Energy performance of housing in the Greater Dublin Area

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ABSTRACT
Energy consumption in the housing stock accounts for 24% of Total Final Consumption in Ireland, with heating energy being a dominant end use. Identifying the influence of housing stock characteristics on heat energy consumption can aid targeted development of energy related policy to meet national objectives of environmental responsibility and security of supply. This paper reports a profiling study of the heat energy consumption of a representative sample of the housing stock in the Greater Dublin Area from the findings of an energy performance survey of Irish housing commissioned by the Sustainable Energy Authority of Ireland (SEI). Theoretical and actual heat energy consumption of a sample of 64 dwellings representing the housing mix in the Greater Dublin Area is presented. Comparison of theoretical and actual heat energy consumption is discussed for a range of stock and individual house operational; fabric and heating system characteristics including results from airtightness testing and thermographic surveys to identify the predominant heat energy consumption drivers. The impact of historical changes in construction practices, design strategies and energy related regulatory instruments on theoretical and actual heat energy consumption are discussed.

KEYWORDS
Housing; energy; consumption

Introduction

Energy consumption in the housing stock accounts for 24% of Total Final Consumption in Ireland (Howley, M., O'Gallachoir, B., 2005). A study of the heating energy performance of a representative sample of the housing stock was commissioned by the Sustainable Energy Authority of Ireland in 2004. This study involved detailed physical surveys and testing of 150 dwellings covering the national geographical spread of the stock. As the Greater Dublin Area (GDA) has the largest regional proportion of existing dwellings a sample of 64 were surveyed and tested for this region.

A primary task in the survey fieldwork was a detailed energy audit and physical survey of the sample dwellings, with the objective of comparing the actual and theoretical or calculated energy performance. This included flue gas combustion analysis of boilers, in a sub-sample of 22 dwellings. Additionally a sub-sample of 20 dwellings were included to evaluate performance of the most recent dwellings constructed between 1997 and 2002 to correlate with the then latest energy related Building Regulations (Anon., 1994, Anon., 1997a, Anon., 1997b, Anon., 2002a).

The sample profile was derived from national (Anon., 2002b) and county statistical data, compiled for the Irish National Survey of Housing Quality 2001-2002, to represent the regional distribution of the three main energy related dwelling characteristics of age (i.e. year of construction), built form and tenure in the 10 counties making up the GDA.

Categories of the three fundamental energy related characteristics, see Table 1, were defined to match energy related amendments to Building Regulations and changes in construction practices, most notably the widespread adoption of cavity-wall construction and uptake of central heating in the 1980's.

Year of construction	**Built form**	**Tenure**
Pre 1960	Detached (D)	Own Outright (OO)
1961 – 1980	Semi-detached (SD)	Purchasing (P)
1981 – 1990	Terraced – mid (Tm)	Local Authority Renter (LAR)
1991 – 1996	Purpose built apartment (PBA)	Private Renter (PR)
1997 - 2002	Converted apartment (CA)	Other (Ot)

Table 1 - Sample profile characteristic categories

County level profiles of age and tenure were derived from transposition of data, compiled for the Irish National Survey of Housing Quality 2001-2002, within defined year of construction categories. These were summed to provide regional profiles of age and tenure. This approach was required as data on dwelling age and built form profiles are found in separate sources. County level profiles of dwelling age, tenure and built form combinations were derived from multiplication of age and tenure data with age and type data from a third source. County profiles are aggregated upwards to derive regional profiles. Finally, regional total sample sizes are multiplied with regional profile proportions to derive statistically accurate regional sample profiles.

There is a large mix of age, form and tenure in the existing GDA region reflecting the widest distribution of primary characteristic combinations of the four main regions in Ireland. The GDA can be seen to have more older dwellings across the various built form and tenure categories, however there are significant proportions of newer semi-detached in the purchasing sector, whilst the local authority renter sector has more terrace dwellings, see Figure 1.

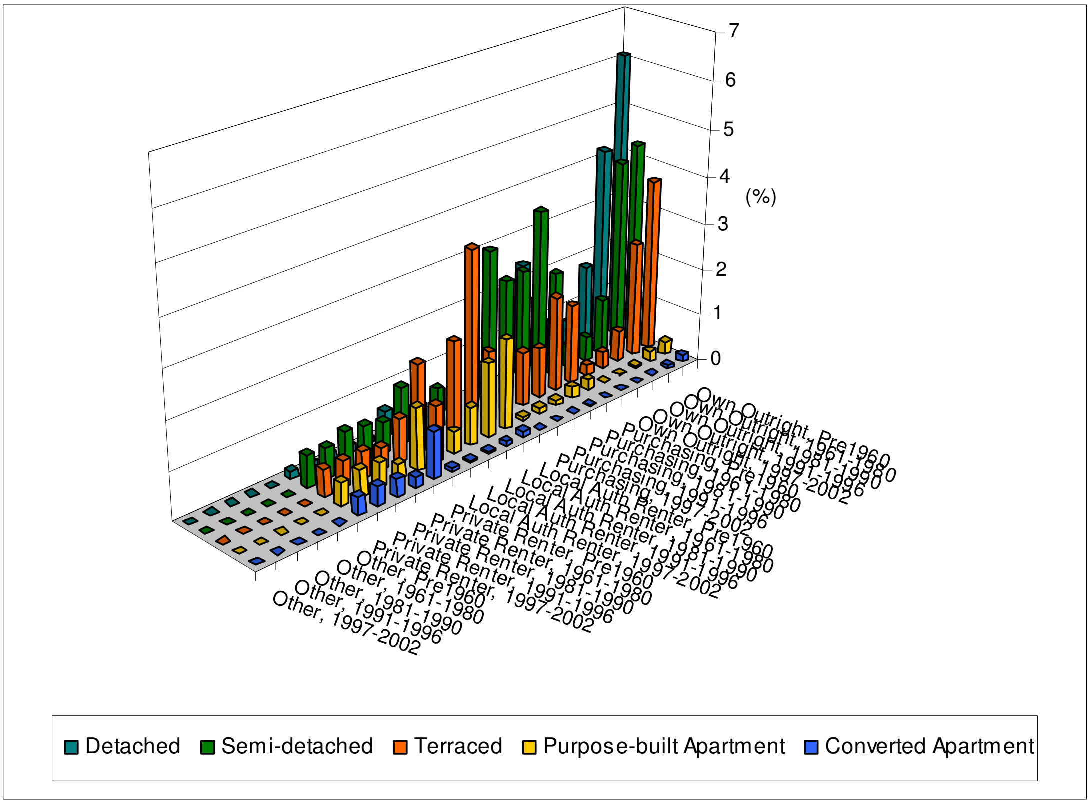

Figure 1 - Greater Dublin Area regional housing stock profile

Where additional dwellings were needed to meet the statistically accurate GDA regional sample size, on the basis of national data, these were defined from characteristics not commonly well represented in Irish energy related housing studies. This meant that 4 additional private renter dwellings were included in the sample profile. The total number of dwellings in the Pre 1997 sub-sample was 44 with 20 in the Post 1997 sub-sample, see Appendix A.

