The Influence of Dwelling Energy Efficiency on the Sensitivity of Inputs to a Steady-state Energy Model

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Abstract
The Standard Assessment Procedure (SAP) is a UK building regulation compliance tool for dwellings. SAP includes over 190 inputs to assess the energy efficiency of dwellings. However, uncertainty within these input parameters will impact energy demand assessments. A local sensitivity analysis is performed on 143 inputs for dwellings of varying energy efficiency to evaluate the influence of input parameters on total energy demand. Influential input parameters are shown to vary depending on the energy efficiency of the dwelling. The most sensitive parameters are heating practices of occupants, heat loss parameters of the dwelling (such as wall U-value and window U-value), building system efficiencies and occupant actions. Using improved estimates of these parameters is essential in reducing uncertainty in dwelling energy demand predictions.

Key Innovations
- Local sensitivity analysis of a steady-state energy model
- Dwellings of distinct energy efficiency levels are assessed and compared.

Practical Implications
Dwelling energy efficiency level impacts which inputs are most influential to energy demand predictions in SAP. Inputs which require the most accurate assumptions will therefore vary depending on the energy efficiency of the dwelling.

Introduction
Background
Building energy prediction tools provide an approach to understanding the energy demand of dwellings, by predicting how a building performs based on complex interactions between aspects of building design and building operation. Building energy prediction tools can be adopted to ensure that design of new buildings meet a certain criterion before development (e.g., minimum energy performance), identify how buildings perform under specific conditions, or to better understand the energy efficiency of buildings (Maile et al, 2007). It is therefore important that the conclusions drawn from the use of building energy models reflect reality.

Building energy models contain a high number of inputs to represent the building characteristics, external conditions, and occupant assumptions. If insufficient knowledge is known about the aspects of a building or in the external conditions, a degree of uncertainty will arise within the model (Malkawi et al, 2004). Uncertainty in the value of an individual input will therefore introduce uncertainty into the predictions. Understanding the influence of input parameters in a building energy model can aid in identifying where uncertainties in a particular input can impact the assessment of energy performance. If values used for individual input parameters in the assessment of building performance do not reflect realistic or accurate values, inaccuracies in energy demand estimations may be a consequence.

UK Standard Assessment Procedure
The assessment of the energy efficiency of UK dwellings is achieved with the Standard Assessment Procedure (SAP) (BRE, 2012). SAP is used as a tool to understand the energy efficiency of dwellings and is commonly used in building regulations, in the development and implementation of building energy policy, and in the production of Energy Performance Certificates (EPCs) for dwellings (HM Government, 2014). The SAP model is also frequently used in the development and implementation of building energy policy, which seek to introduce energy efficiency measures to dwellings.

The procedure was first published by the Building Research Establishment (BRE) in 1995, with revisions published in 1998, 2001, 2005, 2009 and 2012. The most recent revision is SAP 2012 and is part of the method to assess Part L of Building Regulations (HM Government, 2016). SAP is based on the BRE Domestic Energy Model (BREDEM), (Anderson, 1985) and used to calculate the annual energy demand, fuel cost and \( \text{CO}_2 \) emissions of dwellings.

The SAP model is based on a steady state calculation and determines the annual energy demand based on the construction materials, building/heating systems and infiltration of a dwelling, also factoring in internal/solar gains, occupant behaviour and external conditions. The SAP model provides a calculation independent of occupant behaviour, allowing a like for like comparison between dwellings. The key parameters SAP focusses on is space heating demand, hot water demand, and lighting use.

The final outcome of the SAP model is an SAP rating, which is used to produce Energy Performance Certificates (EPC), rating a building between A-G, a measure of the annual energy costs for the dwelling. An Environmental
impact (EI) rating reflects the CO₂ emissions arising from the energy used. Both are based on a scale between 1 to 100, a higher score represents a more energy efficient dwelling with lower CO₂ emissions.

