improvements would seem to invalidate the use of the predictive model.

In all cases except No. 13 the reduction in E.V.R. is less than that indicated by the predictive infiltration reduction and this concurs with a knowledge of window use.

5.3 Summary

The use of empirical estimates of ventilation rates (E.V.R) although a promising technique is frustrated by major deviations between the theoretical and actual performance of some Fabric ELMs.

Where this is not the case the results suggest that reduction in ventilation heat loss actually achieved are highly sensitive to the type and condition of individual dwellings as well as the occupants pattern of window use. However, reductions of 0.3 to 0.6 ac/hr seem typical.

These findings undermine confidence in rules of thumb estimates of cost efficiency for weatherstripping as proposed by e.g. Freemans (12).

6. CONCLUSIONS

- standard retrofit packages based upon 'design' information are inadequate. ECMS perform differently on different dwellings, and also differently when in various combinations. Standardised solutions do not recognise the influence (upon costs and benefits) of fine scale details of individual dwellings.

- predictive models for energy savings which are based upon theoretical estimates of changes in heat loss (e.g. McNair(7) are adequate for average performances.

- it seems that retrofit packages fall into two groups. Put simply these are 'achievers' and 'underachievers'. The former group tend to be simple and low cost whereas the latter are relatively more complex and expensive. The underachievers do so because of their sensitivity to factors such as condition, user influences, workmanship, etc. Those ECMs tending to underachievement seem inappropriate for specification except in cases where older properties are being substantially rehabilitated or the property in question is relatively new, i.e. the base structure is sound and already contains the 'simple' ECMS.

- a more integrated approach to the dwelling is needed than was possible in the EIK field trials. These reflected the contemporary ethos of focusing retrofits on the long life fabric. This overlooks the, now more widely appreciated, considerable potential for energy saving through attention to the dwellings heating and hot water systems.

- it is difficult (impossible?) to separate the effects of different ECMs and in particular the impact of air infiltration reduction measures. As with the whole packages a rule of thumb design estimate of a reduction in ventilation heat loss of 25% (1.0 to 0.75 ac/hr) may concur with average attainment but there are large variations between individual dwellings.

- In several cases there is strong but circumstantial evidence that either due to increased condensation on windows and/or higher room temperatures there is an increase in window use which has inhibited the full attainment of potential savings.

- Finally it cannot be overemphasised that the EIK study consisted essentially of 25 separate case studies and as such scientifically acceptable conclusions and hence generalisations cannot be made. Nevertheless it is hoped that the case law which such studies represent is not undervalued in the field of application.

7. ACKNOWLEDGEMENTS

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Finally the co-operation of dwelling occupants should not go unrecognised.

The views expressed in this paper are those of the authors alone and do not necessarily reflect those of other contributors to the EIK project.

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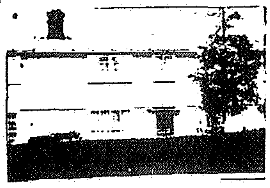
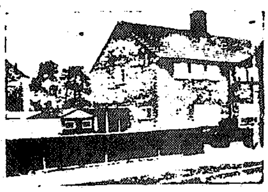
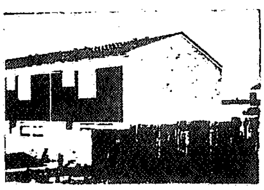
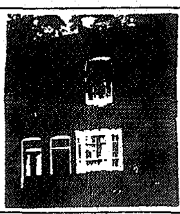
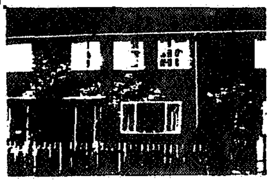
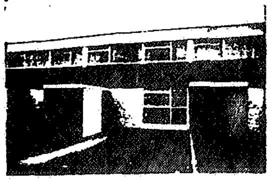
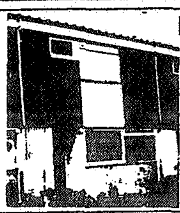
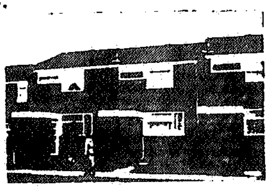
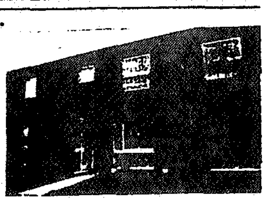
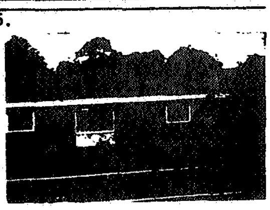
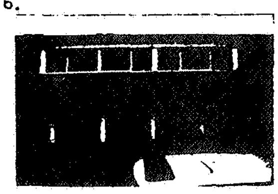
TABLE I

