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Occupant Perception of Running Costs of Domestic Mechanical Ventilation Systems

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0 Synopsis:

An investigation of the performance of a recently built estate of over 50 low-energy rental dwellings indicated that there was a slight but significant increase in electricity use of the "super low energy" designs over the control "low energy" designs. The "super low energy" designs included, in addition to the enhanced fabric specification of the "low-energy" types, active systems such as mechanical ventilation, solar DHW panels and enhanced space heating systems.

While field monitoring indicated that the increased electrical energy usage was attributable equally to all the active energy systems installed, the occupants of these dwellings identified only the permanent mechanical background ventilation system as having a key energy cost. This perception was such that a number of occupants had attempted to disable or disconnect the ventilation system. This reaction to the perception of high running costs is of concern, not only in terms of possible impact on health and safety issues for the occupants, but also of maintenance issues for the estate operators.

1 Introduction

1.1 Background to the study

The Clase housing project resulted from Wale's largest housing society's interest in developing low energy and sustainable housing designs. A development of fifty-one units was undertaken in 1996 on an existing estate in South Wales. The housing was comprised of bungalows, flats, and 2, 3 and 4 bedroom family houses. The estate is managed by the housing society and is operated by them as rental accommodation. The development and assessment of the housing was supported by a grant received under the European Union's Thermie programme for the promotion and demonstration of low energy design and technologies[1].

1.2 Description of the dwellings

All of the fifty-one dwellings in the new development met or exceeded the energy efficiency regulations current at the time of design. All used gas fuel for heating and domestic hot water. There were two separate fabric and services specification levels contained in the development:- the "low energy" and "super low energy" design types.

The "low energy" designs (designated LE) are the baseline specification. They have the roof, external walls and floors insulated to a significantly higher degree than required. The wall construction, for instance, has a design U-value of 0.21 W/m^2/K rather than 0.45 W/m^2/K required by the (then current) building regulations.

The "super low energy" (SLE) designs were intended to take advantage of both passive and active low energy features in order to further improve energy performance. In addition to the fabric specification of the LE types, an SLE dwelling has a mix of the following features:-

- low E double glazing,
- orientation bias, with habitable rooms facing South,
- reduced North glazing areas,

- triple glazing to North facades,
- a South facing sunstore (or conservatory),
- roof mounted solar panels for DHW,
- high-efficiency gas central heating system, including a condensing boiler,
- continuous mechanical ventilation system, incorporating a heat recovery.

The design variants are summarised in table 1. In addition to the new housing, a number of "standard" (e.g. existing) dwellings fell within the boundaries of the assessment exercise. These represent the existing practice on the estate; they meet 1990 building regulations and include no special energy efficiency features.

House Type	Number in sample	Design Energy Standard	Description	Gross Floor Area m2
A(s)	16	Super low energy	2 bedroom bungalow	55
B	2	Low energy	2 bedroom flats	59
B(s)	6	Super low energy	2 bedroom flats	59
C	3	Low energy	2 bedroom semi-detached	70.5
C(s)	6	Super low energy	2 bedroom semi-detached	70.5
D	6	Low energy	3 bedroom semi-detached	85
D(s)	8	Super low energy	3 bedroom semi-detached	85
E	2	Low energy	4 bedroom semi-detached	99
E(s)	2	Super low energy	4 bedroom semi-detached	99
F	2	Standard	2 bedroom semi-detached	69
G	8	Standard	2 bedroom semi-detached	85

Table 1 Design variant summary

A key element in the SLE designs was the inclusion of a continuous mechanical ventilation system. In addition to producing controllable ventilation levels, this system was also intended to move warmth from the south facing sun-store to the other rooms of the house, through a heat exchanger. Following then existing design advice[2] the ventilation system operated continuously providing moderate background ventilation, but under occupant control a boost setting could be selected. There were no controls available to the occupant to turn the system off. Due to the presence of the continuous system, provision for background natural ventilation was reduced in the SLE designs, e.g. there were no trickle ventilators provided.