Energy Performance

Actual heat energy consumption is presented as 'Purchased Heat Energy' (PHE) and theoretical heat energy consumption as 'Home Energy Rating' (HER_m). PHE is derived directly from fuel bills and estimations of fuel use whilst HER_m is calculated using an adjusted Heat Energy Rating (HER_t) (Anon., 1997c). This structure represents the overall heat energy performance of a dwelling taking into account characteristics of the building fabric; heating systems and a limited degree of occupant behaviour.

PHE is a direct measure of the amount of heat energy supplied or available before conversion efficiencies come into play whereas HER_m is based on theoretical heat energy demand adjusted to account for seasonal conversion efficiencies of primary and secondary heat sources, e.g. boilers, open fires etc.

The methodology for calculating HER_m is a two stage process. The first stage follows the standard HER_t, the second stage adjusts the HER_t figure to an HER_m figure to account for the conversion efficiency of primary and secondary heat sources. To maintain relevance to the Irish context the fuel type and seasonal efficiency of primary and secondary heat sources are taken directly from survey results.

The Heat Energy Rating (HER_t) of a dwelling is a calculation of the annual energy output from the heating appliances (such as boilers, fires and electrical heaters) that provide space heating and domestic hot water (DHW) under standardised conditions of operation, room temperature and hot water use. The calculation takes into account solar and internal gains and the type of heating system and controls, but it does not consider the calorific value of the fuel supply or the conversion efficiency of heating appliances. The HER_t is specified in terms of kilowatt-hours per square meter of floor area per year (kWhr/m^2/yr). The estimated space heating demand component of HER_t is based on achieving a specific mean internal temperature between 17.81 K and 19.80 K, for a morning and evening heating pattern, which is determined as a function of predefined heating system responsiveness and control categories (Anon., 1997d).

The PHE, is determined from oil, gas and electricity bills. Gas and electricity consumption data over the previous 2 years were obtained with the written permission of the resident and with the co-operation of ESB Customer Supply and Bord Gáis Energy. Oil bills were averaged over the previous 3 years, as oil fills are generally less regular than gas or electricity meter readings. Solid fuel tonnage was estimated in the event that bills were unavailable. This accounted for all solid fuels and addressed variations in solid fuel mixes and dual fuel appliances. An estimate of electrical consumption for portable space heaters, hot water immersion heaters and electrical showers was made taking into account the metered electricity data and the results of a questionnaire survey with the resident regarding their electricity usage.

The conversion efficiencies of boilers were generally derived from the SEDBUK (http://www.sedbuk.com) data base of gas fired and oil fired boilers, where the boiler make and model could be established. The SEDBUK figures are intended to be representative of the average annual efficiency achieved in typical domestic conditions, making reasonable assumptions about pattern of usage, climate control and other influences. They are calculated from the results of standard laboratory tests together with other factors such as boiler type, ignition arrangement, internal store size, fuel used and knowledge of the UK climate and typical domestic usage patterns.

Comparison of actual purchased heat energy (PHE) against theoretical heat energy consumption (HER_m)

The overall result from the full sample of 64 dwellings, see Figure 2, shows a wide scatter in results, which reflects the evolution of housing forms and standards of insulation over the years in response to upgrading Building Regulations and a changing national demographic profile along with different patterns of occupancy, location and comfort demands. The low correlation co-efficient, $R^2 = 0.0745$, is marginally influenced by a single dwelling having a low PHE (65.55 kWh/m^2/yr) and high HER_m (715.63 kWh/m^2/yr). This large difference between actual and predicted is due to this particular dwelling having a poor fabric thermal performance due to pre

1960 solid wall construction, single glazing, an open fire and bottled butane room heater as the only space heating appliances. These appliances have the lowest efficiencies and no distribution or control systems. The low PHE is due to the occupants low thermal comfort demands, i.e. low internal space temperatures, and heating not being provided in all rooms.

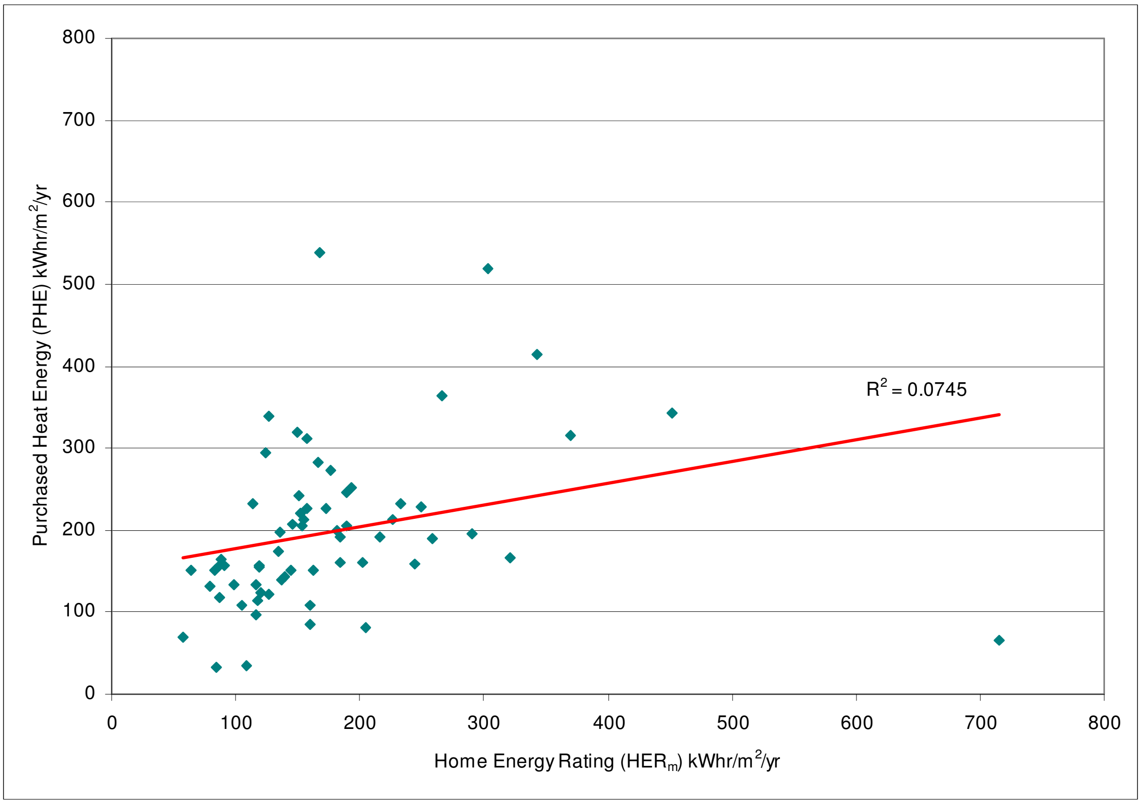

Figure 2 - Purchased Heat Energy (PHE) against Home Energy Rating (HER$_m$)

When the average of all 64 data points is expressed as the average per dwelling the actual heat energy consumption, i.e. PHE, including fuel and electricity for domestic hot water and space heating, is 25,273 kWh/yr/dwelling, compared with a theoretical consumption, i.e. HER$_m$, of 24,425 kWh/yr/dwelling. On a unit gross floor area basis, summing all unit consumptions and dividing through by 64 data points, the average dwelling PHE and HER$_m$ are 198.3 kWh/m^2/yr and 177.1 kWh/m^2/yr respectively. On average more heat energy is used than predicted; i.e. on an annual whole house basis the theoretical HER$_m$ underestimates the actual PHE by 3.3% and on a gross unit floor area by 10.7%. This difference is driven by a small number of dwellings, i.e. 7, consuming significantly more heat energy than predicted.

