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EXPERIENCE IN LOW ENERGY LIVING

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1. Background

Early research on better insulated housing revealed two features. The first was the realisation that there was a wide variety of lifestyles and priorities between families. The second was that ventilation had been neglected. Ventilation becomes progressively more important as the fabric insulation improves (1,2,3).

The ventilation in British houses depends upon the size and location of gaps in the house construction, randomly and accidentally introduced by the builder, the wind speed and direction, and shelter for the house from it, and finally to the householder's desire and ability to open the windows. The actual ventilation needs of the household are primarily determined by the amount of moisture and smells generated within the house.

The window opening habits of householders have been studied and in Britain most houses have at least one window open during the heating season. It is very difficult for the householder to appreciate the amount of energy lost through this route. Equally, for those householders who take steps to seal the house against draughts, there is the problem of under-ventilation and the consequences are dampness and mould problems (4).

The Electricity Council decided to explore the customer reaction to a very well insulated, all-electric house which was designed, constructed and weatherstripped to give minimal infiltration. Planned ventilation was then provided with heat recovery. This was done in co-operation with two national builders and the houses were built, sold and, with the owner's permission, monitored (5,6,7).

2. Design Features

The thermal design was based on the best practicable masonry practice, with a widened, filled wall cavity and fibrous insulation in the roof and under the floor. The thermal transmittance was 0.35 W/m^2°C for all the opaque surfaces of walls and floor and 0.25 W/m^2°C for the top floor ceilings. Double glazing was used throughout. The air tightness was checked by pressurisation and was less than 7 air changes/hour at 50 Pascals. The ventilation system comprised two fans, one supplying fresh outdoor air to the living room and bedrooms, while the other extracted slightly more stale air from the bathroom, toilet and kitchen. A heat exchanger linked the two air flows so that energy could be recovered from the stale outgoing air and used to preheat the cold incoming air. These heat exchangers had a temperature efficiency of 60% but because the outgoing air was humid, the actual energy efficiency was only 40%. The householder could choose from three fan speeds which gave 0.3, 0.5 and 0.75 air changes per hour for the house. There was a special damper on the kitchen cooker hood to rearrange the air flow to give proportionally more air extraction from the cooker hood during cooking. The windows were conventional in design but fitted with electrical contacts which recorded whenever the windows were opened. Another electrical circuit monitored when the house doors were open. A storm porch was recommended to provide an air lock to the house. The houses were all-electric on the Economy 7 tariff which provided electricity between midnight and 7 a.m. at 2p/kWh, while the electricity used for the rest of the day was 5.5p/kWh.

3. Influence of the physical factors

The first effect of thermal insulation is to provide a more uniform temperature both within the house and within the room. The thermal resistances between rooms becomes less important as the outer walls become better insulated and the temperatures found in unheated bedroom is increased (1,8,9).

The second effect is to slow down the rate of cooling of a room and thereby diminish the benefits of regular intermittent operation of the heating. This effect is illustrated in Fig. 1. However, when a change in temperature is required, for example in the bedroom, then the heating system has to be designed for response rather than for steady state losses (10).

The third effect is to reduce the gross heating requirement of the house. The free heat from sunshine, the heat gains from electrical appliances, losses from water heating and distribution, cooking and the sensible metabolic heat from the occupants themselves, then forms a major part of the heating energy. This means that the space heating equipment now has to be responsive and complementary to the availability of the free heat. In these houses the living room is heated by a fan controlled storage radiator supplemented by a charge controlled storage radiator in the hall.

The fourth effect was that the loft would be expected to be colder than in a conventional house. This increases the risk of freezing for the piping and water storage tanks customarily located there. We therefore planned to keep all water services within the occupied envelope of the house. Loft penetrations were minimised too and the service hatch weatherstripped to reduce the quantity of moist air entering the loft. This was done to prevent condensation and the consequent corrosion and rot in the loft.

The fifth effect arises out of the decreasing balance point temperature for the house. The basic temperature for degree day energy calculations in Britain is 15.5°C. The statistical nature of degree days is shown in Fig. 2. As the base temperature falls, so the percentage variation between years grows. At 5°C the degree days over a heating season can vary from below 100 to 500. At 15°C the range is 1,700-2,500. This makes the low energy house rather more sensitive to extremes in weather

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in relative terms. More generous sizing is therefore required for the heating system (11).

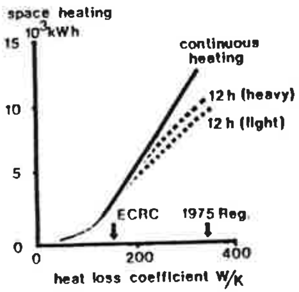

Fig. 1 Energy savings for intermittent operation

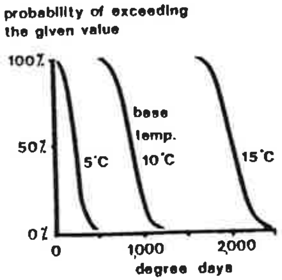

Fig. 2 The year to year variability of degree days

4. User behaviour

The four low energy houses were marketed in the conventional way, through estate agents and the site offices. The price was approximately £30,000 each and these houses were priced at £750 above the similar conventional houses on the estate.

The energy saving features were not a major influencing factor to prospective purchasers. One of the most important features appeared to be site location and once a site looked attractive then the prospective purchasers sought a house with the layout and features which they could afford. Some purchasers bought their house with some misgivings about the electric heating system. All the householders had purchased at least one house previously and all were accustomed to paying normal fuel bills.

The first year of occupancy for all the houses was recorded in detail in terms of moisture generation rate, ventilation, temperatures and energy consumption for different purposes. The householders all had some initial apprehension but relaxed when the running costs became known and they then deliberately operated their houses to be unusually warm. The seasonal average lounge temperatures for the four houses are plotted in Fig. 3 compared with the national trend line (12). Average house temperatures are linked to the design day heat losses and our four houses are in line with predictions based on field surveys (13). This is illustrated in Fig. 4. Families were sensitive to small temperature falls of 1-2°C during the day in the hall (14).

The householders generally used the ventilation system on the lowest fan speed with short excursions to the higher speeds when cooking. This reflects the time of day when food is prepared and shows the regular use of the boost speed for short periods each evening. All the householders found it unnecessary to open the windows for most of the heating season. The total time for which windows were open for thirty weeks of the winter was less than one hour. Towards the end of April, as the heating season was ending, there were a few days when the windows were open for an hour or so. The two doors to each house were open for a total of twenty minutes each day. This time was remarkably similar for all four houses, despite wide differences in family size and age of the children. The average ventilation rate was 0.7 ac/h.