1.3 Description of the monitoring exercise

Monitoring under the remit of the Thermie funded project, was undertaken to determine and demonstrate the energy efficiency of the designs in practice. Monitoring of the energy use and environmental conditions was undertaken by Cardiff University after the construction of the estate and was carried out over the period June 1998 through September 1999.

Three levels of data recording were undertaken:-

- Level 1 - whole-house fuel use (gas and electric) was recorded, at weekly intervals, for all dwellings included in the scheme. This data was supplemented by fuel use records for the preceding year, where these were available.

- Level 2 - whole-house fuel use and internal conditions (living area temperature and humidity, sun-store temperature) were recorded at half-hourly intervals, on a sample of 6 dwellings.
- Level 3 - disaggregated energy use was recorded at half-hourly intervals in one level 2 house.

The above measures were supported by the half-hourly recording on site, of external air temperature, external humidity, site wind speed, horizontal global and south facing inclined solar irradiance. In addition to the physical monitoring, occupant views and reactions were sought through formal interviews and questionnaires.

2 Summary of results

As expected, the new dwellings were found to require considerably less fuel than UK housing norms[3], and to use significantly less ($p<0.05$) gas fuel than the standard housing on site (table 2). An apparent decrease in electricity use in the new dwellings was not statistically significant. The new homes were found to be generally well liked and appreciated by their occupants, who considered them to be a considerable improvement over their previous housing.

Description	number in sample	Gas Use kWh/day	Electric Use kWh/day
Types A,B,C,D,E, averaged over estate, LE and SLE types.	53	**29.6**	**9.3**
references from EHCS[2] :			
Post 80's bungalows	-	45.8	11.2
Post 80's houses	-	52.6	11.0
all housing with SAP >60	-	51.0	10.1
all housing with acceptable heating provision	-	55.9	12.1
Types C,D,E, averaged over estate, LE and SLE types.	26	36.6	11.0
Comparable reference on estate: Type G	7	44.1	12.3

Table 2 Annual energy use summary : 1998-1999

There was opportunity with the B,C,D, and E dwelling types to compare directly the energy use of the LE and SLE designs and so assess the effectiveness of the extra features of the SLE type. Over the course of a year though, the SLE designs were <u>not</u> found to use significantly less gas energy than the LE types. Averaged over all these house types, over all available fuel data and normalised for floor area, the median gas use was 0.382 and 0.376 kWh/day/m^2 for the LE and SLE types respectively (figure 1). The extra energy features of the SLE types did not appear to provide, en mass, a significant energy or cost saving.

When considering electric energy use however, the SLE types show a greater electrical energy demand than the LE types. The median electricity demand's, figure 2, were 0.104 and 0.138 kWh/day/m^2 for the LE and SLE types respectively. Subsequent analysis, using a non-parametric Mann-Whitney test, indicated a statistically significant difference of 0.034 kWh/day/m^2 ($p<0.01$). Without normalising for floor area, the difference was still apparent, with the SLE types using typically ~1.7 kWh/day more electricity than the LE types ($p<0.03$). This increase is equivalent to continuous extra background load of 70W, within a 90% confidence interval of [129 : 17]W. Table 3 shows that the difference exists also between individual dwelling size types (e.g. D-D(s)) alone, with only one marginal comparison with the C size types.

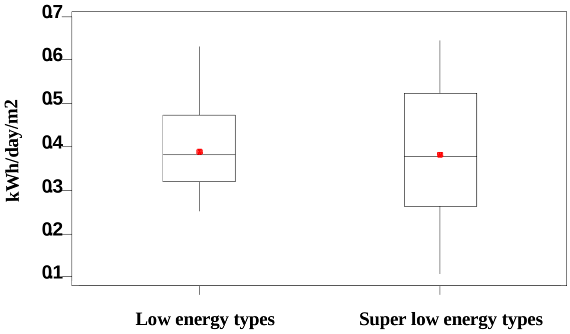

Figure 1 Box plot, typical Gas use

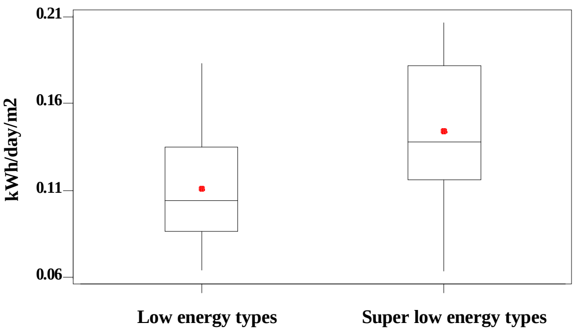

Figure 2 Box plot, typical Electric use.