Using a bin method, the predominant bands of annual heat energy consumption are from 101-150 kWh/m^2/yr to 151-200 kWh/m^2/yr, see Figure 3.

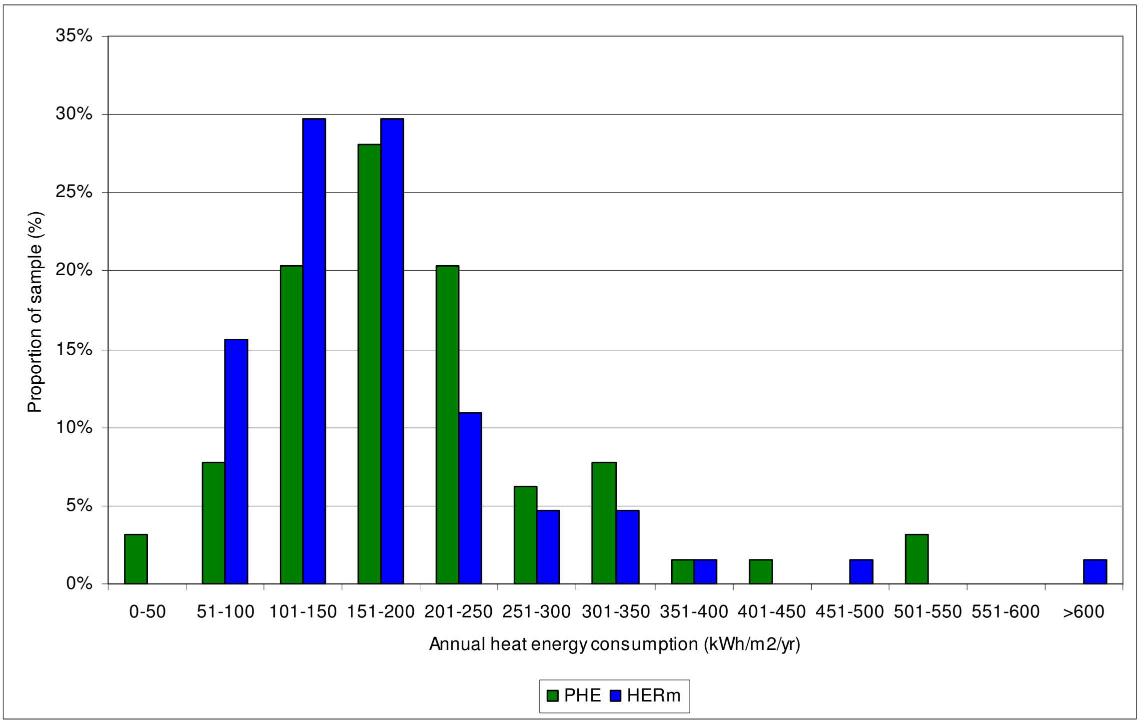

Figure 3 – Distribution of actual (PHE) and theoretical (HER_m) annual heat energy consumption

Using a bin method to analyse the distribution of over and under estimation in the sample there is an indication of a general trend where the theoretical approach (HER_m) underestimates actual consumption (PHE), see Figure 4 where *+x%* represents overestimation, i.e. HER_m greater than PHE, and *–x%* represents underestimation, i.e. HER_m less than PHE. There is a significant occurrence of underestimation being more than *-100%* whereas all cases of overestimation are within *+100%*. Whilst the scatter of data is relatively high, as seen by the uneven distribution of max-min differences, there is a general bias toward underestimation, i.e. higher proportion of sample falling in negative bands of *-x%.* Allowing for the influence of variations in fuel mix, reflected in peaks at *> -101%*, the degree of underestimation can be generalised as being in the range *0 to -10%*.

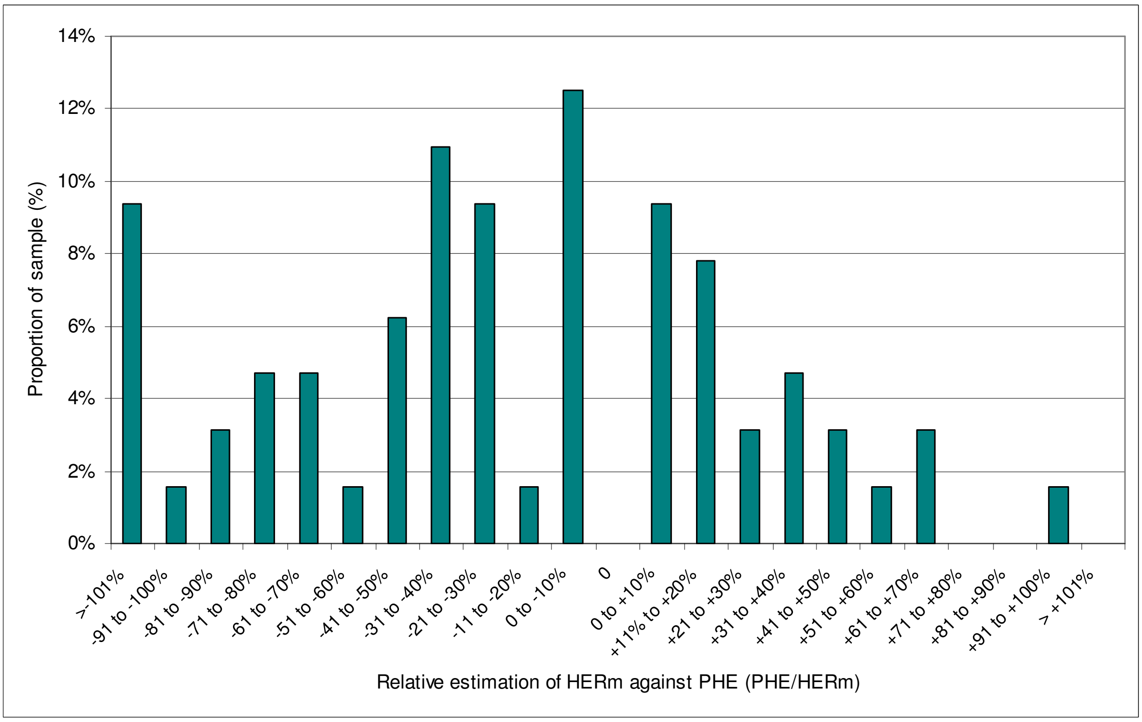

Figure 4 – Distribution of over (*+x%*) and under (*-x%*) estimation of theoretical annual heat energy consumption

The age of the dwelling has an impact on the extent to which the HER_m underestimates the actual energy demand (PHE), see Figure 5, with newer dwellings using more heat than predicted. This can be attributed to the expectation of higher temperature levels in homes which were constructed to higher thermal insulation standards and having modern central heating systems. In the older dwellings, *Pre 1960* and *1961 – 1980*, actual and theoretical consumption are in greater balance.