		DESCRIPTION	ECMs	Cost £
1.		Type Semi-det. 3 bed. 1931. 9" solid brick wall, slate roof with 50 mm ins., timber suspended and solid ground floor. Services Solid fuel (liv) room heater with electric heating to landing and bed 2. Gas cooker	80mm roof ins (50- 130) Draughtstrip, fill airbricks Hardboard line liv. floor Front lobby Replace louvre windows with casement 100 mm ins. to HWC (25- 100) New room heater and 3 rads. Underfloor draught and servicing	49 132 58 114 117 21 894
2.		Type Semi-det. 3 bed. 1948. Cavity wall, tile roof with 100 mm ins. Ground floor concrete and boarding on battens on concrete. Services Gas fire both livs. DHW electric immersion (25 mm ins). Gas cooker	75 mm cavity fill Draughtstrip, fill airbricks 75 mm ins. to HWC (25- 75) Servicing to gas appliances	129 177 7 12
3.		Type Semi-det. 3 bed. 1953. B.I.S.F. tubular steel frame, render on expanded metal lower floor, steel trough sheeting upper. Steel roof with 100 mm ins. Concrete floor. Services Gas fire in liv, flueless gas convector then Feb 1980 paraffin in bed 2 DHW electric immersion (no ins). Gas cooker	(Rockwool to ext. walls (Feb '80) Draughtstrip Close unused flue HWC Boxed inc 50 mm ins (0- 50) Wind up timer for DHW Balanced flue gas heater to hall Servicing to gas appliances	300) 157 60 37 45 103 9
4.		Type Semi-det. 3 bed. 1928. 9" solid brick wall rendered upper floor, slate roof (no ins). Timber suspended and concrete ground floor. Services Gas fire in liv, electric heater in bed 1. DHW electric immersion (no ins). Gas cooker	100 mm ins. to roof (0- 100) 50 mm ext wall ins Draughtstrip, fill air bricks Hardboard line liv. floor Front porch 100 mm ins to HWC (0- 100) Wind up timer to DHW Servicing gas appliances	43 2136 142 52 781 7 45 9
5.		Type End terr. 2 bed. 1951. Cavity walls, tile roof with 100 mm ins. Concrete floor. Services Gas fires in liv. and bed 1, flueless gas convector in hall. D.H.W. electric immersion (100 mm ins). Gas cooker.	50 mm cavity fill Double glazing to liv. and bed 1 Draughtstrip, fill airbricks Entrance porch 75 mm ins to H.W.C. (100 - 75) Wind up timer for D.H.W. Servicing gas appliances	129 654 174 511 7 45 19
6.		Type End terr. 3 bed. 1970. No fines concrete walls, tile roof with 25 mm ins. concrete floor, gasket weatherstripping to windows. Services Gas warm air unit, outlets in kit, liv, hall, roomstat and timeclock. Electric heater in bed 1. D.H.W. electric immersion (25 mm ins). Inst electric shower. Gas cooker	80 mm roof ins (25 - 105) 50 mm external wall ins Draughtstrip, fill airbricks 75 mm ins to H.W.C. (25- 100) Servicing gas appliances	48 2476 84 7 12
7.		Type End terr. 3 bed. 1969. Timber frame with 25 mm ins. Clad with plywood at ground floor, tile hanging at 1st floor, brick at gable end; tile roof with 25 mm ins. Concrete floor. Services Gas warm air unit, outlets in every room, roomstat and timeclock. D.H.W. electric immersion (25 mm ins). Gas cooker	100 mm roof ins (25- 125) 25 mm ins to bottom panel of liv. window Draughtstrip, fill airbricks 75 mm ins to H.W.C. (25- 75) Time clock for D.H.W. Servicing gas appliances	68 12 120 7 50 12
8.		Type Mid terr. 2 bed. pre 1900. 9" solid brick walls, slate roof with 30 mm ins. Timber suspended and solid ground floor, 'tunnel' entry to rear. Services Gas fire in liv. 1, paraffin heater in liv. 2. D.H.W. electric immersion (12 mm ins). Gas cooker	80 mm ins. to main roof (30- 110) 50 mm ext. wall ins. to rear entrance 'tunnel' Flush door replacing glazed door Dryline front bed.(50 mm ins) Draughtstrip, fill airbricks Hardboard line ground floor Gas back boiler for D.H.W. 75 mm ins to H.W.C. (12- 89)	48 1480 63 149 150 85 270 7

