# The Expanding House: Extensions to Domestic Buildings and their Impact on Energy Consumption

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## Abstract
The energy impact of extensions, defined as the percentage increase in total household energy consumption caused by an extension, has been investigated and quantified. This has been achieved through a two-step process. Firstly, a set of typical extension sizes and prevalence was defined through a survey using publicly available aerial imagery and GIS mapping software. Secondly the energy impact of these extensions was predicted through the application of a reduced data Standard Assessment Procedure. A catalogue of extension types has been created and statistically significant relationships between extension prevalence and tenure, household income and building archetype have been proven. The energy impact of extensions has been estimated to be 16% on average across all building and extension types; which would account for 3.8% of England's domestic energy demand if the results of this study were scaled nationally.

## Keywords
Domestic stock model; Domestic energy efficiency; Extension; Energy assessment; Energy Policy.

## Article Outline

## 1. Introduction

The UK made a legal commitment to an ambitious carbon emissions reduction target of 80% of 1990 levels by 2050 in the Climate Change Act of 2008 [H.M. Government, 2008], whilst in 2010 the residential sector represented 17% of the UK's total carbon emissions [DECC, 2011]. The government has made reducing emissions from the domestic sector a policy priority [H.M. Government, 2008], therefore accurately measuring the effectiveness of these policies will be crucial over the next few years.

One well established approach to assessing the likely effectiveness of energy $CO_2$ reduction interventions is through the use of 'bottom-up' domestic stock models [Firth et al, 2010, Jones et al., 2007, Natarajan and Levermore, 2007, Boardman et al., 2005, Johnston et al., 2005]. These models break the housing stock up into groups of similar dwellings represented by a single archetype (a notional typical example that represents the sub-set) and calculate the energy demand of each based upon a the properties assigned to it [Swan and Ugursal, 2009].

If extensions and conversions to houses contributes a significant percentage of total UK energy demand, and yet remain unaccounted for, they could mask the impact of energy efficiency policies. Furthermore, if unaccounted for in the stock models used to inform these policies, they could skew predictions and lead to misleading conclusions. Even though the importance of built form on predictions of housing stock models has been highlighted [Firth et al, 2010, Cheng and Steemers, 2011], the impacts of extensions have not been studied.

This study seeks to define the size, shape and prevalence of extensions to buildings within England and to estimate their energy impact based upon these dimensions. In order to address this aim a set of research questions were developed:

1. In what way do extended houses typically differ geometrically from their parent (the un-modified original building) buildings?
2. How prevalent are extensions and are there any relationships between their prevalence and the socio-economic characteristics of the occupants?
3. What is the possible energy impact of these extensions?

## 2. Methodology

The surveying was carried out using publicly available aerial and on-street imaging, using a combination of Google's Street View and aerial photography and Bing's $45^{o}$ Bird's Eye photography. This allowed the identification of an extension or loft conversion, the dimensions of which were then measured using ArcGIS mapping software.

To enable an investigation into the links between the likelihood of a house being extended and socio-economic variables such as household income and tenure, the dwellings chosen for the survey were those included in the 4M project, referred to as the L575 houses, [Lomas et al, 2010] which provided information about each of the householders.

The database of extended houses that had been created was then sub-divided, first by parent building archetype and then by extension type. The parent buildings were divided into three archetypes: terraced, semi-detached and detached; the dimensions of which were as defined in the BRE's *Standard Dwellings for Modelling* [Allen and Pinney, 1990], which was also used in the Community Domestic Energy Model (CDEM) [Firth et al, 2010]. The extension types were identified based upon the results of the survey and then combined with the measurements taken to create the taxonomy; this is a catalogue of extension types with prevalence and average size for each type.

An rdSAP [DECC, 2010, Appendix S] building energy assessment calculation, carried out in NHER Advisor, was the primary tool used for estimating the energy impact of the extensions surveyed. Firstly an rdSAP calculation was carried out for each of the unmodified archetypes and then for each of the parent building plus extension combinations identified in the taxonomy; the energy consumption of the former was then subtracted from that of the latter.