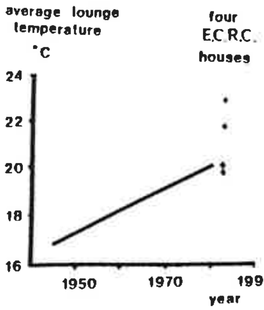

Fig. 3 The trend in lounge temperature

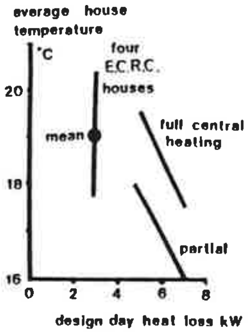

Fig. 4 The influence of design heat loss on house temperature

The householders' appreciation of the air quality inside their houses was an unqualified success but often in unexpected ways. They recognised that the heat recovery component meant that the ventilation system could be used without fear of high energy costs. It provided an indoor air quality better than they had experienced before. It enabled moisture to be controlled and the benefits of this were more widespread than initially envisaged. They were aware of the ability of the system to remove odours, particularly in some cases as cigarette smokers themselves. Individual householders used their ventilation controls imaginatively. Boost speed with cooker extract restricted meant that the bathroom mirrors cleared immediately after a bath or shower and could then be used for grooming. Damp towels dried quickly too. Numerous minor benefits included the fresh sensation when entering the living room in the morning after entertaining friends who had been smoking on the previous evening. They also included having dry cupboards where the sugar and salt would always flow freely, where crisp breakfast cereals stayed crisp for several days after opening the packet, and enjoying a clear, uninterrupted view out of all the windows throughout the year. The cooker hood extract also meant that the kitchen decorations stayed cleaner for much longer because the rate of grease deposition was much lower than normal (15).

The combination of double glazing and mechanical ventilation protected the household from external noises and this was particularly welcomed by one family who worked unsocial hours. However, the exclusion of outdoor noise did make the indoor noise much more noticeable, particularly at night. One householder was very sensitive to the noise which came from the thermostat which controlled the bedroom heater. The ventilation system itself was inaudible at its lowest speed which was used at night.

Minor chores were readily accepted. The cooker hood grease filter had to be cleaned monthly and this could also be done in the dishwasher. Towel fluff collected in the bathroom extract and had to be removed occasionally. Airborne outdoor dust too fine to be stopped by the air filter, caused slight pattern staining around the ceiling inlet grilles but was so slight that the owners did not think additional painting between normal redecoration periods would be needed.

All the families liked their houses. The householders were revisited after two years and they had retained their favourable views of their houses. Their overall energy consumption has stayed relatively constant for the first four years of occupation. The energy analysis for each house is summarised in Table 1 (15,16).

Table 1 Data relevant to heating over a 32 weeks heating season

		22 AG		31 AG		8GC		9GC	
		32 weeks	av. daily	32 weeks	av. daily	32 weeks	av. daily	32 weeks	av. daily
Average temperatures									
Lounge	°C		20.0		22.8		21.7		19.7
Whole house	°C		17.7		20.4		19.3		18.5
Outside	°C		6.1		5.9		6.4		6.4
Difference	K		11.6		14.5		12.9		12.1
House heat losses									
Transmission heat loss coeff.	W/K		137		137		140		140
Transmission heat loss	kWh	8,512	38.0	10,752	48.0	9,715	43.4	9,148	40.8
Ventilation loss	kWh	1,857	8.3	2,363	10.6	2,668	11.9	2,327	10.4
Total		10,367	46.3	13,125	58.6	12,383	55.3	11,476	51.2
Other energies ('free' heat)	kWh								
Water heating	kWh	1,537	6.9	4,014	17.9	1,537	6.9	1,364	6.1
Fan energy	kWh	477	2.1	277	1.2	423	1.9	347	1.6
Cooker	kWh	498	2.2	603	2.7	796	3.6	493	2.2
Other electricity	kWh	1,558	6.9	2,920	13.0	2,534	11.3	1,662	7.4
Metabolic heat	kWh	1,523	6.8	2,195	9.8	1,611	7.2	1,142	5.1
Net solar heating	kWh	2,231	10.0	2,092	9.3	1,836	8.2	1,798	8.0
Total free heat	kWh	7,824	34.9	12,101	54.0	8,737	39.0	6,806	30.4
Space heating	kWh	5,365	24.0	6,428	28.7	5,280	23.6	5,680	25.4
Useful free heat	kWh	5,002	22.3	6,697	29.9	7,103	31.7	5,796	25.9
Lost free heat	kWh	2,822	12.6	5,404	24.1	1,634	7.3	1,010	4.5
% useful free heat			61.6		55.3		81.3		85.2
Family size		2 adults 2 children		2 adults 4 children		4 adults -		2 adults 1 child	

The householders hold two economic concepts. The first and most important is total cost of energy in the home. If this total is too high then economies are more likely to be sought in heating than in lighting, cooking, water heating or appliances. The accepted figure for Britain is 5% of annual expenditure (17). The second concept is value. The running cost of the lower energy house appears to be good value to the householders and therefore they deliberately choose to take some benefit in terms of high comfort standards. This higher temperature standard can be reached with higher air quality and this produces very high levels of satisfaction.

5. Conclusion

(1) The customer satisfaction with the low energy houses is very high. This satisfaction is more related to a freedom to choose high comfort standards at low energy cost without worry, rather than trying to save the maximum energy. Each family chose to have a warm house.

(2) The mechanical ventilation system was an unqualified success. Not only did it provide an attractive indoor climate with low energy penalty but it removed the desire to open the windows. Unexpected but highly popular benefits included an unmisted bathroom mirror, free running sugar and salt, and breakfast cereals which remained crisp when opened.

(3) Free heat from the occupants, sunshine, hot water and electrical appliances and light within the house provided a large amount of the space heating requirement. However, there was a wide difference in the degree of usefulness of these sources of energy. Energy estimates for low energy dwellings are more likely to be accurate if based on total energy rather than space heating energy alone.

(4) The energy saving benefit of daily, intermittent operation of the heating system reduces in the well insulated house because the rooms cool much more slowly. Steady living room temperatures were popular but the heating system in the bedrooms has to be sized for response rather than steady state losses, to enable it to cater for times when the bedrooms are used for social or work activities.

(5) The householders were well protected from external noise but this made internally generated noises more noticeable. More attention will be needed for silent household services and equipment.

(6) Our knowledge of people's preferred comfort temperature and our recognition that for many years now we have spent 5% of our expenditure on fuel and power for the house, should form the basis for an energy labelling scheme for houses which will work well and be popular to live in.

6. References

(1) Brundrett, G.W., Some effects of thermal insulation on design. Applied Energy, 1, 7-30, 1975.

(2) Siviour, J.B., Theoretical and experimental heat losses of a well insulated house. CIB 8th Congress, Oslo, 1980.