	DESCRIPTION	ECMs	Cost £
9. 	Type Mid terr. 3 bed. 1928. 9" solid brick wall, slate roof (no ins). Timber suspended and concrete ground floor. Services Gas fire in liv, electric heater in bed. 1. D.H.W. electric immersion (25 mm ins). Gas cooker	100 mm ins. to roof (0- 100) Draughtstrip, fill air bricks 100 mm ins to H.W.C. (25- 100) Wind up timer to D.H.W. Servicing gas appliances	35 145 7 45 9
10. 	Type Mid terr. 3 bed. 1947. Cavity wall, tile roof (75 mm ins). Boarding on battens on concrete ground floor. 'Tunnel' entry. Rear draught lobby. Services Gas fires both livs, electric heater in bed 1. D.H.W. gas back boiler and electric immersion (25 mm ins). Gas cooker	80 mm ins. to roof (75- 155) 50 mm cavity fill Draughtstrip, fill airbricks Servicing gas appliances	56 70 126 22
11. 	Type Mid terr. 3 bed. 1967. Pre-cast panel walls (25 mm ins), tile hung at 1st floor. Tile roof (25 mm ins). Concrete floor. Services Gas warm air unit outlets in both livs, kitchen and landing; roomstat and time clock. D.H.W. electric immersion (25 mm ins). Gas cooker	80 mm ins. to roof (25- 105) Double glazing to both livs. Draughtstrip, fill airbricks 75 mm ins. to H.W.C. (25- 75) Servicing gas appliances Return air grille above lounge door	54 417 81 7 12 6
12. 	Type Mid terr. 3 bed. 1968. Pre-cost walls (19 mm ins), tile roof (25 mm ins) Concrete floor (edge ins). Services Gas warm air unit outlets in liv, kitchen, hall, 2 beds; roomstat and time clock. D.H.W. electric immersion (25 mm ins). Gas cooker	80 mm ins. to roof (25- 105) Double glazing to liv. Draughtstrip, fill air bricks 75 mm ins to H.W.C. (25- 75) Servicing gas appliances 25mm ins. to store wall Wind up timer (+ later removal)	56 250 81 7 12 19 61
13. 	Type Mid terr. 3 bed. 1970. Cavity walls, tile roof with 25 mm ins. Concrete floor. Front draught lobby (installed by tenant) Services Gas warm air unit, outlets in liv, kit, hall, roomstat and time clock. D.H.W. electric immersion (25mm ins). Gas cooker	80 mm roof ins. (25- 105) 55 mm cavity fill Draughtstrip, fill airbricks 75 mm ins. to H.W.C. (25- 75) Servicing gas appliances	47 57 94 7 12
14. 	Type Mid terr. 2 bed. 1977. Cavity wall at ground floor. Tile hanging on blockwork at 1st floor. Tile roof with 25 mm ins. Concrete floor. Front draught lobby. Services Gas boiler with radiators in liv, kit, hall, bath. D.H.W. from boiler (25 mm ins). Gas cooker	80 mm roof ins. (25- 105) Double glazing to liv. Draughtstrip, fill air bricks 75 mm ins. to H.W.C. (25- 100) Thermostatic radiator valves Servicing gas appliances	49 154 124 7 116 12
15. 	Type Mid terr. bungalow, 1 bed. 1968. Cavity walls. Tile roof with 25 mm ins. Concrete floor. Services Gas warm air unit outlets in kit, liv, hall, bed, roomstat and time-clock. D.H.W. electric immersion (25 mm ins). Gas cooker	100 mm roof ins (25- 125) Draughtstrip, fill airbricks 75 mm ins. to H.W.C. (25- 75) Servicing gas appliances Wind up timer to DHW	59 69 7 18 45
16. 	Type 1st Floor flat. 2 bed. 1968. Pre cast panel walls, tile hung with 25 mm ins. Tile roof with 25 mm ins. Chipboard floor on battens on suspended concrete slab (over garages) with 25 mm ins. Services Gas warm air unit, outlets in liv, hall, bed 2, roomstat and time clock. D.H.W. electric immersion (25 mm ins). Gas cooker	100 mm roof ins. (25- 125) Double glazing to liv. Draughtstrip, fill airbricks 75 mm ins. to H.W.C. (25- 75) Service gas appliances	93 290 102 7 12

DESCRIPTION | ECMs | Cost £

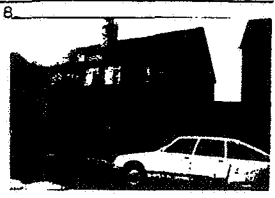
17.

Type 1st Floor flat. 1 bed. 1970 conversion, house 1930. 9" solid brick wall, slate roof (old). Cavity wall, flat timber/board/felt roof (25 mm ins)(new)

Services Gas fire in liv, paraffin on landing and in kitchen. D.H.W. electric immersion (25 mm ins). Gas cooker

ECMs	Cost £
150 mm ins. to slate roof(0-150)	78
75 mm ins. to kitchen ceiling (25-100)	136
50 mm cavity fill	83
Draughtstrip, fill air bricks	63
Replace louvre windows with casements	83
75 mm ins. to H.W.C. (25- 75)	7
Wind up timer to D.H.W.	45
Servicing gas appliances	9

18.

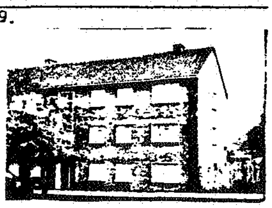


Type Ground floor flat in 2 storey block. 1 bed. 1957. Cavity wall, concrete floor.

