DETERMINING THE EFFECT OF WEATHER DATA UPON BUILDING SIMULATION IN REGULATORY PROCESSES

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ABSTRACT

This paper extends a simplified dynamic method of building simulation: IDEAS – Inverse Dynamics based Energy Assessment and Simulation. IDEAS is a dynamic method which is calibrated to yield results in line with those produced by the UK Government's steady state Standard Assessment Procedure (SAP), the method used in the UK to produce Energy Performance Certificates (EPCs). The extension presented investigates the effect upon energy estimation by varying climactic data, using CIBSE TRY/DSY weather data for 14 locations across the UK. A calibrated standard test case dwelling is initially modelled in IDEAS and SAP; then using each of the weather locations, the variation in energy estimation of this dwelling is analysed. Results suggest that use of localised weather data can have a noteworthy effect on energy estimation and regulatory processes.

INTRODUCTION

The European Directive on the Energy Performance of Buildings (European Parliament 2003; Commission 2010), referred to as the Energy Performance of Buildings Directive (EPBD) stipulates that all European member states must produce an Energy Performance Certificate (EPC) whenever buildings are constructed, sold or rented. In the UK, SAP is the procedure used to generate an EPC, an example EPC generate by SAP for a home in Scotland is shown in Figure 1. SAP is the recognised method for building professionals to meet buildings compliance and is the culmination of three decades of research commencing with BREDEM 1 (Uglow 1981; Uglow 1982).

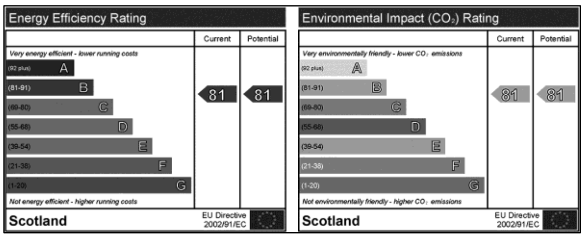

Figure 1. Sample SAP derived Energy Efficiency and Environmental Impact Ratings for Scotland

Studies have shown that there can be variances in results between SAP and dynamic simulation tools (Murphy, Kummert et al. 2010). Fundamental dynamic methods have been shown to be relevant for controllability analysis (Hudson and Underwood 1999; Tashtoush, Molhim et al. 2005; Cho, Hong et al. 2012) and for the energy assessment of buildings (Counsell, Khalid et al. 2010). A benefit of symbolic modelling is that a symbolic model can rapidly and thoroughly determine the effect of disturbances such as free heats gains or external temperature (Tindale 1993).

A novel advanced dynamic calculation method (IDEAS) was originally developed to assess the controllability of a building and its servicing systems. IDEAS can also be used for energy use analysis and estimation, and has been calibrated over a large range of test cases with SAP (Murphy 2012).

The focus of this paper is measuring the effect upon energy estimation in IDEAS by varying external temperature data, using CIBSE TRY/DSY weather data for 14 locations across the UK. By doing so the effect which more localised weather data can have upon regulatory processes can be determined.

METHODOLOGY

Developing a modelling environment

An IDEAS based modelling environment was selected for this study. IDEAS allows for an extension of SAP in many areas, such as the ability to make use of various weather files (Mylona 2012) and the flexibility to amend the heating set-point which is tracked (for example, comparisons can be made between tracking a constant set-point vs. a varying set-point). IDEAS has been described in depth in previous publications (Murphy and Counsell 2011; Murphy, Khalid et al. 2011; Murphy, Baster et al. 2012; Murphy, Counsell et al. 2013). These detail the process and evolution of simulation, validation, calibration and testing with IDEAS, and includes the technical model development and simulation environment. Included hereafter is a brief overview of the modelling procedure and details of the procedure used to determine the effect of varying weather data upon the energy estimation calculations.

While any set-point can be tracked in IDEAS, the set-point tracked in this case is based upon the standard SAP temperature demand profile (Figure 2).

By tracking the standard SAP temperature demand profile set-point, IDEAS will calculate the predicted energy consumption for that modelled dwelling over a year. This energy use will be affected by factors such as weather data and heat gains from appliances and people.