However, there is uncertainty in the inputs that are used in the calculations, impacting the estimation of energy demand and CO₂ emissions of dwellings. This can be caused by insufficient knowledge or using inaccurate assumptions. Identifying which input parameters influence the estimations of energy demand in SAP can show where sufficient data is needed to reduce uncertainty in predictions. This can ensure that sensitive parameters are accurate, reducing uncertainty in estimations.

**Sensitivity Analysis**

Sensitivity analysis is a method to understand how the uncertainty in the output of a model can be attributed to the inputs within the model (Saltelli et al, 2004). The aim of a sensitivity analysis is to identify input parameters which are influential, or insignificant on the output of a model.

Therefore, sensitivity analysis is performed to get an understanding about the impact and influence of inputs in a modelling tool. Sensitivity analysis is useful in identifying where uncertainties in a particular input parameter for building design can have a major influence on the estimations for the energy demand or CO₂ emissions of a dwelling. This is performed by adjusting the value of chosen inputs by a select amount to evaluate how uncertainty in an individual input affects the output of a model.

Lomas et al, (1992) applies multiple sensitivity techniques to three building energy models to evaluate the suitability of these techniques. The study determines that the appropriate choice of technique should depend on the type of information required but identifies differential and Monte-Carlo as the most suitable tools for sensitivity analysis of modelling tools for those evaluated.

Kristiensen et al, (2017) applies three sensitivity analysis techniques in a study to determine the most appropriate methods for evaluating building performance when using a quasi-steady state model and a dynamic simulation tool. The study highlights the differences in determining the most influential parameters depending on the method used. Consideration is required therefore when deciding which technique to use.

Firth et al, (2009) applies local sensitivity analysis to the Community Domestic Energy Model to understand influential parameters of building performance on the CO₂ emissions of UK dwellings. The study discusses the many uncertainties that can significantly impact the predictions of CO₂ emissions in dwellings and the study highlights the potential sources of uncertainties across 47 different dwelling archetypes.

Hughes et al, (2014) performs a sensitivity analysis of the SAP2009 model to understand the most influential parameters on the annual energy demand estimations. The study performs local sensitivity analysis on input parameters in SAP, with uncertainties in inputs ranging up to ±30%. The study applies this to a dwelling stock, determining that large uncertainties in input parameters are non-linear. However, the study applies considerably large uncertainties which may not reflect the level of sensitivity at lower levels of uncertainty in input parameters.

It is shown that sensitivity analysis has been a useful and proven method to identify the influence of parameters across diverse building archetypes in building energy prediction tools. However, the influence of the energy efficiency of a dwelling on the outcome of a sensitivity analysis within these tools is less established. This study aims to address this with a local sensitivity analysis of SAP2012 with dwellings of distinct energy efficiency levels. This paper will identify the most influential input parameters to total energy demand in SAP2012. The local sensitivity analysis is performed on F and B rated dwellings, to evaluate the influence of input parameters at different dwelling energy efficiency levels. All numerical input values are considered, and the sensitivity compared across the two dwelling archetypes to understand the influence of dwelling energy efficiency on the sensitivity analysis of SAP.

**Methodology**

- Two dwelling archetypes are developed, both are detached dwellings with SAP ratings F and B for comparison at different energy efficiency levels.
- One-at-a-time sensitivity analysis is performed to identify the most/least influential input parameters in SAP2012.
- 143 input parameters are evaluated in the study, requiring 1431 model runs for all data to be collected.
- Sensitivity coefficients based on partial derivatives are calculated for comparison of input sensitivity.