Services Gas fire in liv, calor gas in bed. D.H.W. electric immersion (no ins). - unused. Gas cooker

ECMs	Cost £
60 mm cavity fill	75
Draughtstrip, fill airbricks	65
Replace D.H.W. with gas multipoint	302
Balanced flue gas heater to bed.	130
Servicing gas appliances	9

19.

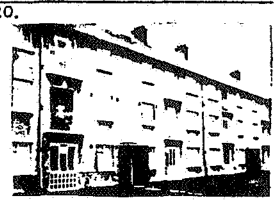


Type Top floor flat in 3 storey block. 3 bed. 1954. Cavity walls. Tile roof with 100 mm ins.

Services Gas fire in liv. D.H.W. electric immersion (10 mm ins). Gas cooker

ECMs	Cost £
60 mm roof ins (100- 160)	74
Drylining (35 mm ins) to bed3/stair) wall, kitchen/drying room wall)	237
Draughtstrip, fill airbricks	98
75 mm ins. to H.W.C. (10- 75)	37
Balanced flue gas conv. to bed 1	224
Servicing gas appliances.	9
(Inspection of cavity walling)	21)

20.



Type Mid floor flat in 3 storey block. 2 bed. 1952. No fines concrete walls. Balcony glazed in by tenant

Services Gas fire in liv, electric heater in hall. D.H.W. electric immersion (no ins). Gas cooker

ECMs	Cost £
50 mm external wall ins.	1087
Draughtstrip, fill air bricks	112
Remove window vents	19
H.W.C. boxed inc. 50 mm ins (0 (0- 50)	37
Wind up timer for D.H.W.	45
Servicing gas appliances	9

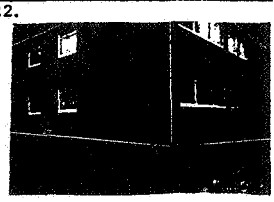
21.

Type Gnd flr maisonette in 4 storey deck access block. 3 bed. 1960. Cavity walls Concrete floor. Ceiling exposed above bed 1, bed 2 and bath. Suspended concrete floor in bed 1 and bath over entry.

Services Gas fire in liv. Flueless gas conversion in hall. D.H.W. electric immersion (25 mm ins). Gas cooker

ECMs	Cost £
50 mm ins. to soffit of entry	235
Dryline ceilings of bed 1, 2 and bath (50 mm ins)	340
Draughtstrip, fill airbricks	102
75 mm ins. to H.W.C. (25- 100)	7
Time clock for D.H.W.	50
Servicing gas appliances	9

22.

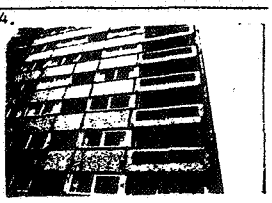


Type Gnd. flr. flat in 12 storey block. 1 bed. 1969. Pre cast panel walls with 25 mm ins. Concrete floor with 12 mm ins. Integral rubber window weather-stripping

Services Off peak electric storage heaters in liv. D.H.W. off peak electric immersion (50 mm ins). Electric cooker

ECMs	Cost £
Draughtstrip, fill airbricks	81

24.

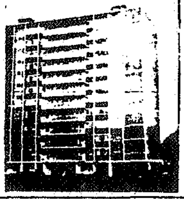


Type 3rd flr. flat in 11 storey block. 1 bed. 1968. Pre cast panel walls with 12 mm ins. 25 mm ins. in communal wall to ventilated fire lobby

Services Off peak electric underfloor heating to liv. and hall. Fixed electric fire in liv. Electric heater in bed. D.H.W. off peak electric immersion (25 mm ins). Electric cooker

ECMs	Cost £
Balcony opening glazed in	396
Draughtstrip, fill airbricks	51
75 mm ins. to H.W.C. (25- 100)	7

25.



Type Top flr. flat in 12 storey block. 1 bed. 1964. Concrete frame with concrete infill panels with 50 mm ins. Concrete roof. Double glazing (4 mm gap) in bed. and kit.

Services Electric heater in liv. D.H.W off peak electric immersion (25 mm ins). Gas cooker.

ECMs	Cost £
Double glazing to liv. and bed.	378
Dryline liv, bed, kit (50 mm ins)	546
Draughtstrip	68
75 mm ins. to H.W.C. (25- 100)	7
Servicing gas appliance	6

23.