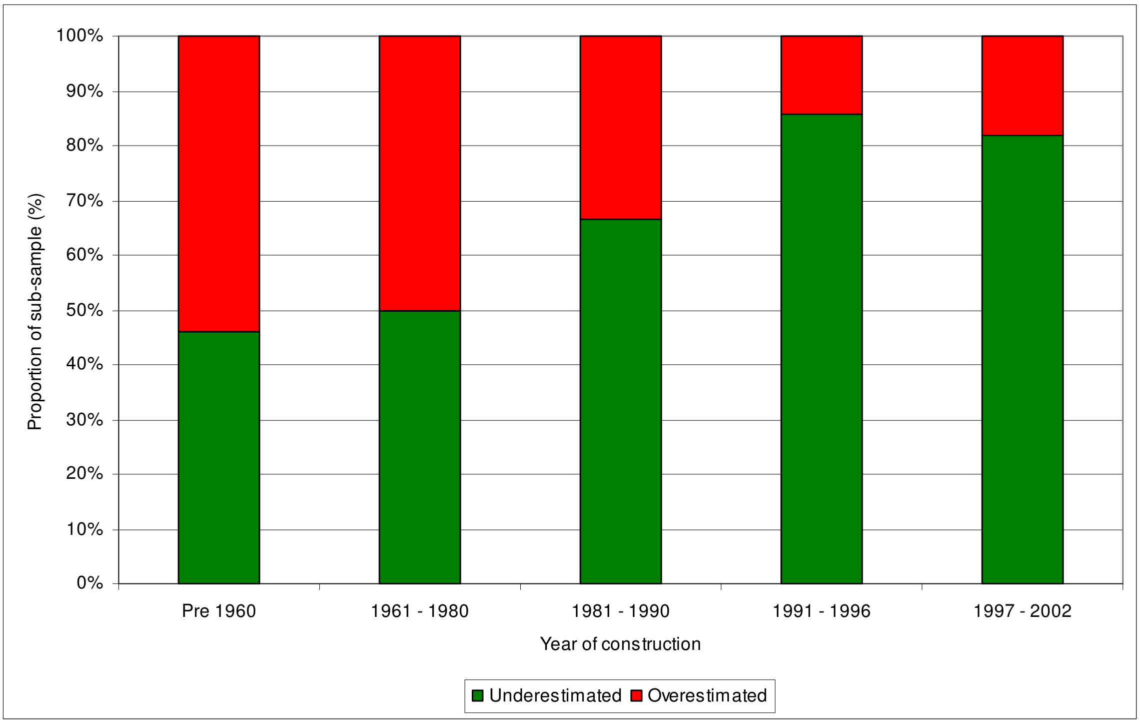

Figure 5 – Distribution of over and under estimation by year of construction

Age of dwellings

There is a general trend in dwellings for the average PHE to decrease with time up to 1996, as indicated by year of construction, Figure 6. However, in dwellings constructed in the period 1997-2002, the average PHE is 13% higher than for the corresponding dwellings in the previous period 1991-1996. This is partly due to the changing mix of built form and also suggests a rise in thermal comfort levels in an increasing number of dwellings, combined with possibly higher domestic hot water consumption in some households. The variation in the PHE data, represented by the difference between max and min data points, follows a similar trend as the average PHE, reducing with time up to 1991-1996 but also increasing significantly for the most recent construction period, 1997-2002. This is in contrast with the expectation of a decrease arising from improvements in the energy related Building Regulations in 1997.

The upward trend in the most recent age cohort is partially influenced by the wider range of PHE, where the difference between max and min is greatest. Whilst this variance within the year of construction sub-samples was also reflected in max-min gross floor areas, this was not the case with average gross floor area. This indicates that the upward trend in average PHE of the most recent age cohort is not entirely due to relative differences in the size of heated spaces in dwellings.

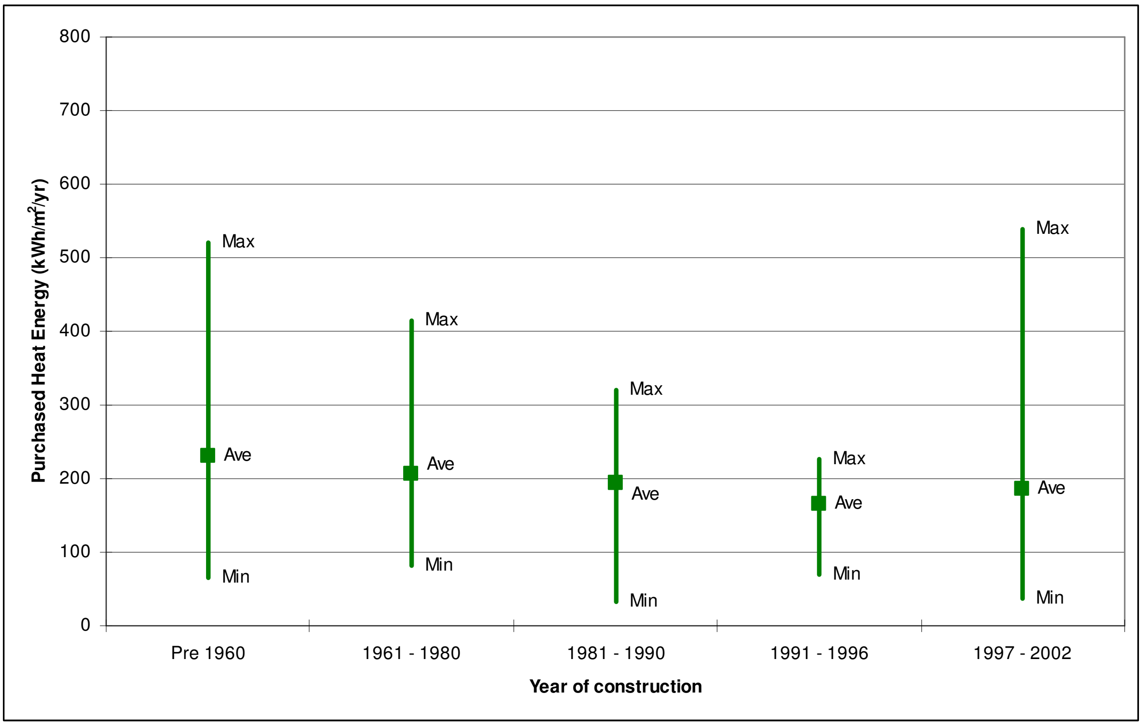

Figure 6 – Purchased Heat Energy (PHE) per year of construction

A trend of a significant increase in both the average and difference between max and min data for the most recent age cohort is not evident in the HER_m data, see Figure 7. This indicates the increase in PHE in the most recent construction period is not due to variations in the physical or theoretical fabric thermal characteristics of the 1997-2002 sub-sample.