**The SAP Model**

A SAP2012-based model has been developed in Python, which undertakes the full calculation of SAP to determine the annual total energy demand and CO₂ emissions of dwellings. Figure 1 shows a layout of the model and the individual constituents which make up the calculation. There are over 190 inputs into the SAP model and input data is required for each of the 12 individual sections in SAP. The 12 sections include dwelling dimensions, ventilation rate, heat loss parameters, hot water requirement, internal gains, solar gains, mean internal temperature, space heating requirement, energy requirements, fuel cost, SAP rating and environmental rating. The model is set up to allow for individual sections of the SAP model to be run independently if specific outputs are required, or for a complete model run to calculate all outputs. There are 192 outputs provided across the 12 sections of the SAP model, the results of each calculation in SAP2012. Within a complete run of the model, 188 of these outputs are intermediate outputs, which feed into further calculations within the model. The final outputs of the model are total annual energy demand, annual CO₂ emissions, SAP rating and EI rating. The number of inputs for each section that are required by the
Local Sensitivity Analysis

The study uses the one at a time technique (OAT) to evaluate the inputs into the SAP2012 model. OAT is a local sensitivity analysis method, which involves the varying of input parameters one at a time to understand the impact on the model output (Saltelli et al, 2004). This allows the individual influence of a parameter to be determined. The method requires the altering of one input from the base value, and then directly measuring the impact this adjustment has on the outcome. The value is then returned to the base case assumption before moving on to the next input to be evaluated. This process is repeated for all inputs that are to be assessed. The adjustment of an input will consistently be from the base case value.

A full evaluation of the SAP2012 model requires each input to be adjusted by a chosen amount. For this study, each input is adjusted in increments of ±1% up to a final adjustment of ±5%. The reasoning behind a small adjustment in each input value is to identify the potential for a non-linear relationship between the input and the output.

For this study, all numerical inputs in SAP2012 which are used to calculate the total annual energy demand are considered. In total, 143 inputs into the model were considered to evaluate the impact each input has on the total annual energy demand of dwellings. The model output for each input adjustment is saved and returned after all inputs have been assessed.

To evaluate the influence and compare the relative impact across the inputs, a sensitivity coefficient is calculated for each input. The sensitivity coefficient allows for a direct comparison between inputs, to understand the most/least influential in the model. The sensitivity coefficient is based on partial derivatives and is calculated at each model run.

Changing the value of an input, \( x_i \), from the base case value, \( x_{bc} \), and looking at the corresponding change in output, \( y_i \), from the base case value, \( y_{bc} \), will show the impact of adjusting the input value on total energy demand. By considering the percentage change in total energy demand, \( \%\Delta y \), by the percentage change in the input adjustment, \( \%\Delta x \), an elasticity of variation can be defined (Kristiensen et al, 2016). The sensitivity coefficient, \( S \), can be defined as:

\[
S = \left( \frac{\%\Delta y}{\%\Delta x} \right) \times 100 \quad (1)
\]

Where:

\[
\%\Delta y = \frac{y_i - y_{bc}}{y_{bc}} \times 100 \quad (3)
\]

\[
\%\Delta x = \frac{x_i - x_{bc}}{x_{bc}} \times 100 \quad (4)
\]
Where \( x_{bc} \) and \( y_{bc} \) refer to the base values for the input and output, and \( x_i \) and \( y_i \) refer to the adjusted value for the input and corresponding output of each run, respectively. The coefficient is then averaged across each 1% increment to determine an average sensitivity coefficient for each input parameter. This is defined as:

\[
S = \frac{1}{N} \sum_{i} \frac{b_{i} y_{i}}{a_{i}}
\]  

(5)

where \( N \) refers to the number of runs of the model for a given individual parameter. For this study, \( N=10 \), referring to the 10 parameter adjustments generated for each parameter. The average sensitivity coefficient effectively shows the impact a 1% increase in an input has on the output (e.g., a 1% increase in thermostat setting increases total annual energy demand by 1.76%). This provides a useful identification about the influence of inputs and applying this approach can be used to determine the most influential parameters through a means of ranking their individual significance. The benefit of using a sensitivity coefficient, is that the relative sensitivity of all inputs can be compared.