Finally, the energy impact of extensions on a nationwide scale was estimated. This was achieved by applying the observed occurrences of each extension type to the total number of houses of each archetype in England to give an estimate of the total number of un-modified and extended houses of each type in the country. These totals were then multiplied by the energy consumption calculated for each un-modified and parent plus extension case to give a total consumption accounting for extensions.

## 3. Results

The survey showed that just over 19% of the houses in the survey had an extension, with detached houses being the most commonly extended.

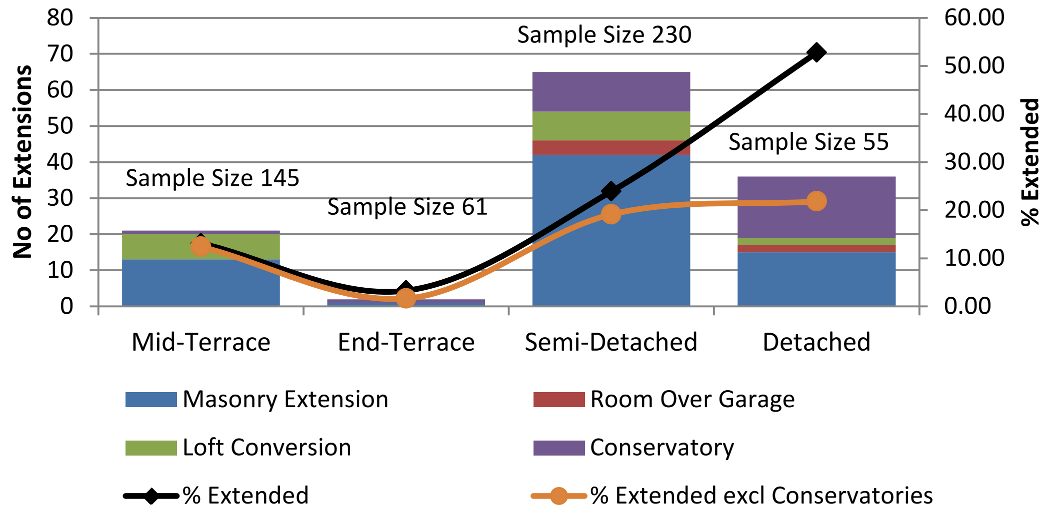


**Figure 1: Total number of extensions sub-divided by parent archetype. Note: Some houses have more than one extension of different types.**

Statistically significant relationships, at the 1% significance level ($p<0.01$), have been found between the presence of an extensions and housing archetype, tenure and household income, they suggest that houses are more likely to be extended if they:

- Are occupied by households with higher incomes
- Are owned by the occupier
- Are detached or semi-detached, rather than terraced houses

The strength of the relationships were compared using the outputs of the Spearman's correlation test applied to each case which showed that tenure has the greatest influence on the likelihood of a house being extended; followed by household income and finally housing archetype. That these results are as one might expect intuitively gives confidence in the surveying method.

The extensions observed in the survey are fully characterised in the taxonomy which is sub-divided by parent building archetype, as an example the terraced taxonomy is shown below.