Type & Services as 24 but no double glazing

ECMs	Cost £
Double glazing to liv. and bed.	378
Draughtstrip	68
75 mm ins. to HWC (25-100)	7

TABLE II

E. C. Ms. Cost - Benefits - Pre-Installation Knowledge

ECM Type	£	Change in U/(W/^{o}Cm^2	£/Δ U
Air infiltration			
- Window & door weatherstripping Silicone rubber & brush	1.74 to 2.02/m		
- Airbrick removal	3 ea		
- Unused flues - 'sealed'	27 ea		
- Louvre windows replaced	83 - 109 ea		
- Suspended floors 'lined'	3/m^2		
- Porches	511 - 655		
Roof Insulation			
- Fibreglassquilt (tmm)	(40 + t/2)p per m^2	1.70 to 0.17	0.89 to 11.11
- Drylining (50mm polystyrene)	12 - 15 per m^2	0.5 to 1.5	8 to 28
Wall Insulation			
- Cavity (U foam) - tmm	(122 + 15 t/25) per m^2	1.0	1.6
- Internal (50mm polystyrene)	11.50/m^2	1.5	7.7
- External (50mm insulation)	29/m^2	1.5	19.3
Double glazing			
- Secondary Aluminium frame	51/m^2	2.8	18.2

Table III Pressurisation Test Results *

EIK No	2		5		10		13		19	
Approx vol. (m^3)	158		128		158		150		114	
Approx. surface area (m^2)	141		123		127		90		145	
Before or After ECMS	B	A	B	A	B	A	B	A	B	A
No. of air vents	6	0	6	0	5	0	1	1	6	1
No. of flues	3	3	2	2	3	3	1	1	1	1
Leakage at 50pa(m^3/s										
- flues sealed	1.36	0.48	0.88	0.38	0.89	0.41	0.75	0.64	0.78	0.30
- corrected for flues	1.66	0.78	1.09	0.58	1.19	0.71	0.79	0.68	0.88	0.40
Effective Orifice Area (50pa)m^2	0.247	0.087	0.161	0.069	0.161	0.075	0.136	0.116	0.142	0.055
% Reduc - All		65		57		53		15		61
- vents alone		23		6		6		-		29

(* Courtesy of British Gas - Research & Development Div.)