The number of runs of the model is equivalent to the initial base case run in addition to the number of adjustments multiplied by the number of inputs to be evaluated. Therefore, the model was run 1431 times to cover the 143 inputs with the outputs collected for each model run.

Initially, the base case input parameters are loaded into the model and the SAP2012 model is run to provide the base case results (Figure 1). An input parameter is then selected, and a set of value adjustments are generated. Ten values for the input parameter are generated in 1% increments from the base case, up to ±5%. The model is run for each of these input adjustments and the total energy demand of each run saved in a csv file. The input parameter is then returned to the base case value (Figure 1). This process is repeated for 143 numerical inputs in SAP2012, and the results saved in a csv file. The sensitivity coefficients for each input are then calculated using Equation 5. The study also evaluates two intermediate outputs of the model: effective air rate change and daily hot water usage. This is to understand the influence of ventilation and occupant actions regarding hot water usage on total energy demand. These intermediate parameters cannot be adjusted in the same approach as they are determined by calculations in the model. To address this, an input used in the calculation of these parameters can be adjusted by a determined amount to represent a ±1% change in the intermediate parameter. Therefore, to evaluate effective air rate change in ±1% increments, infiltration rate was adjusted by increments of ±1.2% and ±4.2% for the F-rated and B-rated dwelling, respectively. To evaluate daily hot water usage in ±1% increments, assumed occupancy was adjusted by increments of ±1.52% in both dwellings.

**Base Case Dwellings**

Two base case dwellings are used in this study, both are detached dwellings with SAP ratings of F and B. These are created to provide initial values for the input data and to get an understanding about the influence of parameters in SAP at different levels of energy efficiency. For this study, the F-rated dwelling has low levels of insulation and poor boiler efficiency. The B-rated dwelling is designed to passivhaus standard, with high levels of insulation and airtightness (BRE, 2014). The dwelling archetypes provide the opportunity to compare the influence of input parameter uncertainty for dwellings of different inherent energy efficiency.

To create the dwelling archetypes, a study by Allen et al. (1990) was used, which details standard dwellings for modelling. The study is a guide in developing standard dwellings for the purpose of modelling and describes the features of typical UK dwellings. The detached dwelling developed is shown in figure 2. The SAP2012 guide (BRE, 2014) is used throughout the development of dwelling archetypes to provide the input data for the dwelling elements and systems, occupant behaviour and external conditions. The SAP2012 guide provides a comprehensive and detailed directory for all inputs that are required for the SAP calculation. The SAP2012 guide also outlines all necessary calculations as part of SAP.

Table 1 (below) shows the dwelling dimensions that were used in the development of both dwelling archetypes as gathered from Allen et al. (1990). The table also shows the assumptions used as base case values for dwelling elements and systems, external conditions, and occupant behaviour.

For each dwelling archetype, the base case used average UK external conditions (external temperature, wind speed, solar flux etc.) and standardised occupant behaviour assumptions as detailed in the SAP2012 guide.