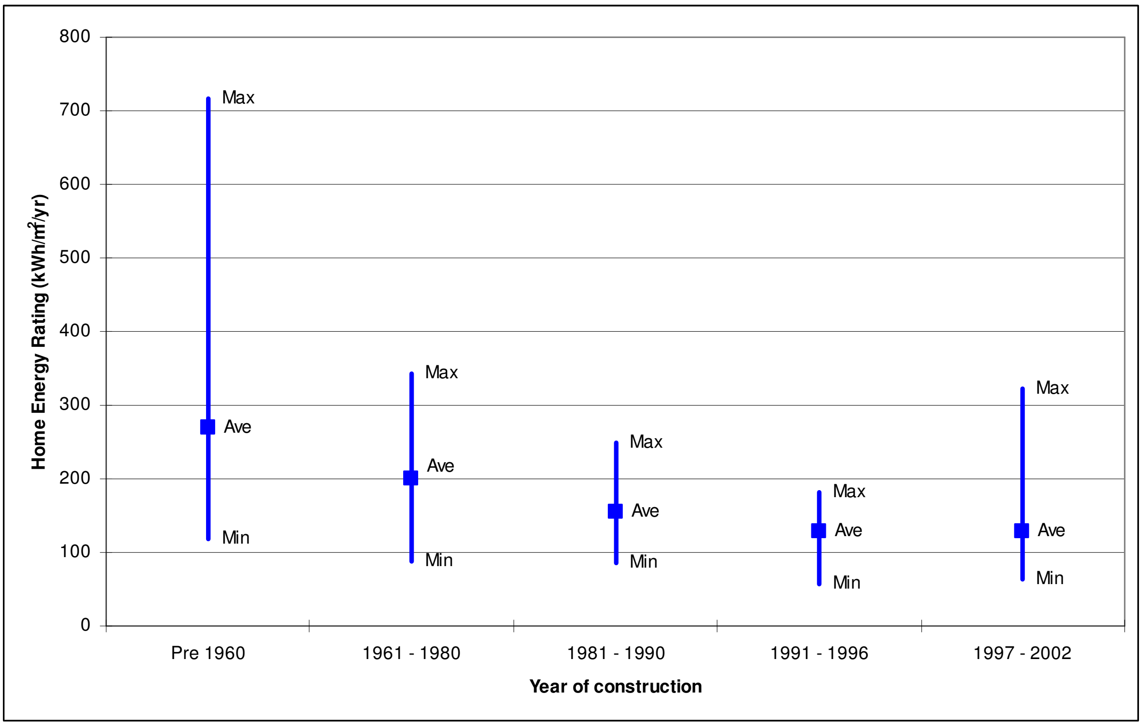

Figure 7 – Home Energy Rating (HER_m) per year of construction

The general trend of decreasing average HER_m with decreasing age, see Figure 7, corresponds generally to expectation, given the progressively decreasing U-values and other energy efficiency provisions, such as pipe and storage tank insulation and basic automatic heating controls, introduced in successive Building Regulations.

Built form

The range of PHE data between the maximum and minimum is found to be greatest in detached houses, due to the wide variety of shapes and configurations of detached houses and is confirmed by a corresponding wide range in theoretical HER_m.

Tenure

Dwellings owned outright are typically the oldest in the sample; reflected by having the highest average PHE, 223.0 kWh/m^2/yr, and HER_m, 258.9 kWh/m^2/yr. Notably the local authority renter sector has a comparable average PHE, 222.7 kWh/m^2/yr, but a much lower average HER_m of 135.7 kWh/m^2/yr. This is attributed to a higher than average occupancy level found in this sector.

Heating Degree Days (HDD)

As HDD are at the core of the HER_m calculation there is a reasonably strong correlation, i.e. R^2 = 0.531, between HDD and HER_m, see Figure 9. However, there is poor correlation between PHE and HDD, i.e. R^2=0.0849, see Figure 8, suggesting that predicted variation in ambient temperature is not such a dominant factor in actual heat energy consumption. The relatively strong correlation between HDD and HER_m indicates the dominance of space heating is largely unaffected by domestic hot water demand in the theoretical approach.

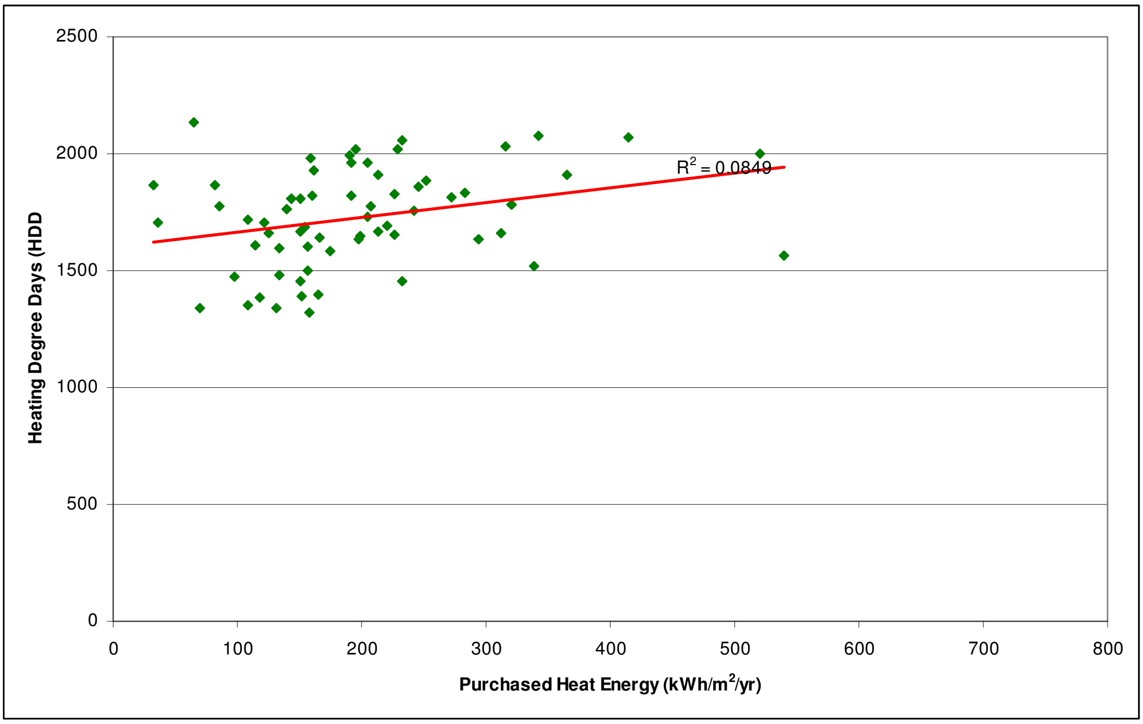

Figure 8 – Purchased Heat Energy (PHE) against Heating Degree Days (HDD)