(3) Green, M.B., Heat services for future housing, Part 2. The design of gas systems for insulated housing. Building Services Engineer, 45, 155-162, 1977.

(4) Brundrett, G.W. & Poultney, G., Use of natural ventilation. 3rd AIC Conference, London, September 1982.

(5) Siviour, J.B., Experimental thermal calibration of houses. Conference on Comparative experimentation of low energy houses. University of Liege, Belgium, May 1981.

(6) Siviour, J.B., Theoretical and practical realisation of low energy houses in Britain. CIB 9th Congress, Stockholm, 1983.

(7) Siviour, J.B. & Millar, R.M., The Capenhurst Lowen house: general report. ECRC/R 1972, July 1985.

(8) Anderson, B.R., Field studies on the effect of increased thermal insulation in some electrically heated houses. Heating and Ventilating Engineer, 52 (613), 6-12, 1978.

(9) Pimbert, S.L. & Fishman, D.S., Some recent research into home heating. J. Consumer Studies & Home Economics, (5), 1-12, 1981.

(10) McIntyre, D.A., The control of storage radiators. ECRC/R1686, 1985.

(11) Hitchin, E.R., Degree days in Britain. Building Services Engineering Research and Technology, 2 (2), 73-82, 1981.

(12) Hunt, D.R.G., & Steel, M.R., Domestic temperature trends. Heating and Ventilating Engineer, 54 (626), 5-15, 1979.

(13) Uglow, C.E., The calculation of energy use in buildings. BSERT, 2, (1), 1-14, 1981.

(14) McIntyre, D.A., Space heating in the Capenhurst low energy houses. ECRC/M1736, Electricity Council, 1985.

(15) Siviour, J.B., The Capenhurst trial houses revisited. ECRC/M1962, Electricity Council, 1985.

(16) McIntyre, D.A., Siviour, J.B., & Edwards, J.P., ECRC low energy houses: data collection and computer analysis. ECRC/M1768, 1986.

(17) Social Trends 1984. Central Statistical Office, HMSO, 1985.

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Audit methods and results

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A COMPARISON OF MULTIFAMILY RETROFITS IN THE U.S. AND EUROPE: MEASURED RESULTS AND POLICY IMPLICATIONS

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Overview of the BECA Data Base

The Buildings Energy-Use Compilation and Analysis ("BECA") data base is an international reference source for policy-makers, practitioners, and researchers on the *measured* performance and cost-effectiveness of buildings designed or retrofitted—to save energy and reduce peak electricity demand (1). The data base is maintained at Lawrence Berkeley Laboratory (LBL), with the help of other research centers within and outside the U.S. who contribute data or staff assistance. BECA contains carefully screened records on over 2200 energy-efficient residential and non-residential buildings, mostly in the U.S., Canada, and Western Europe. Part B of the data base covers retrofits of single-family and multifamily residences. The present paper focuses on multifamily retrofit results, including over 100 recently added data points that allow an initial comparison of retrofit experience in the U.S. and in three European countries. Results summarized here are presented elsewhere in more detail (2) and will be included in a forthcoming LBL report updating BECA-B.

Early retrofit programs in the U.S. concentrated on single-family houses, with attention shifting, in recent years, to multifamily buildings. The opposite trend has occurred in most of Europe: the initial retrofit emphasis was often on multifamily buildings, with a later focus on single-family homes (3).* Energy efficiency in the multifamily sector merits special attention for several reasons. In most developed countries, multifamily buildings represent a large fraction of all housing units. This is especially true in Western Europe, with about 45 to 55%

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* For example, in France over 90% of the residential energy audits completed as of mid-1984 were in multifamily buildings.

multifamily units,* but less so in the U.S. with 24% multifamily (4,5,6). Oil use and oil-saving opportunities are found to a greater extent in multifamily buildings than elsewhere in the stock. Although most newer French and U.S. multifamily buildings are electrically heated (or furnished with individual gas space and water heaters for each apartment), the less-efficient older stock tends to have central oil or gas-fired heating plants. Annual energy costs in U.S. multifamily buildings (with 5+ dwelling units) total $ 11 billion, or $830/unit. Per dwelling unit, this is 20% lower than for U.S. single-family housing, but nearly twice as high in terms of energy cost per heated floor area (6). Also, compared with the single-family stock, energy costs in multifamily buildings are more often paid by households with below-average incomes, or else—in the case of social (public) housing—from tax revenues. In Western Europe, energy use and costs in multifamily dwellings are generally lower than in the U.S., reflecting both lower appliance energy use and somewhat *higher* degree-days in most of Europe.

A comparison of U.S. and European multifamily retrofits is interesting because the latter appear to represent a "second-generation" effort. The European retrofits in the BECA data base were generally more expensive than those in the U.S., and achieved similar percentage savings—but on a lower pre-retrofit base. Lower pre-retrofit consumption of these European buildings may be due to better equipment maintenance and operation, and to building shells that were initially tighter and better insulated. The European buildings emphasized shell rather than system improvements. Most shell retrofits in multifamily buildings, while less cost-effective in energy terms, may offer other benefits in improved appearance, comfort, and structural preservation. We discuss data sources, methods, and results in the next sections.

Data Sources and Analysis Methods

BECA-B data sources include local government energy offices, public housing authorities, private and non-profit building owners and managers, research organizations, and utility companies. The data vary in completeness and level of detail; at a minimum they include *measured* energy use for periods before and after retrofit (or post-retrofit data for a treated and a control building), retrofit costs and type of measures, and selected building characteristics. Each data point is screened for completeness, internal consistency, and common definitions of key terms such as fuel heating value, retrofit type, and floorspace measurement. Energy use of the space heat fuel is normalized either for floor area or number of dwelling units.** Where there are measured data for several periods, energy use is weather-normalized using a statistical fit (7). Where only seasonal energy data are available, we normalize using the ratio of that year's heating degree-days (base 18 °C) to HDD for an average year. Due to insufficient data, we do not at present adjust for differences—either among buildings or between the pre- and post-retrofit periods—in inside temperature, internal gains, window-opening

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* Within Europe there is considerable variation; the U.K. has fewer than 20% multifamily residences, Switzerland about 80%.

** Where space heat energy is not separately metered, we use summer consumption or typical "space-heat fractions" to separate it from water heating and other end-uses.

practices, etc.

Energy costs and retrofit costs (including labor and materials) are both expressed as constant (1985) U.S. dollars. Energy costs reflect actual local prices paid at the time of retrofit (or, as a default, national average residential energy prices). For U.S. projects, the GNP deflator is used to convert costs to 1985 dollars. For other countries, original energy and retrofit costs are translated to 1981 local currency using that country's GDP cost deflator, converted to US dollars using 1981 exchange rates, and then expressed as constant 1985 US dollars using the U.S. deflator.* This procedure allows a more consistent comparison of retrofit economics in the different countries, without affecting payback calculations or other indices, such as the retrofit "investment index" (ratio of investment to annual pre-retrofit energy expenses).