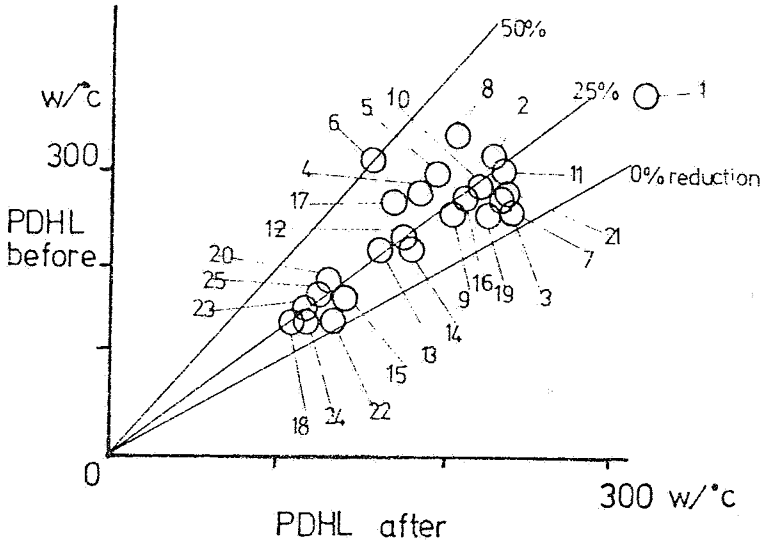


FIGURE 1

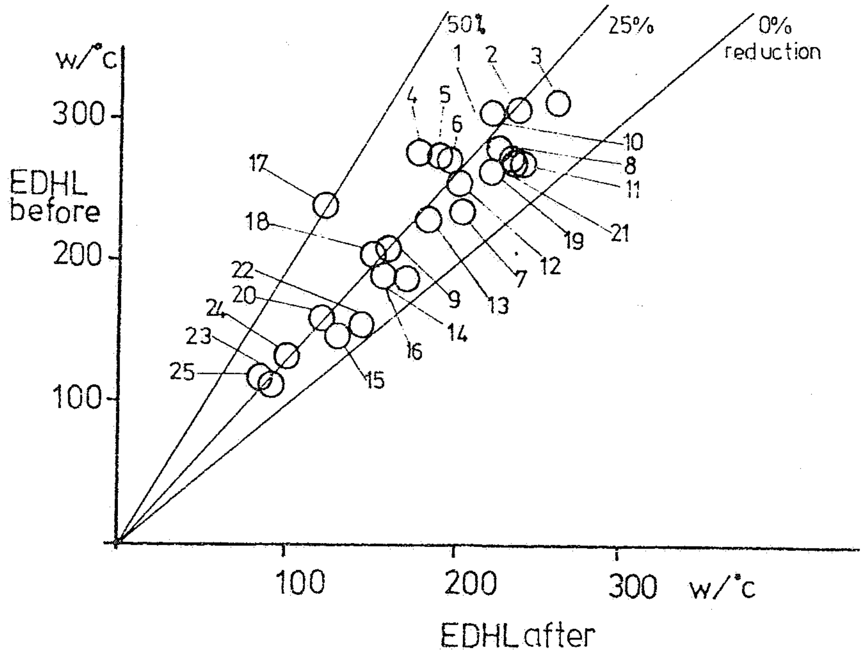


FIGURE 2

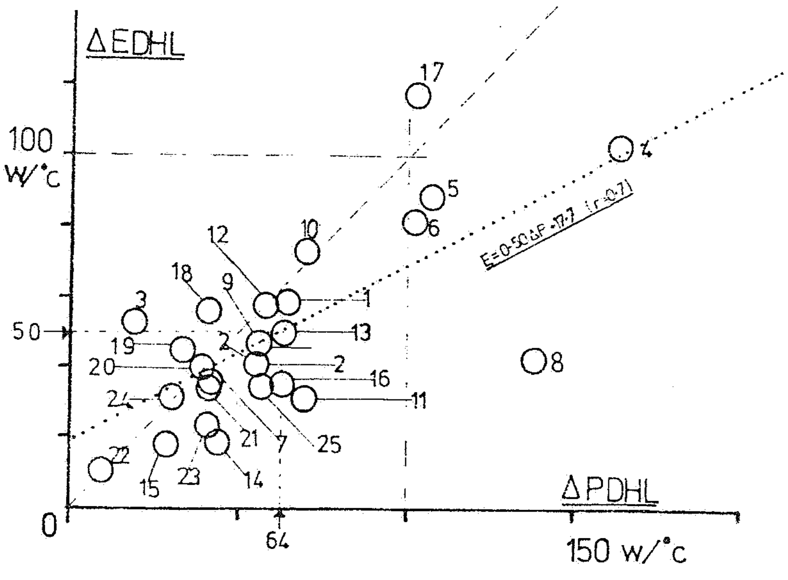


FIGURE 3

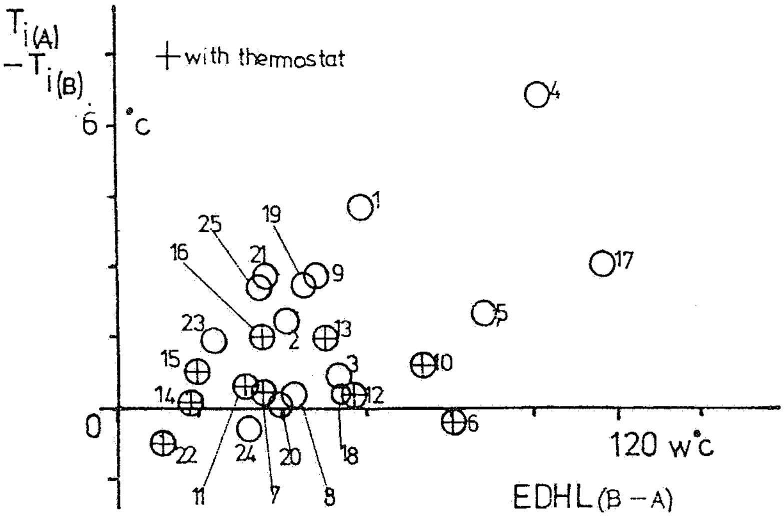
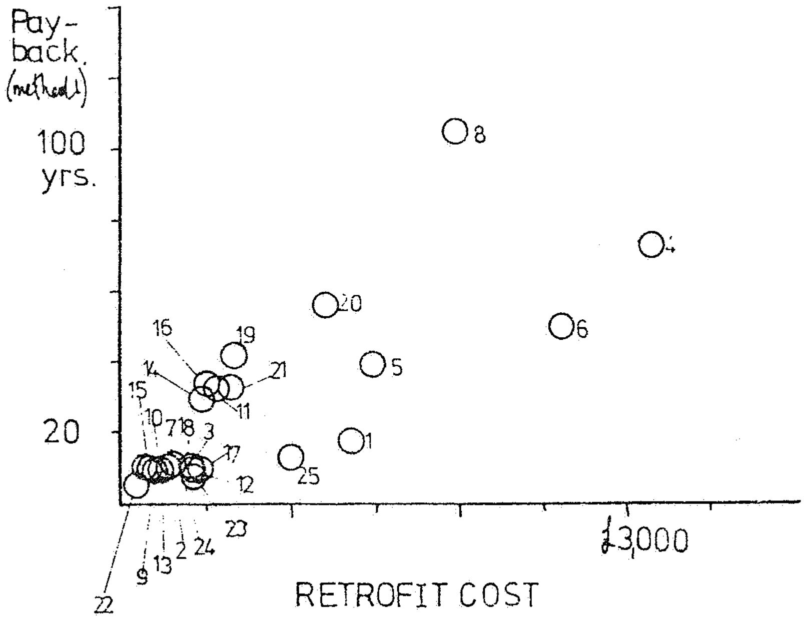