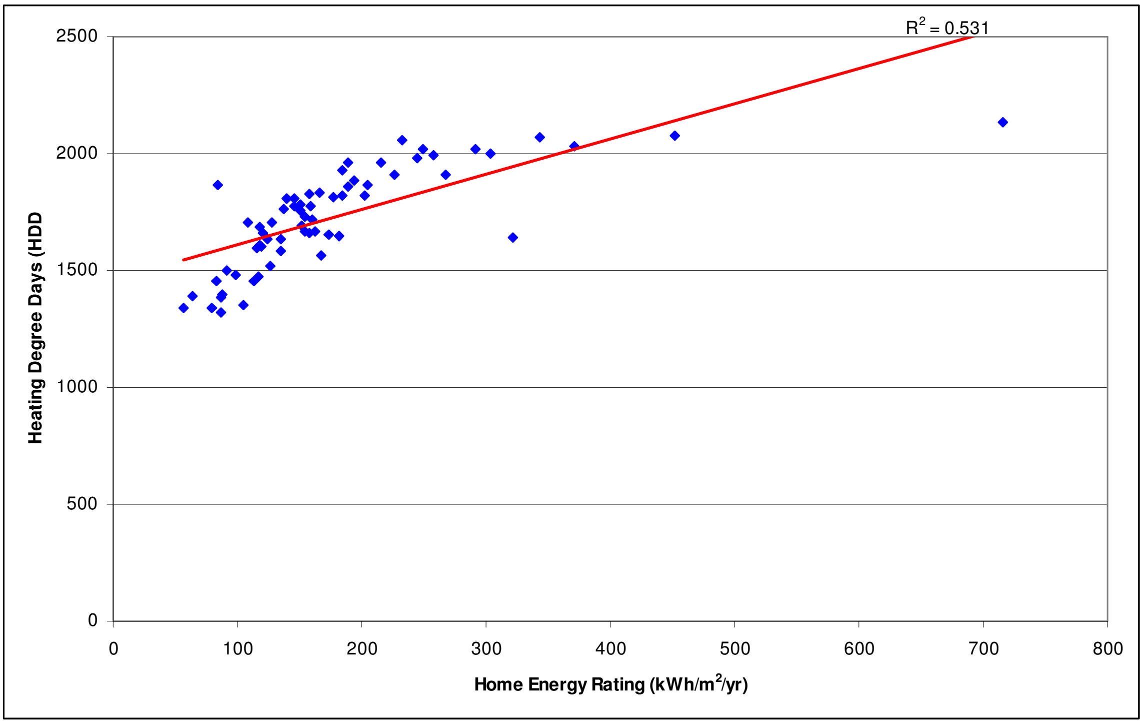

Figure 9 – Home Energy Rating (HER_m) against Heating Degree Days (HDD)

With the sample having a good spread of exposure ratings, i.e. 52% sheltered; 34% semi-exposed and 14% exposed, there is a strong trend found between increasing exposure and increasing PHE but no clear trend with associated HER_m.

A similar approach was taken to approximate the extent of overshadowing. However, the spread of different levels of overshadowing is much more restricted with a majority of 70% being rated as having average overshadowing. No clear trend was found between extent of overshadowing and PHE or HER_m indicating the insignificant impact passive solar heating has on heat energy consumption in conventionally designed dwellings.

Building Fabric

Results show that thermal performance of external walls and roofs, as assessed by the U-value, have improved progressively since 1960 as a result of higher specifications introduced through successive Building Regulations, Technical Guidance Document L. Additionally, the variation in U-values has also decreased over time through the homogenisation of construction techniques and through the use of standard constructions and materials.

Evaluating the impact of fabric thermal performance can be provided by correlation of Overall U-value with delivered Purchased Heat Energy (PHE_d) and Heat Energy Rating (HER_t). PHE_d is the PHE adjusted to account for the conversion efficiency of all heating appliances and calorific values of all fuel types used in each dwelling. This is an approximate measure of the amount of heat delivered to heated spaces once fuel has been converted to heat energy. HER_t is the theoretical heat energy demand delivered to heated spaces before conversion efficiencies and fuel mix calorific values are taken into account.

There is no correlation between PHE_d and Overall U-value illustrating the minimal impact theoretical thermal performance of the building fabric has on actual heat energy consumption, see Figure 10. This is in sharp contrast to the relatively strong correlation between HER_t and Overall U-value, see Figure 11. The clear difference in correlations indicates the strong influence operational factors, such as occupancy patterns and usage characteristics, have on heat energy consumption.