Building Characteristics

We summarize characteristics of the 250 multifamily retrofit projects in the data base, by country, in Table 1. Average dwelling size is largest in the Swiss buildings (8). The 21 French retrofit projects, exclusively in social housing, included the largest buildings (both in number of units and total floorspace) but had the smallest average unit size: slightly below the French stock average (9,10). With few exceptions, all the retrofitted buildings were centrally heated with oil or gas; as noted, this is more typical of older multifamily stock than of recent construction. For the U.S., retrofits in gas-heated buildings are overrepresented compared to the stock. The opposite is true for France, with only one gas-heated building in the data base, *vs.* 30% gas heat in the centrally heated stock (11).

Average pre-retrofit energy intensities for space and water heating are significantly greater in the U.S. buildings than for the three European countries: 40% higher than the French buildings and twice as high as the Swedish cases. U.S. buildings in the data base used about 40% more energy prior to retrofit than the overall multifamily stock average (12). Prior to retrofit, the French buildings, as a group, were about average for the multifamily stock—but used about 25% more energy than the typical social housing project (9). Pre-retrofit energy intensity for the Swiss buildings was about 10% above the stock average; for the Swedish buildings pre-retrofit usage appears typical of the stock, or slightly lower (4,5).

Types of Retrofit Measures and Levels of Investment

Table 1 also shows the frequency of each main type of retrofit measure, by country. Shell insulation (typically exterior insulation on masonry buildings) is much more common in the European retrofit cases than in the U.S. examples. Heating equipment changes occurred in one-half to three-quarters of the cases for each country in the data base. Heating control changes, water heating retrofits, and other measures were most common in the U.S. and Switzerland. Without

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* 1981 rates are considered more typical of long-term trends, given the fluctuating rates of recent years.

Table 1. Multifamily Building Features, Retrofits, Energy Savings and Cost-Effectiveness.

	U.S.	France	Switzerland	Sweden
Number of Projects[a]	147	21	64	18
Building Type:				
High-rise	36	7	15	15
Low-rise (≤ 4 floors)	107	9	47	0
Combination/Unknown	4	5	2	3
No. dwellings/building *	40 [22]	60 [45]	17 [12]	38 [37]
Floor area/dwelling (m^2) *	77 [73]	64 [58]	99 [91]	74 [75]
Heating System Type:				
Central	134	21	64	18
Individual	8	0	0	0
Heating Fuel Type:				
Natural Gas	100	1	1	0
Oil	38	16	63	0
Electricity	5	0	0	0
Mixed Fuel[b]	5	3	0	3
District Heating	0	0	0	15
Climate Zone ($HDD_{18^{\cdot}C}$)				
< 2000 HDD	12	8	0	0
2000 - 3000 HDD	57	13	0	0
3000 - 4000 HDD	13	0	64	15
> 4000 HDD	65	0	0	3
Energy Intensity (MJ/m^2): *,[c]				
Pre-retrofit	1453 [1347]	1038 [1038]	849 [839]	726 [720]
Post-retrofit	1183 [1123]	885 [871]	628 [624]	605 [583]
Percent Savings	17 [16]	15 [15]	27 [26]	16 [14]
Frequency of Retrofit Measures (%):[d]				
Insulation	15	76	67	72
Windows	25	24	20	22
Heating Equipment	48	81	70	56
Heating Controls	61	24	44	56
Domestic Hot Water	23	5	9	50
Other	26	33	30	50
Retrofit Investment: *				
$US (1985)/$m^2$	11 [5]	31 [20]	46 [38]	38 [16]
Investment Index[c]	1.3 [0.6]	4.7 [3.0]	6.6 [5.5]	4.5 [2.3]
Simple Payback Time (years) *	11 [4]	41 [20]	52 [23]	24 [27]

* Values are given as mean [median]

[a] A project may include one or more retrofitted buildings at one site, which are treated as a unit for this analysis

[b] "Mixed Fuel" means that either two fuels are used for space heating (typically gas and oil, depending on availability), or that fuel switching occurred after the retrofit

[c] Energy used for space and water heating; water heating energy is estimated in some cases, using a default value of 0.15 kWh/m^2-day

[d] As a percent of all projects from that country in the database. Totals reflect multiple measures per site.

[e] Ratio of retrofit investment to pre-retrofit annual energy expenses

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better data on retrofitting patterns in the multifamily stock, it is difficult to determine how typical are the 250 cases in the data base. However, in France, a 1982 survey of multifamily retrofits produced results that can be compared with our 21 social housing examples. The survey shows about the same rate of heating equipment retrofits (27%); greater emphasis on system maintenance (23%), controls (17%), and window measures (13%); and lower frequency of insulation in walls/floors (17%) and roof/attics (12%) (13). One guide to Swiss retrofits suggests that shell measures are about 50% more common than system retrofits in multifamily buildings (14).

Average levels of retrofit investment also differ dramatically by country, as shown in Table 1. Average retrofit costs for the U.S. buildings were less than one-third the costs in the European buildings in the data base (under 25%, compared with the Swiss buildings). This holds true for both indicators: retrofit cost per unit floor area, and retrofit cost indexed to (pre-retrofit) annual energy expenses. As noted earlier, however, to the extent that the European retrofits emphasized shell insulation, some of the retrofit cost could reasonably be attributed to building preservation and restoration, not to energy savings alone.

Energy Savings and Cost-Effectiveness

Table 1 shows that, on average, the U.S. buildings saved the most energy per dwelling, but also had much higher pre-retrofit energy intensities. Average percentage savings were similar in the U.S., French, and Swedish examples (15-17%), and higher in the Swiss buildings (27%). Most dramatically, average simple payback periods for the European retrofits were between two and four times longer than for the U.S. buildings. * Payback periods this long would be unacceptable to most public or private sector building owners in the U.S. However, many of the European buildings were retrofitted earlier than their U.S. counterparts, often as part of demonstration programs that were subsidized by the government, which partially accounts for the higher cost of the European projects.

Figures 1 and 2 present the same energy savings and cost-effectiveness results in graphic form. Figure 1 shows annual energy savings *vs* pre-retrofit annual consumption.** By country, the U.S. buildings tended to have the highest pre-retrofit energy use, and the Swedish buildings the lowest. French buildings showed little variation in pre-retrofit use. In terms of percentage savings, the Swiss retrofits, as a group, performed best. U.S. buildings with similarly high percentage savings tended to be those which were very energy-intensive to begin with—often due to poorly-controlled boilers and distribution systems.