House type	Median Electric use low energy kWh/day	Median Electric use super low energy kWh/day	Estimate of difference kWh/day	level of significance
Type B	5.1	8.1	2.8	$p<0.04$
Type C	9.1	10.9	1.5	$p<0.22$
Type D	10.2	12.3	2.5	$p<0.07$
Type E	7.6	11.3	4.0	$p<0.05$
All (B,C,D,E)	8.7	10.8	1.7	$p<0.03$
All, normalised for floor area	0.104 (kWh/day/m^2)	0.138 (kWh/day/m^2)	0.034 (kWh/day/m^2)	$p<0.01$

Table 3 Comparison of electric use for different design types

3 Further analysis of electric use

It was considered that the difference in use of electric energy between our sample dwellings could arise from one or more of the following:-

- a difference in ownership of domestic appliances, e.g. dishwasher, electric cooker, set-top boxes, etc.
- a difference in usage patterns, e.g. a greater number of washing loads per day,
- a difference in the standby losses of appliances, e.g. a difference in age or quality of appliances, or

- a difference in the energy demands of the services, e.g. due to standby and operational loads of the more sophisticated low energy systems included in the SLE types.

A full survey of the appliance characteristics of all dwellings in the scheme site was not undertaken during this project. However from the information available, and assuming a relatively homogeneous population demographic taken from a small geographic area and distributed randomly across the design types, there is no basis to assume a significant difference in ownership, mean use, or age of appliances between the LE and SLE occupants. This leaves the active low-energy systems as the prime candidates for the increased electrical consumption.

The active low energy systems defining the "super low energy" types were the solar panel hot water system, the heating system, and the ventilation system. The energy use characteristics of each these could be measured or estimated.

3.1 Electric use patterns

Detailed electric monitoring was available only for the type As designs. The type As mean electric use of 0.138 kWh/day/m^2 was comparable to that of the types Bs, Cs, Ds, and Es (0.133 kWh/m^2). Therefore it was considered that this data could be used to explore the electric energy use patterns of the SLE types as a whole.

The level 2 monitoring indicated a low-level continuous background use. Between the hours of 3 and 5 AM, when little occupancy related load would be expected, the mean electric use measured was 167W, while 90% of the time in that period the load was greater than 70W. This is illustrated in figures 3 and 4.