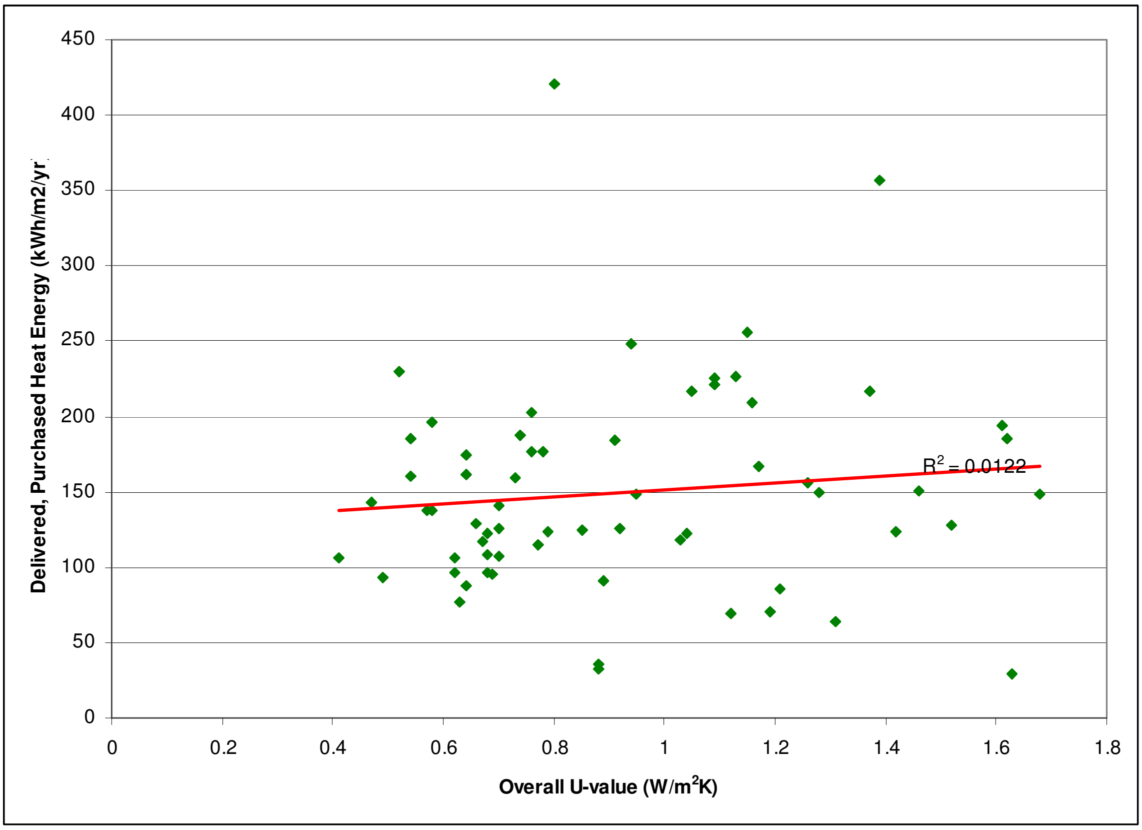

Figure 10 – Delivered, Purchased Heat Energy (PHE_d) against Overall U-value

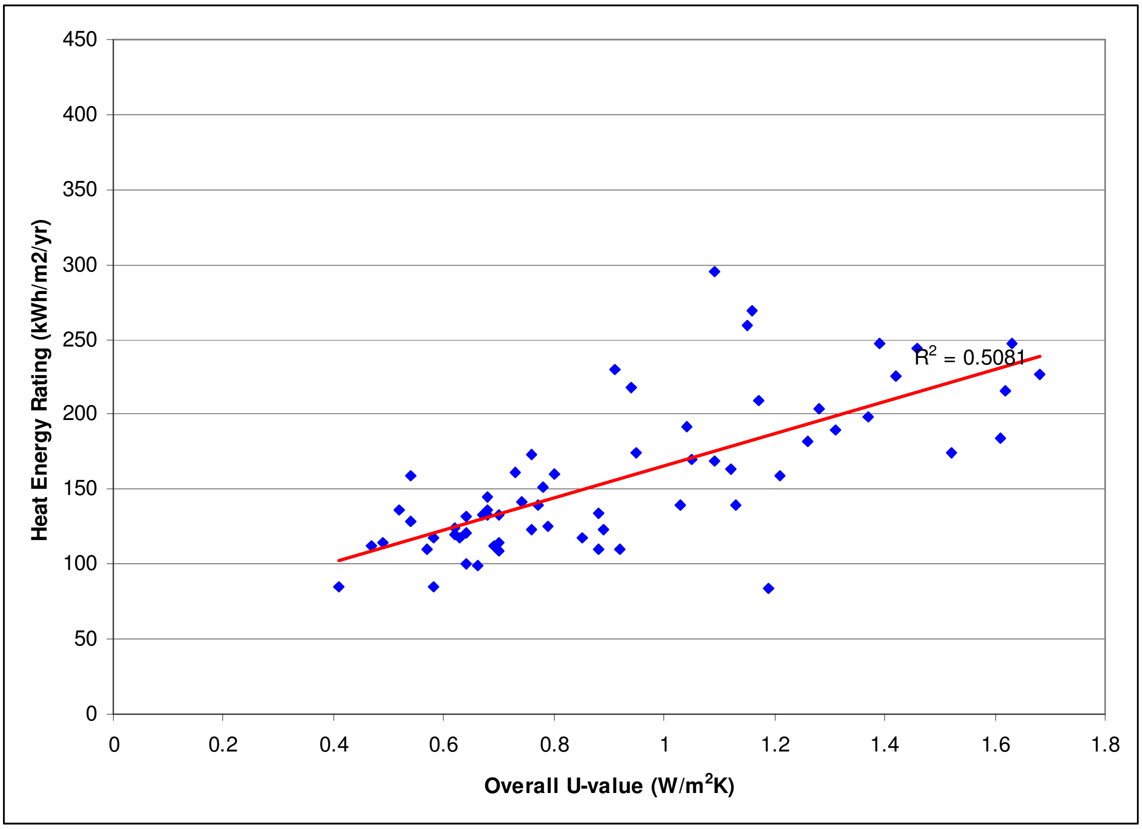

Figure 11 – Heat Energy Rating (HER_t) against Overall U-value

Physical tests

Physical tests were carried out on 15 dwellings to further investigate fabric thermal characteristics and the extent of uncontrolled air infiltration. Physical testing included Infra-red thermography and multi-point depressurisation air tightness.

Local thermal bridging, at window sills and lintels and at wall closure, was found in two-thirds of the 15 dwellings which were examined by infra red thermography. Missing insulation was also found in two-thirds of walls and two-thirds of roofs. The effect on heat loss is much less significant for thermal bridging than for missing insulation, as the decrease of internal wall surface temperature due to thermal bridging is typically 0.5°C, as compared with a typical corresponding decrease of 5 °C due to missing insulation.

Air changes per hour (ACH) and air permeability are the most commonly used airtightness indices in Ireland, with ACH at normal pressures being the metric adopted in the Irish Heat Energy Rating (HER_t) method. The average ACH and air permeability of the 15 dwellings tested that were constructed in the period 1997-2002, is 0.49 ACH at normal pressures and 25.5 $m^3/hr/m^2$ at 50Pa respectively. These reflect a poor level of airtightness being achieved when compared to related good practice levels of air permeability of 7.0 $m^3/hr/m^2$ at 50Pa (Anon., 2003).

There is no correlation between measured ACH and PHE_d, see Figure 11. The insignificance of the influence infiltration heat loss has on PHE_d is shown by the negative trend. Whilst this is contrary to theory, it shows that other factors have an overriding influence on PHE_d indicating that further significant reductions in heat energy consumption cannot be achieved by increasing airtightness alone.

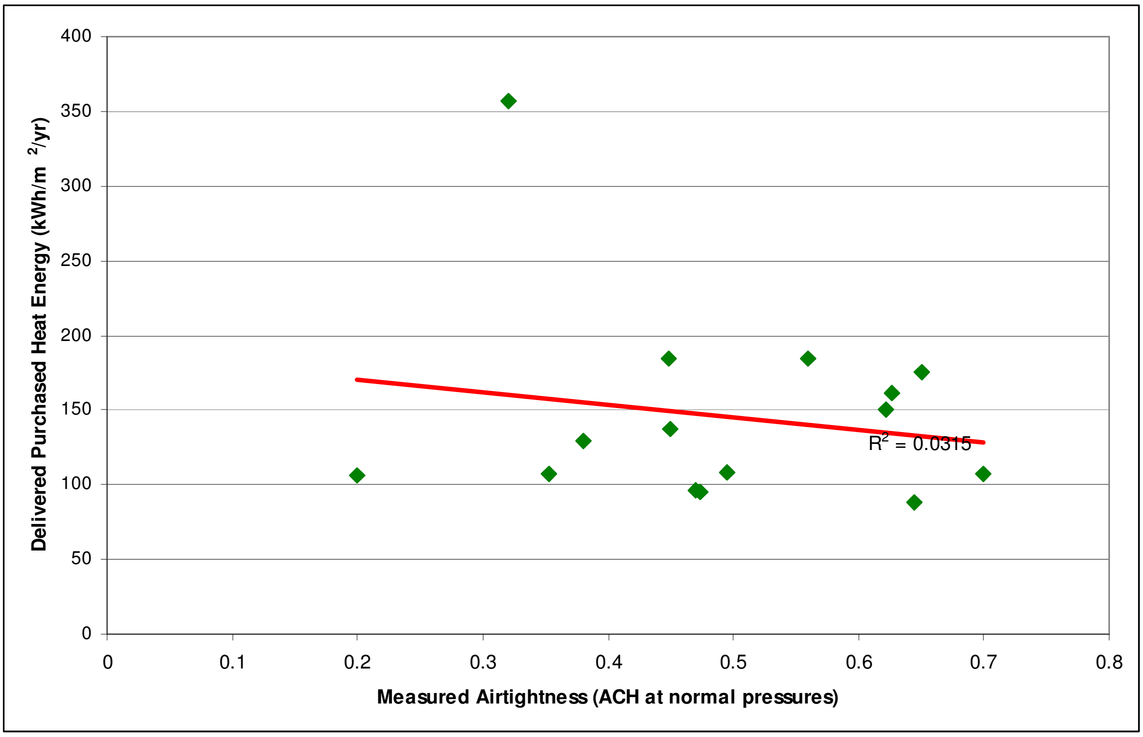

Figure 11 – Measured airtightness against Delivered Purchased Heat Energy (PHE_d)

Domestic Heating Systems

Domestic heating systems have the greatest influence on efficient use and control of fuel consumption to meet heating energy demands. System characteristics typically influence occupant interaction in their pursuit of thermal comfort. Occupant surveys were conducted to determine satisfaction with thermal comfort levels and system responsiveness correlated against the three main heating system components of heat source, distribution system and emitter types.