Figure 2 shows percentage savings as a function of the investment intensity index for each project. As in the first figure, a primary impression is of large scatter in the data. A number of the very low-cost U.S. projects involved adding

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* Note, however, that to facilitate comparisons, the payback values in Table 1 do *not* include any increase—or decrease— in real energy prices after the date of retrofit.)

**Consumption includes energy used for space heating, domestic hot water, and, for many U.S. buildings, cooking. (In cases where hot water consumption was not available, estimated domestic hot water consumption of 190 MJ/sq.m. has been added to space heat use.)

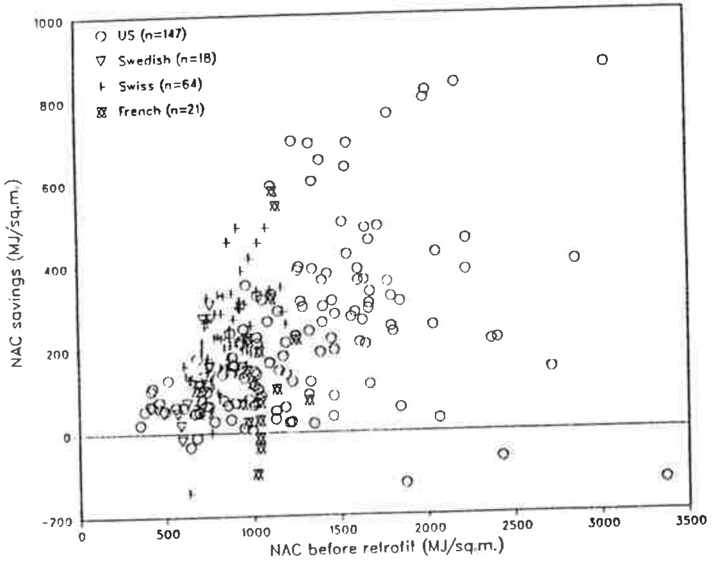

Fig. 1. Energy savings vs. pre-retrofit energy use, for U.S. and European multifamily buildings.

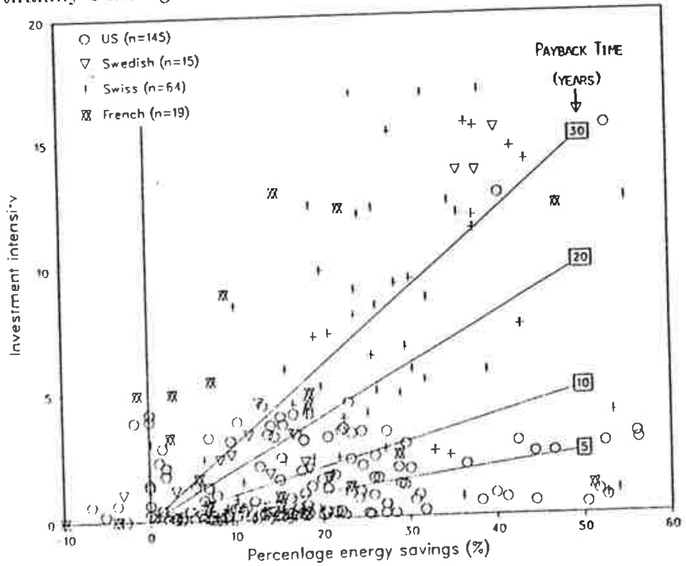

Fig. 2. Retrofit investment intensity vs. percentage savings. "Investment intensity" equals retrofit cost divided by annual pre-retrofit energy costs. A few U.S., French, and Swiss buildings lie outside the boundaries of this plot. Constant payback lines are illustrated for five through thirty year payback times.

controls to large central heating systems. The Swiss buildings, as a group, showed the highest levels of investment and also saved the most—but not enough to avoid very long payback periods.

Conclusions and Plans for Future Research

While the small, non-random samples presently in the BECA-B multifamily data base may not be typical of general retrofit practices and results in any of the four countries, a comparison of the results is at least suggestive on two points: (a) U.S. multifamily buildings, because of their higher initial energy use, may offer more obvious opportunities for low-cost savings, and (b) owners of existing multifamily buildings in Europe appear to be more willing than those in the U.S. to make major investments in preserving and improving the existing stock—based on very long time-horizons (or alternatively, low discount rates). A third factor may have been that the European retrofits were undertaken at a time when many building owners expected continuing major increases in oil and gas prices, a trend which has been temporarily slowed or reversed. In this sense, these European multifamily retrofit results may offer a preview of future retrofit possibilities in U.S. buildings, as well as an indication of what might be done in the remaining un-retrofitted buildings in each European country.

Under the BECA project, we continue to compile and review data from buildings in both the U.S. and Europe; suggestions and further leads from readers are welcome. Future work will include improved methods for weather- and occupancy-normalization, more detailed comparison of retrofitted buildings in the data base with typical stock, submetered end-use energy data, and increased efforts to document the *long-term* performance and reliability of retrofits—beyond the first one or two years. Detailed (submetered) retrofit monitoring projects now underway in the U.S. and Europe are trying to explain the scatter observed in energy savings: How much is due to differences in building operation, occupant behavior, retrofit product or installation quality, or other factors? These data will be included in BECA as they become available. We will also look in more detail more at how individual, well-documented retrofit projects compare with general practice affecting the multifamily stock in each country. We plan to develop and test more refined methods to compare building energy performance, retrofits, and operating practices among different countries.

At the policy level, an important issue is the extent to which further energy and cost savings can be achieved, despite the end of most government retrofit subsidies, through low-capital-investment strategies or "alternative" (third-party) financing. Perhaps the largest remaining opportunities for energy management in existing buildings lie in the continued, effective management and maintenance of existing facilities, increasingly assisted by remote telemetry or by computerized, on-site, control systems. New "hardware" technologies should not be overlooked, but neither should the training and encouragement of competent personnel with the responsibility and knowledge to keep them working well.

Acknowledgements

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References

(1) J. Harris, "The BECA Data Base on Energy-Efficient Buildings - Selected Results and Policy Implications," in *Proceedings,* CLIMA 2000, 2:509, Copenhagen, August 1985 (also LBL Report 19347).

(2) C. Goldman and K. Greely, "Energy Savings in Retrofitted Multi-family Buildings: New Results from the BECA-B Project," Proceedings of the 1986 Summer Study on Energy Efficiency, Santa Cruz, Calif., American Council for an Energy-Efficient Economy, 8/86 (also LBL Report 22688).

(3) Agence Francaise pour la Maîtrise de l'Energie (AFME), "Receuil de Données sur l'Energie," 1984-85.

(4) B. Aebischer, CUEPE, Personal communication, March 1987.

(5) A. Ketoff, International Energy Studies Group, Energy Analysis Program, LBL, Personal communication (based on data from the LBL International Energy End-use Data Base), March 1987.

(6) EIA, "Housing Characteristics, 1984, Residential Energy Consumption Survey," Report #DOE/EIA-0314, October 1986.