**Results**

**Base Case Results**

The total annual energy demand of the two dwelling archetypes are 37600 kWh and 2300 kWh for the F-rated and B-rated dwelling, respectively, resulting in annual CO\(_2\) emissions of 8700kg for the F-rating and 1100kg for the B-rating. The calculated SAP ratings is 36 for the F-rated dwelling and 88 for the B-rated dwelling. The B-rated dwelling shows a 94% reduction in total energy demand and an 87% reduction in CO\(_2\) emissions when
Table 1: Key parameters in SAP. Table shows the initial input value and the calculated sensitivity coefficient for key input parameters in SAP. Table summarises the F-rated and B-rated dwellings.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Input Parameter</th>
<th>Initial Input Value</th>
<th>Sensitivity Coefficient, S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>F-Rating</td>
<td>B-Rating</td>
</tr>
<tr>
<td>Fabric</td>
<td>Wall U-value (W/m²K)</td>
<td>2.1</td>
<td>0.14</td>
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<tr>
<td></td>
<td>Window U-value (W/m²K)</td>
<td>4.8</td>
<td>0.8</td>
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<tr>
<td></td>
<td>Roof U-value (W/m²K)</td>
<td>2.3</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>Floor U-value (W/m²K)</td>
<td>0.76</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Thermal Bridging (W/K)</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Total Floor Area (m²)</td>
<td>98.94</td>
<td>98.94</td>
</tr>
<tr>
<td></td>
<td>Storey Height</td>
<td>2.5</td>
<td>2.5</td>
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<td>Building Systems</td>
<td>Main heating system efficiency (%)</td>
<td>66</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>Heating System Responsiveness</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Hot Water System Efficiency (%)</td>
<td>57</td>
<td>170</td>
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<td>Occupancy</td>
<td>Assumed Occupancy</td>
<td>2.71</td>
<td>2.71</td>
</tr>
<tr>
<td></td>
<td>Thermostat Setting (°C)</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Heating Schedule Weekday (hours)</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Heating Schedule Weekend (hours)</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Daily Hot Water Usage (L)</td>
<td>104.4</td>
<td>104.4</td>
</tr>
<tr>
<td>External</td>
<td>Wind Speed (m/s)</td>
<td>4.38</td>
<td>4.38</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Effective Air Change Rate (ach)</td>
<td>0.76</td>
<td>0.16</td>
</tr>
</tbody>
</table>

![Figure 3: Proportion of total energy demand by end use for the F-rated and B-rated dwellings. Figure shows contribution of space heating, hot water, lighting, and losses as a proportions of total energy demand.](image)

The heat transfer coefficient of the F-rated dwelling is 600W/K, with 90% of this due to fabric heat loss. For the B-rated dwelling, the heat transfer coefficient is 62W/K with 80% due to fabric heat loss. Internal and solar heat gains account for 20% of total heat gains in the F-rated dwelling, with 80% from heating demand. For B-rated dwelling, internal and solar heat gains account for 85% of total heat gains, with 15% from heating demand. This shows a considerable increase in the heating requirement achieved from internal gains.

Figure 3 shows the breakdown of annual energy demand for the F-rated and B-rated dwellings. The charts show the compared to the F-rated dwelling, highlighting the significance of insulation measures and improved energy efficient dwellings.

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Figure 3 shows the breakdown of annual energy demand for the F-rated and B-rated dwellings. The charts show the

![Figure 4: Linearity of input adjustments on total energy demand for the F-rated dwelling. Graph shows that for influential parameters, a linear relationship is observed significant proportion of total energy demand due to space heating demand for the F-rated dwelling. This suggests that input parameters influencing the fabric heat loss will play a major role in the determining the energy demand for the dwelling. The space heating requirements are significantly reduced in the B-rated, a result of greater insulation measures and energy efficiency. In the case of the B-rated dwelling, hot water demand becomes the most significant source of energy demand in the dwelling. Sensitivity Analysis Results](image)

Figure 4 shows the plot of total annual energy demand for the adjustments between ±5% from the base case for some of the most sensitive parameters in SAP2012 for the F-
rated dwelling. The graph shows that within a ±5% range of the base case, there exists a linear relationship between the input parameters and the total annual energy demand.

Table 1 summarises the sensitivity indices for the main input parameters in SAP2012 for the F-rated and B-rated dwellings for total annual energy demand.

The table shows the input parameters that total energy demand is most sensitive to focus on aspects regarding the main heating system (boiler efficiency, responsiveness) and the heating practices of occupants in the dwelling (thermostat setting, heating schedule) in the F-rated dwelling.

The significance of input parameters on annual energy demand are shown to vary across the different building archetypes. In the F-rated rated dwelling, annual energy demand is shown to be sensitive to parameters regarding fabric heat loss such as the U-values of the windows, wall, and roof parameters regarding the heating systems. As the fabric efficiency and airtightness is improved in the B-rated dwelling, total energy demand becomes less sensitive to elements which affect the heating demand and more sensitive to parameters regarding occupant actions, and hot water demand. Factors such as number of occupants, daily hot water usage and efficiency of the water heater become significantly influential. However, in both dwelling archetypes, thermostat setting is shown to be the most influential, suggesting that occupants heating preferences is the key influential parameter in SAP.