A notional scale from 1 to 5 was used to assess occupants' consideration of the rate at which heating systems achieve acceptable levels of thermal comfort (i.e. 1 = slow; 3 = moderate and 5 = fast). Pumped water distribution is considered by occupants to have the fastest response with systems having no distribution (i.e. heating provided direct from heat source only), being the slowest. Whilst variation of occupants' opinion of system responsiveness is greatest with electric heating, there is significant variation associated with all distribution types.

Occupant satisfaction with internal temperature was recorded using a notional scale of 1 to 5, where 1= cold and 5 = warm. Correlating this data with system distribution type results show, occupant satisfaction with internal temperature is significantly lower in cases where the primary heating system does not have a distribution system, i.e. a heat source only, for example open coal fire without back boiler or heater cooker appliance. Heat emitter type is directly related to distribution type. Occupant satisfaction with temperature as a function of emitter type is similar to that correlated with distribution type. In each case portable heaters and open fires show the lowest satisfaction rating.

There is a slight but noticeable trend between control type and occupant satisfaction with responsiveness, where increasing control complexity results in higher levels of satisfaction.

Heating Control Type	**Basic control, i.e. single room thermostat plus timer**	**Thermostatic radiator valve or similar**	**Full time and temperature zone control (at least two zones)**
Average occupant satisfaction with responsiveness	3.8	3.9	4.5

Table 2 – Heating system responsiveness and control type

Spot measurements of primary heat source efficiency were taken for a sub-set of 22 dwellings. Whilst conventional gas hot water central heating boilers are the most common (i.e. 82%) primary heat source in the sub-sample the statistical distribution in the national housing stock is 90% (Watson, D., Williams, J., 2003). The average primary heat source rating is 18.6 kW and the average measured efficiency is 84% compared with an average net efficiency (NCV) of 90%. A slight trend was found between spot measured efficiency, on an NCV basis, and PHE_d.

Discussion

The energy performance survey of 64 dwellings reflecting the housing stock profile in the Greater Dublin Area (GDA), has shown both expected results and some that are contrary to theory. Whilst, at a building stock level, there is a tendency for the theoretical approach to underestimate actual consumption by between 0% and 10%, the theoretical approach has been found to adequately represent the average of a range of variations in dwelling design, construction, microclimate and operation. However, when viewed from the perspective of some discrete housing characteristics the variation between actual and theoretical increases.

The GDA sample show a general reduction in actual heat energy consumption corresponding with increases in energy related regulations and modern building approaches but the reduction is not as large as predicted by theory. In the most recent portions of the sample, constructed between 1997 and 2002, actual heat energy consumption has increased beyond that predicted by theory. This is considered to be a reflection of rising demand for thermal comfort associated with higher performing dwellings. Although, the local authority renter portion of the sample have a relatively high actual heat energy consumption, due to high occupancy patterns, other macro scale characteristics of the housing stock related to built form and tenure generally show actual and theoretical heat energy consumption correlations as would be expected.

Whilst theoretical calculation, based on heating degree days (HDD), of heat energy consumption correlates well with HDD no clear correlation was found between HDD and actual heat energy consumption. HDD, or an averaged quantification of ambient temperature does not provide a useful guide to actual heat energy consumption.

The elemental thermal performance of dwellings in the GDA has increased with historical increases in minimum fabric thermal specifications controlled through Building Regulations. The poor correlation found between overall U-value and actual heat energy consumption illustrates the relatively low impact fabric thermal performance has on actual consumption. A similar situation is found with envelope airtightness where no correlation is found between increasing airtightness and reducing actual heat energy consumption. These results indicate the dominance of other factors, such as operational characteristics, in driving actual heat energy consumption.

The heating systems in the sample dwellings were found to provide adequate levels of efficiency. Additionally, a number of general expected factors were confirmed through occupant questionnaires, including occupant satisfaction with thermal comfort and amenity increases with increasing complexity of control systems, centralised heat sources with powered distribution systems provide greatest satisfaction whilst electric storage heating is equally accepted.

The results of the survey have shown there is a need to further explore the operational characteristics of dwellings and integrate findings with accepted theoretical approaches to identify ways to enhance the effectiveness of energy efficient strategies and solutions.

References

Anon., 1994. European Communities (efficiency requirements for new hot water boilers fired with liquid or gaseous fuels) Regulations 1994, Stationary Office, Ireland

Anon., 1997a. Building Regulations, 1997, Technical Guidance Document L Conservation of Fuel and Energy, Stationary Office, Ireland

Anon., 1997b. Building Regulations, 1997, Technical Guidance Document J Heat Producing Appliances, Stationary Office, Ireland

Anon., 1997c. Building Regulations, 1997, Technical Guidance Document L Conservation of Fuel and Energy, Stationary Office, Ireland, Appendix C Heat Energy Rating: Standard Calculation Method pp. 37-47

Anon., 1997d. Building Regulations, 1997, Technical Guidance Document L Conservation of Fuel and Energy, Stationary Office, Ireland, Table 27 pp. 46

Anon., 2002a. Building Regulations, 1997, Technical Guidance Document F Ventilation, Stationary Office, Ireland

Anon., 2002b.Census 2002, Principal Demographic Results, Stationary Office, Ireland

Anon., 2003. CE12, 2003, Energy Efficient Best Practice in New Housing, Energy Savings Trust, U.K.

Howley, M., O'Gallachoir, B., 2005. Energy in Ireland 1990-2003 Trends, issues and indicators, Sustainable Energy Ireland, Ireland pp. 16

Watson, D., Wiliiams, J., 2003. Irish National Survey of Housing Quality 2001-2002, The Economic and Social Research Institute, Ireland pp. 82

Appendix A: Greater Dublin Area (GDA) Sample profile

GREATER DUBLIN AREA	Detached	Semi-detached	Terraced	Purpose-built Apartment	Converted Apartment
Own Outright, Pre1960	6	4	4	0	0
Own Outright, 1961-1980	4	4	2	0	0
Own Outright, 1981-1990	2	1	1	0	0
Own Outright, 1991-1996	1	1	0	0	0
Own Outright, 1997-2002	1	0	0	0	0
Purchasing, Pre1960	2	2	2	0	0
Purchasing, 1961-1980	2	4	2	0	0
Purchasing, 1981-1990	2	3	1	0	0
Purchasing, 1991-1996	2	3	1	0	0
Purchasing, 1997-2002	3	3	1	0	0
Local Auth Renter, Pre1960	0	0	1	2	0
Local Auth Renter, 1961-1980	0	2	4	2	0
Local Auth Renter, 1981-1990	0	1	2	1	0
Local Auth Renter, 1991-1996	0	0	1	0	0
Local Auth Renter, 1997-2002	1	1	2	1	0
Private Renter, Pre1960	0	1	1	1	1
Private Renter, 1961-1980	0	1	0	0	0
Private Renter, 1981-1990	0	1	1	1	0
Private Renter, 1991-1996	0	1	1	1	0
Private Renter, 1997-2002	0	1	1	1	0