(7) M. Fels, "The Princeton Scorekeeping Method: An Introduction," *Energy and Buildings,* 9:1, 1986.

(8) F. Berthoud, E. Bermudez, B. Giovannini, A. Gsponer, "Fiches Techniques D'Amélioration Thermique," Vol. 1, CUEPE, Geneva, March 1985.

(9) Centre National des Etudes Techniques, H.L.M. (CNET-HLM, 1984a), "Enquête Statistique sue les Caractértistiques Thermiques du Parc des Logements HLM," Contract #3.240.0015, Paris, 30 Jan. 1984. Agence Francaise pour la Maîtrise de l'Energie (AFME), "Receuil de Données sur l'Energie," 1983, 1984-85 and 1986-87.

(10) CNET-HLM, 1984b, "Synthèse des Différentes Opérations de Démonstration Entreprises par L'Union des H.L.M. depuis 1975 ayant Bénéficié d'un Financement de l'AFME," Contract #658, Paris, May 1984.

(11) Agence Francaise pour la Maîtrise de l'Energie (AFME), "Receuil de Données sur l'Energie," 1986-87.

(12) Energy Information Administration (EIA), U.S. Dept. of Energy, 1982 Residential Energy Consumption Survey, Public Use Tape.

(13) Agence Francaise pour la Maîtrise de l'Energie (AFME), "Receuil de Données sur l'Energie," 1983.

(14) Office Fédéral des Questions Conjoncturelles (OFQC), "Amélioraton Thermique des Bâtiments: Expériences Pratiques," Bern, 1985.

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THE ISPRA "BENCHMARK" EXPERIMENT TO COMPARE EXISTING BUILDING ENERGY AUDITING SCHEMES.

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1. Introduction

The space heating of buildings accounts for over 25% of total energy consumption within the European Community. With a building renewal rate of about 2% p.a. it is clear that an appreciable reduction in this consumption can only be obtained by improving existing buildings.

Selection of the most appropriate energy saving measures for a particular building requires careful analysis of the energy flows within it, using what are known as Energy Auditing (E.A.) techniques. If the E.A. and the recommended Energy Conserving Opportunities (E.C.O.) are, jointly, to be cost-effective, it is essential that the cost of the E.A. alone be low by comparison with the value of the probable energy savings.

The E.A. schemes currently used in Europe (1), range very widely in their degree of complexity and cost, so that the question arises for the consumer as to whether cheap audits can be relied upon or conversely whether more expensive audits can be justified by greater accuracy. The Ispra "Benchmark Experiment" was devised by the Joint Research Centre (J.R.C.) in an attempt to answer this question. Four companies were commissioned to carry out separate E.A.s of the same set of buildings. Their reports were then compared not only with each other but with a much more thorough study (the benchmark) carried out by the JRC's own staff. Preliminary results have already been presented (2).

The buildings selected, all publicly owned, and in the Ispra area, were:
a) six, 5-floor apartment buildings connected to one heating plant by a small district heating network. Built in 1965;
b) a primary school, built in the early 70s;
c) a single-family, mid-terrace house, built in the early 80s.

The auditing companies came from three different countries and each employed a different level of auditing. The audits were as follws:

Company n.1: most detailed audit: infra-red (Thermovision) study of envelope with computer processing of images; dynamic thermal simulation model for larger buildings, static for the terrace house.

Company n.2: detailed audit but somewhat simpler than above: hand-held infra-red viewer to inspect envelope, static thermal simulation model.

Company n.3: audit concentrated on the performance of the heating plants ; a small data logger used to obtain the "Building Energy Signature". This, together with reference values, used to calculate the annual energy consumption, to indicate heating plant oversizing and incorrect control setting,etc. Other data taken from building plans.

Company n.4: non- instrumented, walk-through audit. Data collected during site visit used in conjunction with data from building plans to run static simulation model. Low man-hours and cost.
The manpower required and costs are given in table 1.

Table 1. COMPARISON OF AUDIT MANPOWER AND COSTS

		Audit 1	Audit 2	Audit 3	Audit 4
Man-hours:	ON SITE	26	11	12	4.5
	OFFICE	120	24	24	11.5
Cost (ECU):	SCHOOL	3110	1420	827	628
	APARTMENTS	5909	1279	827	894
	TERRACE-HOUSE	581	332	827	190
Total Cost (ECU)		9600	3031	2481	1712

2. Execution and results of the audits

Whatever their type, all audits are carried out in 3 stages. The first stage is the collection of data for input to the second stage which is the thermal simulation. The third stage is the identification and evaluation of ECOs in order to formulate recommendations. To compare the audits each stage is considered in turn.

2.1 Comparison of Data Collected

To ensure a common basis for the evaluation, each company received the following information :

- climatic data for the Ispra area, valid for all the buildings
- gas and electricity bills for the previous 3 years
- building plans
- a list of material and labour costs for a variety of energy saving measures.

In spite of this, input data such as building volumes, envelope surface areas, degree-days and heating periods showed considerable variations, see Table 2.

Variations appear even more marked when considering such points as ventilation rates and the heat transmittance of certain building components.

2.2 Comparison of the Thermal Simulations

Two distinct types of thermal simulation models were used by the auditors: dynamic and static. These generally derived values for the seasonal heat losses and gains and hence the useful heat requirements and the delivered auxiliary energy. Table 2 shows the variations in the values of various energy flows. The greatest variation was found in ventilation losses (245% for the school building) and the least in transmission losses, even though considerable variations were found in the transmittance values of individual envelope areas.

In order to translate the calculated useful heat requirement into the delivered energy (auxiliary heating in Table 2), a number of efficiencies have to be applied. The values used for emission, distribution and regulation efficiencies vary considerably (up to 300%), but, nevertheless the overall plant efficiencies show quite good agreement (15%).
The auxiliary heating requirement shows variations of only 6.7% for the apartment buildings but 47.2% for the school. By contrast, when the input data collected by each company were run on the same dynamic simulation model SPIEL (3) the variation was close to 20% for all buildings.

Table 2. AUDIT COMPARISON, DATA AND RESULTS
The variation in values obtained by the 4 audits is expressed as a percentage of the mean value for each item.