**Discussion**

Figures 5 shows the 15 most influential parameters for the F and B-rated dwellings, as ranked by the value of the calculated sensitivity coefficient. The figures highlight the considerable differences in the most influential input parameters at different dwelling efficiencies. This indicates that the base dwelling efficiency will impact the evaluation of sensitivity analysis.

In both dwelling archetypes, the thermostat setting is shown as the parameter that most influences total energy demand, but the magnitude of sensitivity changes considerably at different dwelling efficiency. Thermostat setting has a sensitivity coefficient of 1.83 for the F-rated dwelling, compared to 0.97 for the B-rated dwelling. This could be due to the significant improvements, in heat loss parameters and heating system efficiency, making total energy demand less sensitive to heating preferences.

Beyond this however, there are major differences in the most influential parameters at different dwelling energy efficiencies. For the F-rated dwelling, space heating is responsible for the majority of annual energy demand and CO₂ emissions, due to inefficient heat loss and heating systems parameters. It is clear that input parameters contributing to this will therefore have a major influence on the overall energy demand of a dwelling. Input parameters focussed on the heating systems and heat loss rate of the dwelling are shown to be the most influential (figure 5) including heating system efficiency, wall U-value, window U-value and roof U-value.

The B-rated dwelling has substantial improvements in energy efficiency, significantly reducing space heating demand and total energy demand. This impacts the ranking of the most influential parameters. It is shown that for the B-rated dwelling, parameters regarding hot water demand become significantly more influential. The figure also shows the increased influence of occupant behaviour within B-rated dwellings, suggesting that occupant behaviour plays a greater role in highly efficient dwellings.

The most influential parameters on annual energy demand of dwellings are in agreement with studies by Firth et al. (2009) and Hughes, et al (2014) supporting the view that heating practices and heat loss parameters are influential. Both studies showed that thermostat setting is the most influential parameter, with building system efficiencies, and wall U-value also being influential. The ranking of

![Figure 5: 15 most influential parameters ranked for the F-rating and B-rating dwellings, respectively. Figure shows the change in the order of ranking for the most influential parameters at different dwelling energy efficiencies.](image-url)
parameters however does vary compared to these studies, which could be due to performing the sensitivity analysis on different dwelling archetypes. The study by Firth et al., (2009) also highlights the change in the sensitivity of inputs across 47 different dwelling archetypes, supporting the view that the ranking of the most influential parameters does change depending on the evaluated archetype.

The study identifies that within a ±5% range of an input parameter, the annual energy demand varies linearly. However, the study by Hughes et al., (2014) determined that the sensitivity of inputs at large uncertainties was non-linear in SAP 2009. This suggests that if uncertainties in an input parameter are larger than the ±5% range considered in this study, then there is the potential for sensitivities to vary, potentially increasing uncertainty in the output.

Implications
It is shown that the dwelling efficiency plays a role in determining the most influential parameters in SAP. This suggests that the input parameters which require accurate assumptions or sufficient knowledge will vary according to the energy efficiency of the dwelling. The study uses the SAP2012 guide for the values of all input parameters, to develop the building archetypes and base case scenarios. If the values in the SAP2012 guide are not accurate, or do not reflect actual values, this could introduce uncertainty into the SAP calculations, leading to discrepancies between predicted and actual energy consumption. Table 2 shows the impact of a 5% adjustment of sensitive inputs on total annual energy demand of the F-rating and B-rating dwellings. The results suggest that even small uncertainties in input parameters can impact the estimated energy demand of a dwelling.