FIGURE 4



FIGURE

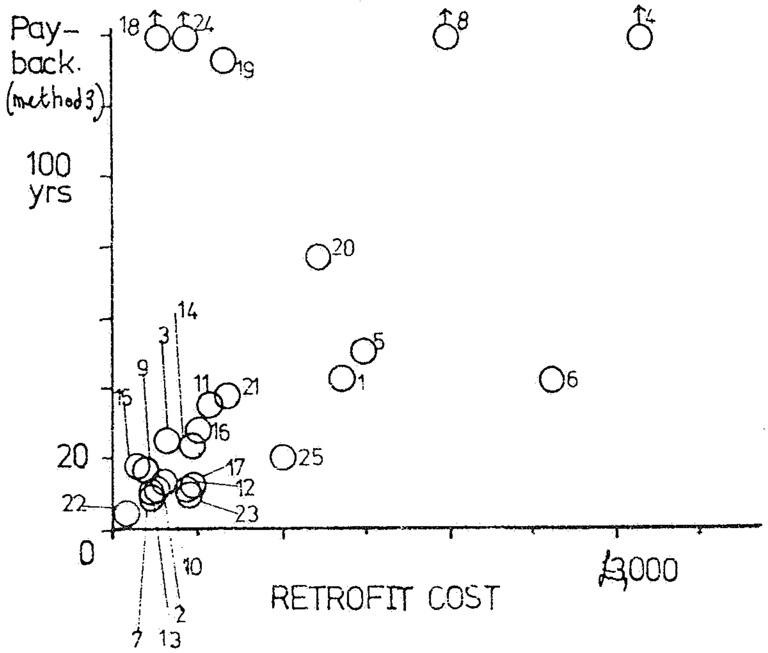


FIGURE 5(b)

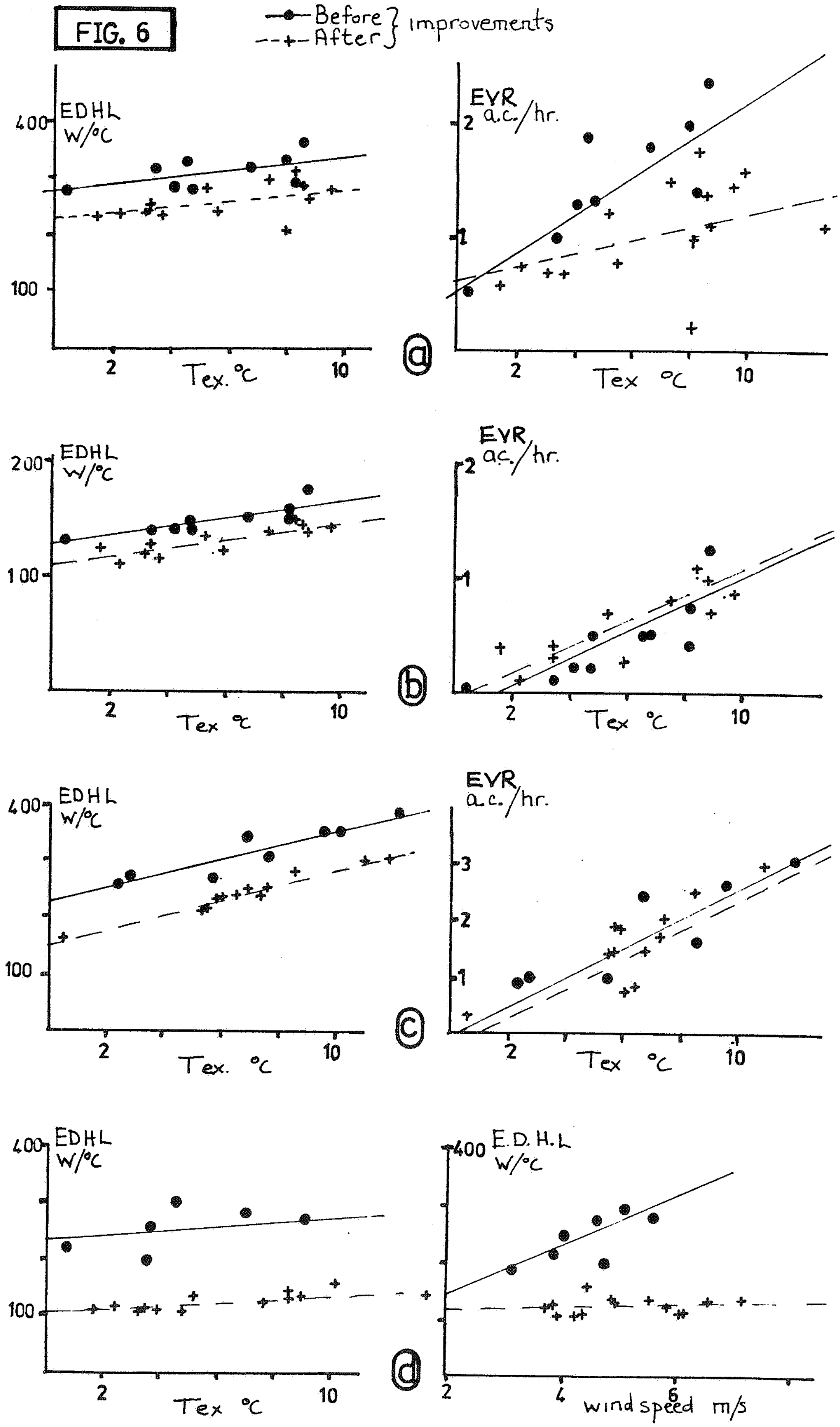


FIG. 6
Before } improvements
After
EDHL W/°C
400
100
2
10
Tex. °C
EVR a.c./hr.
2
1
Tex °C
(a)
EDHL W/°C
200
100
2
10
Tex °C
EVR a.c./hr.
2
1
2
10
Tex °C
(b)
EDHL W/°C
400
100
2
10
Tex. °C
EVR a.c./hr.
3
2
1
2
10
Tex °C
(c)
EDHL W/°C
400
100
2
10
Tex °C
E.D.H.L W/°C
400
2
4
6
wind speed m/s
(d)