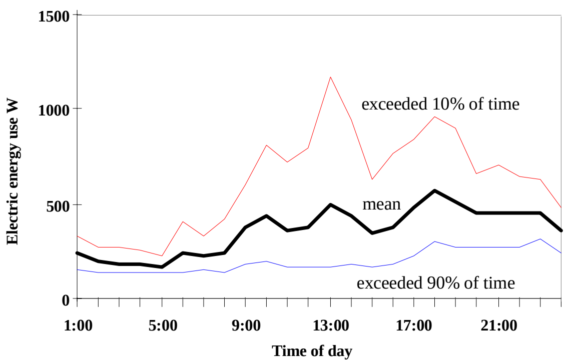

Figure 3 Electric demand profile, Type As, in Winter

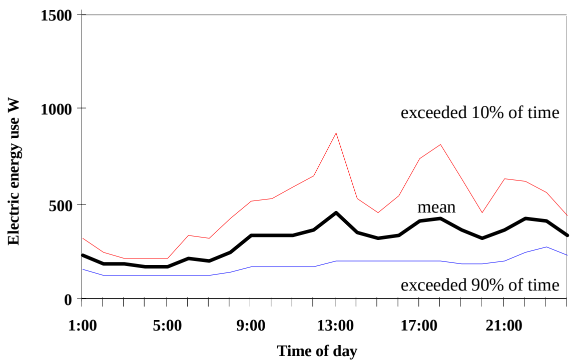

Figure 4 As fig. 3, for Summer

3.2 Electric use by heating services

Recent studies of standby losses, or "electric leakage"[4], show that background loads of 50-80W can easily be accounted for by modern domestic appliances: televisions, set-top boxes, battery rechargers etc. Many such surveys appear to disregard services (e.g. heating systems), but standby electric loads in this type of equipment will be comparable to other appliances. Measurements made by us on a modern central heating boiler, typical of late 1990's UK installations (a fan-flued "combi"-boiler with built in circulation pump and electronic ignition) showed that its continuous standby load was 8W, or 0.2 kWh/day. During firing, this boilers' typical demand was 200W, which included ~100W for the flue fan. In summer, providing DHW only, the systems total electric energy use was, on average, 0.7 kWh/day. In winter, longer firing times for space heating would double or treble this load. A less sophisticated balanced flue boiler with pilot light would of course require pump and gas-valve solenoid power as well. Taking this into account, it is estimated that the more modern system uses an additional 0.5 - 0.7 kWh/day electrical energy over the course of a year.

3.3 Electric use by solar panels

The circulation pump of the DHW solar panel system operated automatically when the panel fluid temperature was above that of the DHW storage vessel. The recorded performance of an example panel system indicated an average pumping duty factor of 0.25 over the course of a full year. This suggests a typical annual electrical energy load of the solar panel system would be ~0.4 kWh/day.

3.4 Electric use by the ventilation system

The mechanical ventilation system was a two speed system. Measured fan loads were 20W on the normal rate and 60W on boosted flow. Monitored use over a full year the typical energy load was 0.54 kWh/day, representing about 1.5 hours per day on boost rate.

Thus each low energy system of a SLE type, with an incremental electrical energy load of approximately 0.5 kWh/day, would in itself not be sufficient to cause the electrical energy difference of 1.7 kWh observed. The total demand of all three systems together is however comparable. It is therefore concluded that the increased electronics and electrics load associated with all the low energy systems provided in the SLE designs could explain the increase in electrical energy demand.

4 Occupant perception of the ventilation system and running costs

4.1 Ratings and reactions

The results of the occupant surveys and interviews indicated that the occupants rated their homes highly on satisfaction and comfort. However they were sensitive to their fuel costs; while many occupants felt they were using less gas for heating, as compared to those of their previous dwellings, they were less sure about their electricity costs. A number commented informally that their electricity costs were higher than expected. Although such comparisons may be spurious, their perceptions are notable in the light of the above findings.

While it would appear from the monitoring data that an increase in electric use in the SLE dwellings could be attributed equally to all three active energy systems in the designs, in the perception of the occupants this was notably not the case. Many occupants, aware that the mechanical ventilation system ran constantly, identified it, in isolation, as a key contributor to their electric fuel costs.

In the surveys, occupants were asked to rank their appreciation of the energy systems in their homes. They generally rated the ventilation system last, while the solar panel DHW system and heating system were most often favoured, and the sun-space middle-ranked.

Most of the residents questioned were either not aware of, or not very motivated by, the environmental or energy benefits of the energy systems in their homes, but were very enthusiastic about any potential benefits in terms of cost savings. Many were impressed with the solar panel system, and believed it saved them money. While the sun-space generated some criticism, generally centred on leaks and comfort issues, it was however perceived to offer amenity value, e.g. extra living space. When asked which single energy system they would like to have in their next home (apart from a heating system), most nominated a solar DHW system, with a conservatory following up. No one chose the ventilation system as a desirable feature.

All occupants questioned were aware of the mechanical ventilation system (notably not all were aware of the solar panel system), and it appeared to be actively used (e.g. the manual boost rate was operated). The boost rate was reported to be used predominantly for the same reasons that windows were opened:- because it was too hot, because of odours, to obtain fresh air, or to clear condensation. Noise and comfort were the main reported reasons for switching the ventilation system back to normal operation.