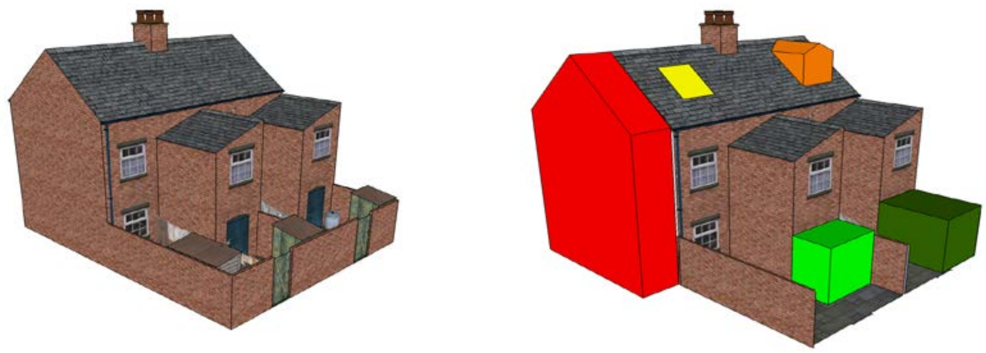

**Figure 2: The terrace archetype before and after extension; the colours are assigned to extension types in Table 1.**

| Extension Type | Description | Diagram Colour | Occurrence (%) |
|---|---|---|---|
| T1a | Single Storey, Rear, 2 Rooms | Dark Green | 3.4% |
| T1b | Single Storey, Rear, 1 Room | Light Green | 3.4% |
| T2a | Loft Conversion, Skylight | Yellow | 3.4% |
| T2b | Loft Conversion, Dormer | Orange | 0.0% |
| T3 | Two Storey, Side (End Terrace) | Red | 0.5% |
| T4 | Conservatory | | 1.0% |

**Table 1: Taxonomy data describing the occurence of each extension type in the L575 survey.**

| Type | Perimeter Increase | Surface Area Increase | Volume Increase | Perimeter (m) | Connection Length (m) | Surface Area ($m^2$) | Volume ($m^3$) |
|---|---|---|---|---|---|---|---|
| T1a | 60.46% | 28.04% | 16.99% | 15.24 | 1.86 | 58.90 | 30.82 |
| T1b | 30.81% | 10.78% | 5.50% | 7.76 | 1.34 | 24.09 | 9.97 |

**Table 2: Data detailing the change in dimensions with reference to the parent building caused by each extension type and archetype extension dimensions for each extension type.**

The results of the energy modelling show that the extensions observed cause a clear and significant increase to the energy consumption of the building, as shown in Figure 3. A range of energy impacts of between 7.4% and 33.3% was observed, referring to a single storey extension to the front of a detached house (D7) and a two storey extension to the side of a semi-detached house (S1) respectively. In each calculation the parent building was assumed to have building properties typical of the most commonly occurring aged building of the appropriate archetype in the dataset, while the extension was assumed to have been constructed in the period 1996-2002.