<table>
<thead>
<tr>
<th>Input Parameter</th>
<th>F-Rating</th>
<th>B-Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermostat Setting</td>
<td>9.15%</td>
<td>4.85%</td>
</tr>
<tr>
<td>Wall U-value</td>
<td>1.85%</td>
<td>0.90%</td>
</tr>
<tr>
<td>Heating System Efficiency</td>
<td>4.75%</td>
<td>0.85%</td>
</tr>
<tr>
<td>Water System Efficiency</td>
<td>0.05%</td>
<td>2.20%</td>
</tr>
<tr>
<td>Assumed Occupancy</td>
<td>0.10%</td>
<td>0.85%</td>
</tr>
</tbody>
</table>

Therefore, ensuring the assumptions within the SAP2012 guide are accurate and reflect the actual values for building properties is essential, as this will introduce uncertainties in the SAP calculations, impacting estimations for energy demand, policy analysis and the theoretical potential for energy savings.

The study shows the considerable contribution to the heating demand that is met by internal and solar heat gains in the B-rated dwelling. 85% of heat gains in the B-rated dwelling are obtained through internal and solar gains. This therefore suggests high energy efficient dwellings and space heating demand become more sensitive to internal gains in the dwelling. A major source of internal gains is through the presence and the actions of occupants in a dwelling (metabolic gains, lighting gains, hot water gains, cooking, appliances etc.). This is supported by the results, with the sensitivity coefficient for assumed occupancy increasing from 0.02 in the F-rated dwelling to 0.17 in the B-rated dwelling. Occupant actions such as thermostat setting, and daily hot water usage are also influential parameters in the B-rated dwelling. The influence of these input parameters and the sensitivity of total energy demand to internal gains suggest that occupancy and occupant actions become more influential as dwelling efficiency improves. Therefore, if occupant actions differ from the standard assumptions within SAP, this can have an impact on the estimated total energy demand.

Limitations
Previous studies have suggested that SAP overestimates the internal gains in very energy efficient dwellings (AECB, 2008; Moutzouri, 2011) due to assuming lower energy efficient appliances, which can significantly impact the space heating. This can give the impression that a dwelling is more efficient than in reality, leading to a higher energy demand than predicted. This therefore suggests that to assess internal heat gains more accurately in highly efficient dwellings, more reliable data on occupant behaviour is required.

Another limitation of the study is due to using two dwelling archetypes at opposing levels of energy efficiency. This means that many of the building systems and heat loss parameters have changed between the two archetypes. The use of additional building archetypes may help identify the parameters that are driving the changes in total energy demand and therefore the influential input parameters.

Further work
The study provides a technical review for the sensitivity of SAP2012 and considers the impact the energy efficiency of dwellings has on the outcome. However, the study only considers one local sensitivity analysis technique. Further work could look at applying additional sensitivity analysis techniques, to determine total uncertainty in energy demand predictions.

The study shows the influence of input parameters regarding occupancy on the total energy demand. Further work could evaluate the impact of uncertainty in occupancy and occupant actions to total energy demand when using monitored data from UK dwellings.

Conclusion
- One at a time sensitivity analysis is applied to the SAP2012 model to determine the most influential parameters on the estimation of total annual energy
demand of UK dwellings. The model shows a linear relationship between the input parameters and total energy demand when varying inputs by up to ±5%.

- The most influential parameters are shown to vary depending on energy efficiency of dwellings. It is therefore shown that the energy efficiency of a dwellings plays a role in determining the most influential parameters.
- The study shows that some inputs have a considerable influence on uncertainty within SAP. Ensuring that assumptions used in SAP assessments is essential in providing accurate and reliable estimations for the energy efficiency of dwellings.
- Occupancy and the magnitude of internal gains becomes influential as dwelling efficiency improves. Ensuring accurate assumptions for occupant actions is therefore essential in providing reliable estimations.
- Further work could apply further sensitivity analysis techniques to provide a full review of the inputs in SAP

References