INPUT VALUES		APARTMENT BUILDINGS	EUROPEAN SCHOOL	TERRACE HOUSE
Volume		40.4%	35.6%	31.9%
Envelope Surface Area		25.6%	34.6%	64.4%
Degree-Days		18.6%	16.3%	16.3%
Heating Period		24.5%	50.4%	18.6%
Mean Transmitt.	U-value	54.0%	15.2%	42.2%
Outer Wall (type 1)	"	66.9%	47.8%	121.0%
Outer Wall (type 2)	"	99.2%	48.2%	
Attic Floor/Roof	"	86.5%	51.0%	116.5%
Lowest Floor	"	29.3%	68.6%	93.8%
Windows	"	33.2%	31.7%	18.9%
Doors	"	24.0%	31.7%	7.1%
Ventilation Rate	(ach)	109.1%	154.5%	33.3%

ENERGY BALANCE DISAGGREGATION

Auxiliary Heating	6.7%	47.2%	27.3%
Internal+Solar Gains	74.5%	166.3%	100.0%
Useful Heat	39.3%	91.2%	39.0%
Useful Heat (common calc.)	29.6%	28.0%	27.2%
Transmission Losses	45.4%	88.7%	41.6%
Ventilation Losses	133.1%	245.2%	38.0%
Heating System Losses	53.3%	30.1%	51.6%
Total Losses	24.7%	69.7%	29.0%

HEATING SYSTEM EFFICIENCIES

Combustion Efficiencies	1.1%	1.0%	4.5%
Seasonal Plant Effic.	8.1%	11.2%	14.3%
Distrib.& Regul. Losses	48.3%	159.0%	300.0%
Emission Losses	300.0%	246.0%	300.0%
Overall System Effic.	14.5%	14.1%	17.2%

2.3 Evaluation of Energy Conservation Options

The purpose of energy auditing is to recommend to the building owner as complete a list as possible of those ECOs which would be cost-effective in that building. In these audits, the decisions as to whether ECOs were recommendable or not were based on calculations of the probable energy savings, using thermal simulation models, and estimates of the likely investment costs. This led to probable pay-back times which allowed the ECOs to be ranked according to cost-effectiveness.

Table 3
J.R.C ISPRA ENERGY AUDIT BENCHMARK EXERCISE
ECO EVALUATION BY AUDITS (% Energy Saving for ECOs taken singly)

ECOS IDENTIFIED FOR APARTMENT BUILDINGS	BENCHMARK JRC *	COMP. No.1	COMP. No.2	COMP. No.3	COMP. No.4
-ENVELOPE------------------------					
Add attic insulation	7	7	7.7	n.e.	n.e.
Insulate outer walls externally	28	24	29.9	n.e.	n.r. 20
Insulate ext.walls by cavity filling					17
Insulate outer walls internally					n.r. 9
Add insulation behind radiators	9				
Insulate 'ground' floor	4	6	3	n.e.	3
Install double glazing	8				n.r. 21
-HEATING SYSTEM---------------------					
Install new advanced boiler				n.e.	6
Regulation of burners	5		2.9	n.e.	
Improve regulation & distribution				n.e.	
Fit recuperating condenser			20		
Fit thermostatic radiator valves	10				

n.e. = recommended ECO but not evaluated
n.r. = ECO evaluated but not recommended
* The Benchmark figures are obtained using SPIEL dyn.simulation model

Table 4. List of some ECOs neglected by Audit Companies

1.Repair/install window and door closing devices
2.Repair/install weatherstripping
3.Close convective paths to & from stairs (apartment bldg.)
4.Add insulating and reflective layer behind radiators " "
5.Insulate and seal roller blind cases " "
6.Close air-gaps in the false ceiling (school)
7.Replace broken glazing "
8.Displace entrance doors outwards to line of building "
9.Rebalance heat distribution to building zones
10.Break up air stratification with large roof fans (school)
11.Install damper to close aperture of kitchen fan when off "
12.Insulate garage doors (house)
13.Close passage way at both ends "
14.Close off balconies to improve insulation and create sun-spaces
15.Upgrade boiler and piping insulation
16.Install thermostatic radiator valves in rooms exposed to sun

The probable energy savings calculated by various audits for a variety of ECOs, are shown in Table 3 which is for the apartment buildings. The audits only agree on the most obvious measures such as roof and ground floor insulation whilst disagreeing on all the other ECOs. Several apparently very cost-effective ECOs , such as latent heat recovering condensers for flue gases were mentioned by only one auditor. The maximum number of ECOs recommended for a building was 5 and the minimum 1.

In so limiting their final recommendations, the companies completely disregarded a large number of (minor) ECOs, even though some of them were noticed during the visits. A list of these ECOs is given in Table 4. In addition, although explicitly requested, no suggestions were given for service hot water , for general services or the electrical system. The amount of energy saving potential missed by ignoring items in Table 4 was calculated to be 22% for the apartment buildings, over 50% for the school and 42% for the terrace house.

2.4Comparison Between the Commercial and the Benchmark Analyses

The variations displayed in Table 2 highlight those areas in which the greatest disagreement exists between audits, viz: the U-values derived for important areas of the building envelopes, ventilation rates and the estimates of internal and solar gains. The JRC team, therefore, tried to obtain more reliable values for these quantities.

The thermal transmittances of several important areas were derived in 3 ways: by use of a heat flux meter averaging over periods of several days, by measurement of surface and air temperatures, and by calculation from the known or supposed composition of the element.

The results, however, were rather inconclusive in some cases, inspite of the fact that the measurements had absorbed considerably more man-hours than could possibly be justified in a commercial audit. It is clear, therefore, that this area is far from satisfactory. Improvements are required in measuring techniques and internationally agreed standard values are needed for the thermal transmittances of materials under real conditions and for surface resistances.

The large variation in the ventilation rates assumed is mainly due to one audit in which the ventilation rate was not assumed but derived as a consequence of the dynamic simulation used. The other audits all assumed rates close to the reference values expected for the type of building, e.g. 0.5 - 0.8 ach. The JRC tracer-gas measurements lay between 0.4 - 0.5 ach for heated spaces and around 1. ach for the stair wells in the apartment buildings. This high value was probably due to the fact that the automatic closing devices on the main entrance doors were defective. Only one audit used a separate rate for the stairwells and this was one quarter that of the apartments.

It should be noted that the ventilation measurements were carried out under conditions of low wind speed, typical of the Ispra area, and were therefore more representative of the stack effect alone. Had the buildings been situated in a windier region, the ventilation rates would have been much higher. It was not clear whether the auditors had taken this into account when deciding in the ventilation rates to use.

In three of the audits, the internal gains were lumped together with solar gains and subtracted from the global envelope losses to give the net useful heat requirement. The first audit, which used a dynamic simulation model, disaggregated the gains for the apartment buildings and the school. The JRC estimates of internal gains were obtained by carefully taking into account the observed occupancy patterns of the buildings and using the SPIEL simulation model. The solar gains,which were regarded as potential rather than actual, were derived from a 3-dimensional modelling procedure developed at the JRC (4). The estimated solar gains agree well with those of audit no.1, but tend to be much smaller than those of the other audits. Details of this part of the "Benchmark" have been reported elsewhere (5).