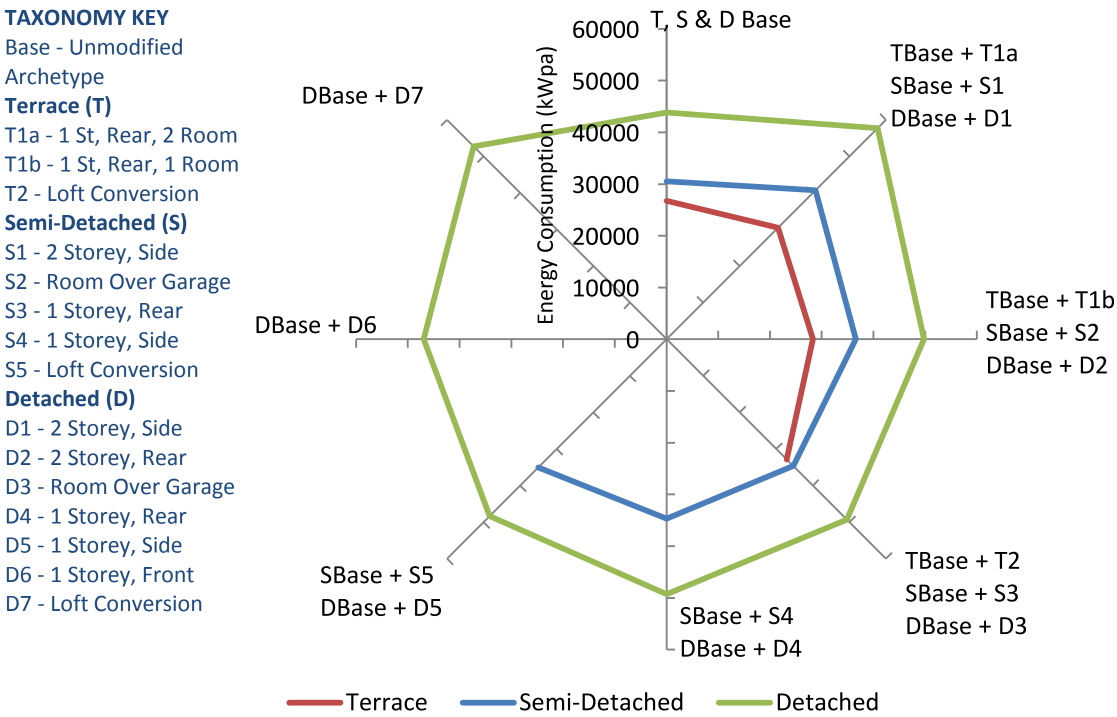


**Figure 3: Total energy consumption of each base case and extension combination.**

The average energy impact for the extensions to both the terraced and semi-detached archetypes was 14%, while for the extensions to the detached archetype it was 15%. The average energy impact across the extensions to all three archetypes was 16%. The predicted energy impact of extensions to all terraced, semi-detached and detached dwellings in England was estimated to be 3.8%.

## 4. Discussion

The results of this study predict that the total energy impact of lofts conversions and extensions, excluding conservatories, across England is 3.8%, or 23.6TWh, across the three archetypes studied: detached, semi-detached and terraced houses. This observation assumes that there is the same prevalence of extensions nationwide as in the Leicester sample.

The question is: how important is this compared to other factors that influence energy demand? If it is assumed that the all of this extra energy consumption is generated from natural gas, which is not unreasonable as by far the largest contributor is space heating, then direct comparisons can be made between the percentage increase in energy consumption and percentage changes in $CO_2$ emissions predicted by other models. For example, Firth et al estimate that a $CO_2$ reduction for the whole of the Leicester stock of 8% could be made by applying insulation to all solid wall buildings in the city, and a total saving of 35% for a full suite of energy efficiency retrofits.

Given that this study has been undertaken across a relatively small sample size, 575 homes, and has only included dwellings in Leicester, a high level of confidence cannot be guaranteed when scaled nationally.

In fact, the 2008 English Housing Survey recorded a 13.3% higher percentage (i.e. 22.3% extended) of all dwellings extended than the L575 survey, this is thought to be largely due to location as a correlation between household income and likelihood of extension has been proven here and Leicester's average household income is significantly below the average. Therefore the estimate for the total number of extensions and hence energy impact of extensions predicted by this study is likely to be lower than the national average.

In order to reduce the English stock down to a few archetypes and extension types, average or typical values for each archetype have to be assigned. In this study, the parent archetypes were all assumed to possess properties typical, as defined by the SAP, of the most commonly occurring building age in each archetype's sample. The results of the rdSAP calculations for each archetype plus extension combination were compared with metered values for houses of the same type from the L575 dataset. This showed an average rdSAP over-estimate of total energy consumption of 32%.

Previous research has shown that an overestimation of energy consumption has occurred due to unrealistically high attributed indoor temperature conditions applied in the rdSAP modelling process whereby values based on nationally averaged data are not representative on a local scale [Clinch et al., 2001, Cheng and Steemers, 2011]. For instance, Druckman and Jackson found significant variations in energy consumption between very deprived and wealthy areas; comparing two areas they found that average household energy use in the deprived area was 78% of the national average and 136% of the national mean in the wealthy area [Druckman and Jackson, 2008]. Given that households in Leicester tend to have relatively low household incomes, it is to be expected that the average internal temperature conditions in the city will be lower than the national average causing an overestimate of energy consumption as the SAP average internal conditions have been used in this study.

## 5. Conclusions

- 19% of buildings surveyed had an extension or conversion.
- A taxonomy describing the size, shape and prevalence of these extensions was developed.

- Statistically significant relationships ($p<0.01$) have been found between likelihood of extension and tenure, household income and parent archetype with the relative strength of the relationships in that order.
- A range of energy impacts of between 7% and 33%, with a mean impact across all extension types of, 16% has been estimated.
- An estimate of the energy impact of extensions on an England-wide scale of 3.8% has been calculated, which is of a similar magnitude to the impact of a typical energy efficiency retrofit.

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