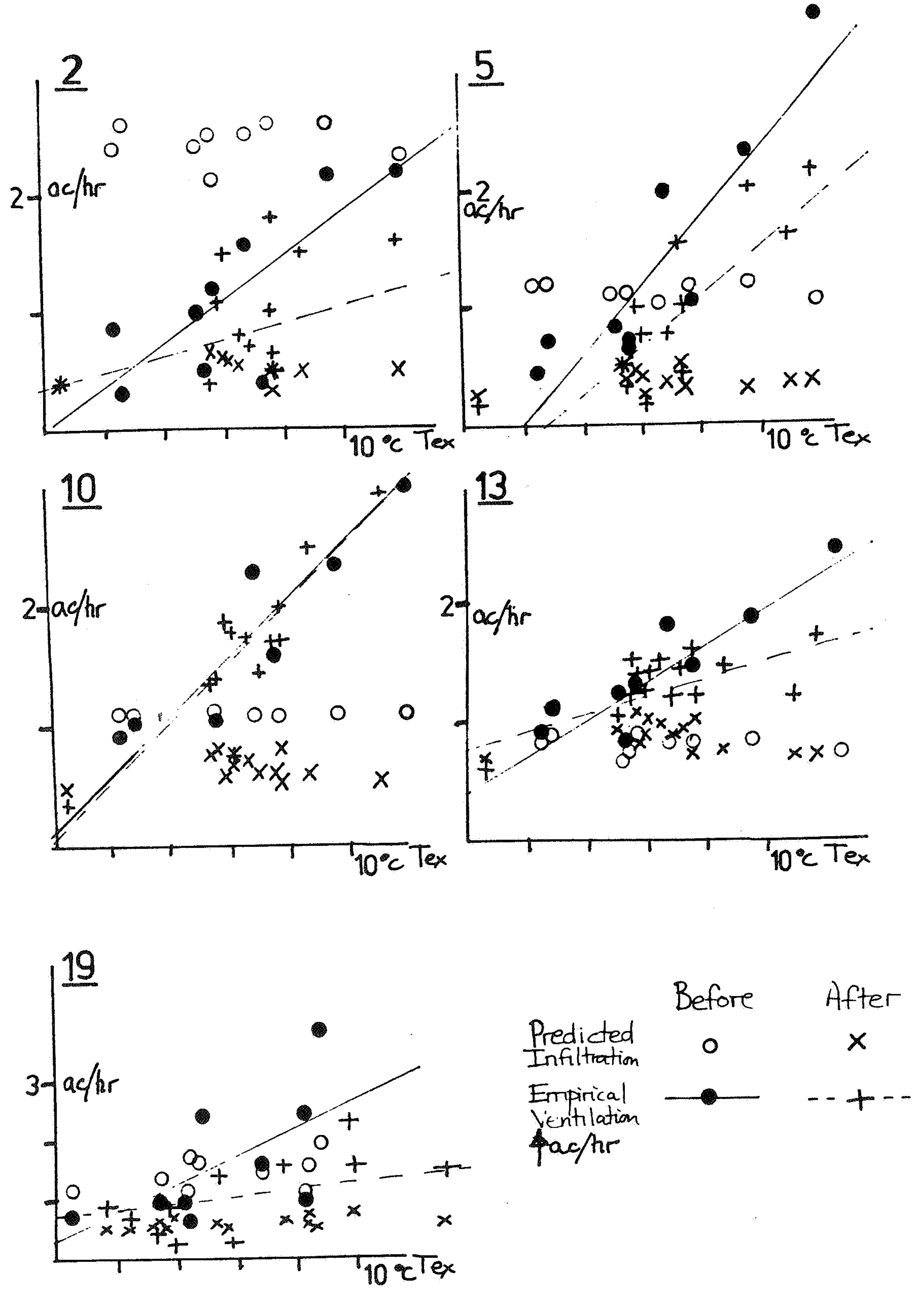

2
2
ac/hr
10 °c Tex
5
2
ac/hr
10 °c Tex
10
2
ac/hr
10°c Tex
13
2
ac/hr
10°c Tex
19
3
ac/hr
10 °c Tex
Before
After
Predicted Infiltration
Empirical Ventilation
ac/hr

FIGURE 7