The ventilation system generated a number of criticisms from the occupants, generally regarding to noise and draughts. The ventilation systems could be gauged to be working satisfactorily, in that humidity was found to be acceptable (90% of the time less than 57% RH in the level 2 dwellings). There were few reports of condensation problems, and occupant satisfaction with air quality was high. These however were apparently not seen by the occupants as tangible benefits to be associated with the ventilation system.

It was not clear from the surveys why the ventilation system was so in disfavour, but it is considered to be due to a combination of tangible disbenefits (e.g. noise and draughts), perceived high operational costs, and the perception of little or no tangible benefits.

The identification of the ventilation system alone with high running costs was considered to be due in part to the increased awareness of the occupants to this system, compared to the other systems in operation. The ventilation system, noisy, producing discomfort from time to time, and with a control panel with no "off" setting, became their prime target for suspicion. In their awareness, the solar panel or the heating system boiler were less obvious candidates for concern.

4.2 Action and intervention by occupants

The (mistaken) identification of the ventilation system as having high running costs was so strong that in a few instances occupants were found to have disabled the ventilation system by entering the loft (where the fan unit was located) and using the maintenance isolator to switch it off. The immediate result of such action would be of course to leave the dwelling relying on background leakage and on window opening for ventilation.

This disabling of the continuous mechanical ventilation is a serious side-effect of perceived running costs, with a great potential to introduce problems in air quality, humidity, condensation and mould growth. While, in this study, none of these effects were noted or reported, the concern remains that such a reaction from occupants may have a more profound impact on housing built to higher levels of air-tightness. Solutions and strategies are needed to counter the mis-perception of high running costs, while allowing low energy features to continue to operate and contribute to energy efficiency.

5 Potential solutions

The mechanical ventilation system was apparently perceived by the occupants as having a net cost with little or no associated benefit. Potential solutions to such a problem would therefore involve:- improving information and understanding in order to highlight or establish benefits, reducing the perception of running costs, and/or reducing actual running costs.

5.1 Education and information

The education of occupants, promoting the understanding of the intents, operation, and consequences of mis-use of a low-energy feature, has been cited as a solution to poor performance in practice for a number of decades. However it is apparent that in practice this advice is still rarely being followed. In this case only a few of the residents questioned had been given written information on how to use the special features of their homes. Many reported that when they had first moved in they didn't know how to use the energy features and weren't aware of what they were intended to do. Often, the only source of information available to them was advice from neighbours.

The issue of information supply and management is particularly significant when dealing, as in this case, with rental housing. Although appropriate documentation may have been prepared and originally made available, it may be unlikely to be passed on intact from tenant to tenant. In practice a "tuition" scheme for each new tenant would make unreasonable demands on the housing operators. As noted, some "community" driven information supply was evident in this case; community or residents groups should be seen as important agents in this vital information management.

5.2 Reducing "visibility"

It was considered that part of the cause of the mis-perception of the high running costs of the ventilation system was due to that systems' high position in the occupants awareness. Noise and comfort problems had made the ventilation system "visible". Addressing these crucial design issues in detail would perhaps reduce this awareness and so may help to reduce the incidence of the mis-perception of running costs.

5.3 Reducing energy costs

A reduction in electrical running costs across all energy systems in a low energy dwelling should be considered as a matter of course. Lower running costs can be achieved through careful selection of services and equipment; systems with low power/high efficiency fans and pumps, and with low power standby electronics should be considered and specified. Calls are being made in America and elsewhere for manufacturers to produce consumer equipment with less than 1 W standby loads[5], and these calls should be extended to energy systems.

5.4 Offsetting energy use

Alternative renewable energy systems (e.g. wind power and photovoltaics (PV)) are of current interest. Small scale autonomous systems, associated with each dwelling and intended only to supplement rather than replace mains electrical supply, offer the potential to reduce the background electricity burden. As a small scale system would not be aiming for net export, nor to match peak demand, the size, complexity, and cost of these systems could be limited.

In addition to any energy produced, it may be hoped that as identifiably positive energy features (like solar DHW panels) such a device may be considered by the occupants as positive components of an overall system. The coupling of a positively perceived feature to a neutral or negatively perceived one, such as the ventilation system, may help to allay fears of high running cost.