3. Critical Discussion of the Audits

As stated earlier, the purpose of an audit is to provide the building owner with specific recommendations for energy saving measures which would be cost-effective in that building. How these recommendations are arrived at is unimportant provided they can be trusted. This study has shown, however,that the auditors disagree about what should be done, which naturally casts doubts on the reliability of their advice.

If, then, the recommendations made in the audits are not entirely reliable, what are the reasons? Each stage of the auditing process has shown considerable variations in important data. Which, if any, of these can explain the lack of agreement?

In the comparison of data collected, much of the variation can be explained by differences in methodology sometimes imposed by national codes. Volumes, for example, can be total, or heated zones only and can be measured inside the fabric or outside. The same applies to surface areas. Degree-days and the heating period can be official figures for the area, actual values from the Ispra climatic data, or may use a different base temperature. It is not likely that these variations affected the final choice of ECOs.

The large variations observed in the thermal transmittances could affect ECO recommendations. It is important, for example, to be able to distinguish between insulated and non-insulated walls when wall insulation is being considered as a possible ECO. In all the audits, the method used to evaluate thermal transmittance was based on the supposed composition of the element. This is impossible to verify without piercing it, a rarely acceptable procedure. The inadequacy of this method is demonstrated by the results, so that an alternative and more reliable one must be found.

Thermographic studies are non-intrusive and were able to show the presence of insulating slabs, arranged haphazardly in the school wall panels. These measurements are expensive, however.

Heat flux meters would not have been suitable for audits since the measurements take much too long. Moreover, the meter used by the JRC gave erratic results which could not be checked without damaging the element being measured.

The only method which seems capable of distinguishing between insulated and non-insulated elements, in a short period, seems to be that which involves the measurement of surface and air temperatures. These, together with reliable values of wall surface resistances, can be used to obtain values for the thermal transmittance of the element. Given its simplicity and speed, the method deserves further consideration.

Unless they are actually measured, excessive ventilation rates are unlikely to be detected. The audits mostly used reference values correctly and, except for the stairwells, obtained ventilation rates close to those measured. They did not, however, observe or comment on building defects which would tend to increase ventilation and which could be corrected by the ECOs included in Table 4.

The variations found in the estimates of internal and solar gains are unacceptably large. Those calculated with sophisticated models seem much better than those obtained with simpler methods, which tend towards gross overestimation . Given that the heating plants could not respond to decreased heat requirements in the rooms exposed to the sun, large heat gains seem unlikely. Such overestimation of gains could lead to optimistic evaluations of passive solar ECOs and undersizing of new heating plants after the implementation of energy saving measures. It also led in this case to the neglect of ECOs designed to allow greater utilisation of solar gains. The simpler methods currently available for the evaluation of potential and actual solar gains should be reviewed and an improved method agreed upon.

The audits did not consider energy consumption for hot water production, lighting or electrical services. The electricity bills indicated price penalties for the power factor and for exceeding the contracted maximum power, yet no ECOs were suggested in this area.

The neglect of many ECOs exclusive to a particular building (Table 4, ECOs no.6,8,10,11,12,13) and many minor ECOs (same table, ECOs no.1,2,7,etc.) seems to indicate too heavy a reliance on the computer program. These will be designed to consider common and important ECOs such as roof and wall insulation, etc. but will not deal with the ECOs in Table 4, most of which are likely to be very cost-effective.

This highlights an important point which emerges whenever a computer program is available to aid a particular task. It is so convenient that the user is seduced by it, is satisfied by the results it produces, and considers only those things covered by it, to the exclusion of everything else. This tendency explains why data specific to Italy and Ispra was not always used.

Each audit's computer program would have had its own data base for information such as climatic data, labour and material prices. This is very convenient and it would have been much more work to feed the Ispra data into the computer.

If auditing is to be relatively quick and low cost it is, of course, essential to make use of computer programs but these must be designed to deal with more than just the most obvious ECOs. The auditor must be asked, both in his checklist and by the computer, whether there are any other ECOs exclusive to the building being audited.

4.Conclusions

This study set out to answer a question. The question was whether cheap audits can be relied upon or conversely whether more expensive audits can be justified by greater accuracy.

The answer is that there is little correlation between the cost of an audit and the accuracy or quality of the information provided. Paying more for an audit does not ensure more original or ingenious recommendations.

The most expensive audit revealed information through an infra-red study which was not available to the other audits but this seemed to have little effect on the recommendations. Similarly it obtained the most reliable values for solar gains, again with little effect on the recommendations.

If building owners are to have confidence in energy auditing, the level of disagreement observed in this study must be reduced. There should always be scope for the experienced auditor to produce better recommendations than his less experienced colleague, but the differences here were not a result of inexperience on the part of the auditors. Part of the problem lies in the technical difficulty of determining such parameters as thermal transmittance , ventilation rates and heating system efficiencies. These are fundamental to the energy balance, yet values can only be obtained as "guesstimates" or by very laborious field measurements. There is a need for improved measurement techniques. Better data, collected on an international basis, together with common, agreed definitions and calculations of the various efficiencies would also help.

Much of the disagreement on input values stems from the fact that the auditing companies came from different countries. This meant that different conventions were used for estimating those parameters which were not measured. These came from norms and reference values which are national in character. Some of the problems associated with norms and reference values are being tackled by the European Commission's General Directorate for Industry in Brussels which is working on a EUROCODE for energy efficient buildings. The final report (6) on the first stage of the work describes current practice in various countries and gives recommendations for a unified approach.

The principal reason for disagreement on the ECO recommendations is not so much the use of different input data, but the use of different auditing schemes. Each audit was apparently limited by its own scheme to the consideration of a predetermined list of ECOs, the list differing slightly from company to company.

The main recommendation of this report must, therefore, be that auditing schemes should be widened to consider a larger number of ECOs not only connected with the heating of a building but also with other kinds of energy uses. The checklist and computer programs should be designed to encourage the observation of details and the proposal of measures more specific to the building being audited.

References

(1) Etude pour la mise en place d'un outil européen pour le diagnostique énergétique de l'habitat.
INIEX 1984 . Contract n. 2075-83-03 ED ISP B

(2) F.Conti,B.Daniotti,G.Helcké
A field comparison and critical analysis of existing schemes of building Energy Auditing.
Proceedings of PLEA '86 Conference - Pecs (Hungary) 1986

(3) SPIEL, Ecotech, Sheffield, UK

(4) R.J.Peckham
Shading Evaluations with General 3-Dimensional Models
C.A.D. Journal Vol.17, No.7, 1985

(5) R.J.Peckham, B.Daniotti
Evaluation of the Passive Solar Potential in Existing Buildings
The efficient use of Energy in Buildings-2nd UK-ISES Conference, Cranfield , Sept. 1986

(6) Commission of the European Communities
Study for a EUROCODE on the rational use of energy in buildings.
Report n. 2973/III/86