In order to assess the application of such systems in this case, site data for inclined solar irradiance and local wind speed was used to estimate the potential energy contribution, to this scheme, of two simple systems of approximately 1m^2 collector area.

5.4.1 Photovoltaic system

This example considers a modular 1m^2 PV roof mounted system, complete with inverter. The panel dimensions would be comparable to the solar panel units already present. Mounted on a south facing roof, such a system would have produced an average peak output of 45W (see figure 5), and have contributed typically 0.3 kWh/day over a year.

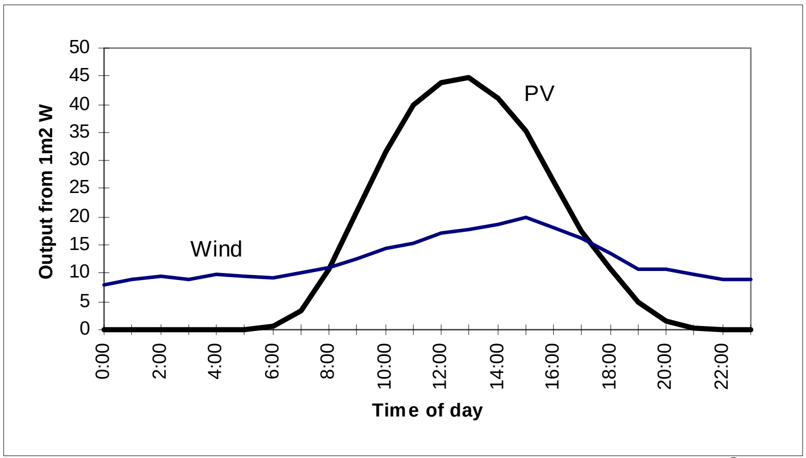

Figure 5 Average day output from small scale PV and wind systems (1m^2 "collector" area in each case)

5.4.2 Wind system

As an example a small scale turbine, with a rotor area of 1m^2 (~ 1.2m diameter) was considered. There are major wind generation facilities in the region, but on site and within a few meters of the buildings' height local wind speeds only rarely (33% of the time) rose above 3 m/s. As most wind generators require approximately 3m/s to "cut in", this is a severe limitation to their application. This small system was estimated as producing a mean peak output of only 20 W (figure 5). However, as wind energy shows less time dependence than solar energy, over a full day such a wind system would have produced similar energy output (0.3 kWh/day) to the PV system considered above.

Small systems such as these would not significantly offset the total background load, nor significantly reduce total energy costs, but arguably they are sufficient to offset a component of the mechanical ventilation system load.

6 Conclusions

A statistically significant increase in electric use was found to be associated with "super low energy" designs on a housing estate. This increase of approximately 1.7 kWh/day ($p < 0.03$), was considered to be associated with the active low-energy systems in these designs (mechanical ventilation, solar panel DHW, and space heating), rather than due to consumer goods or other occupancy effect.

Although the mechanical ventilation system contributed to the increase in electric use, at ~0.5 kWh/day it was not considered to be the sole nor the most important energy load present.

In the perception of the occupants however, it was identified, apparently mistakenly, as a key electric fuel cost. In general the ventilation system was disliked, and produced complaints over noise, draughts and running costs. The mis-perception in running costs lead, at its most severe, to the disablement of the system by some occupants. This reaction could have lead to unhealthy conditions and to high maintenance costs due to condensation problems, although these were not detected in this study.

To avoid such problems occurring in new low energy dwellings, it is important to combat this mis-perception of running costs. The successful application of low energy design features requires that occupants understand the operation of the energy systems and the consequences of their misuse. Further they must value the often intangible contribution that the systems make to their environment. Increased care in the detailed design and application of systems, so as to limit causes for complaint, may reduce occupant awareness of active systems, and reduce their identification as energy users. To minimise the energy requirements of such systems, care must be taken to specify components featuring low energy electric and electronics technology.

Small scale renewable energy systems may not be strictly economically viable due to their high capital cost and low expectation for energy production. However if their presence can be associated in the mind of occupant with offsetting the running costs of other systems in the dwelling, they may help to ally fears of running costs, and so prevent such adverse user interventions as seen in this case.

Acknowledgements

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