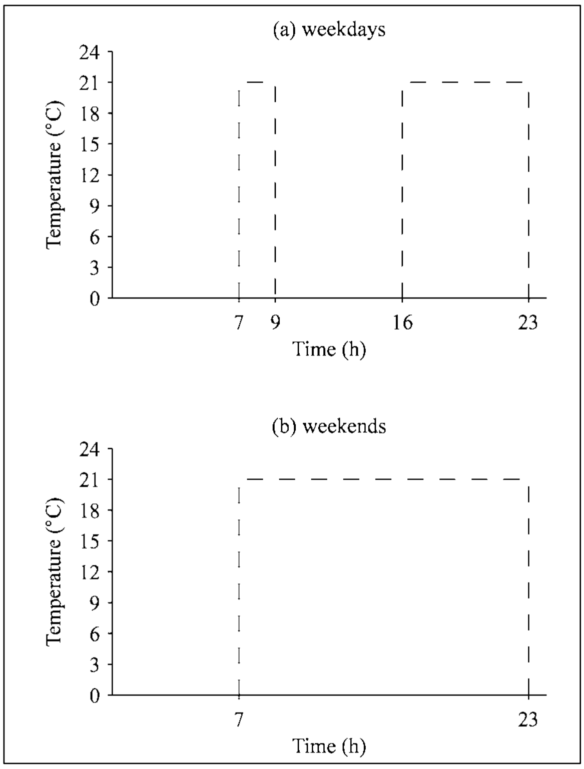

Figure 2. Standard SAP temperature demand profile for (a) weekdays, (b) weekends

In IDEAS, the disturbance inputs are comprised of the metabolic, solar radiation, electrical appliance heat gains; and the external weather data. These disturbances play an important part in the overall energy estimation analysis of a dwelling. For example, the larger the free heat gain inputs are, the less heat input will be required from the heating system in order to meet the temperature demand profile.

These disturbance inputs must also be calibrated with SAP to allow for an assessment to be made regarding the impact of weather data in the regulatory process. SAP makes assumptions for factors such as occupancy and hot water use based upon the 'total floor area' of a dwelling while a single representative weather location (taken as East Pennines, UK) is used as the basis for solar gains. Appliance gains were taken from an International Energy Agency / Energy Conservation in Buildings and Community Systems Program (ECBCS) Annex 42 study based upon real UK test data for 69 monitored buildings (Beausoleil-Morrison 2008). Appliance gains were fixed for each of the test cases in this study. Solar radiation data for the East Pennines, UK was imported into the IDEAS model for calibration with SAP, using data from Meteonorm (Meteotest 2011). Solar data was fixed for each of the test cases in this study. For each simulation, the external temperature data will be taken from one of the 14 weather locations provided in the CIBSE TRY/DRY temperature data files. This will focus the variation of results purely upon the variation of external temperature as provided for each of the weather locations.

Baseline model calibration

The IDEAS model has been calibrated with SAP over a range of test cases; in this paper one test case is presented as a baseline; the Standard Test Case which is an unfilled cavity construction. The building physics for this Standard Test Case are presented in Figure 3. The differential equations that describe the IDEAS model can be derived by following the thermal resistance-capacitance network given in Figure 3 for each of the temperature nodes. These differential equations are subsequently converted into a state-space representation for implementation within the MATLAB/Simulink environment. Full

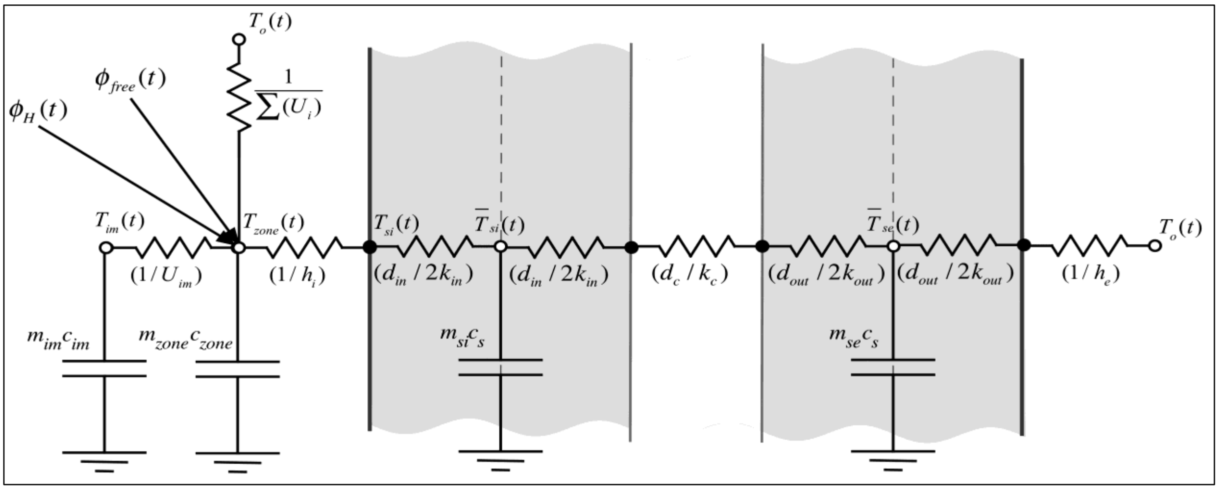

Figure 3. Thermal resistance network for Standard Test Case IDEAS model

details of the modelling procedure have been previously published (Murphy, Counsell et al. 2013).

A standard construction dwelling was modelled, with a structure U-Value of $1W/m^2K$, which is representative of unfilled cavity wall structure. Full test case parameters are provided in Table A.

Figure 4 and Figure 5 show the correlation between the results obtained when taking the mean monthly temperature and energy values from SAP and comparing these with the mean monthly temperature and energy values calculated by the IDEAS model.

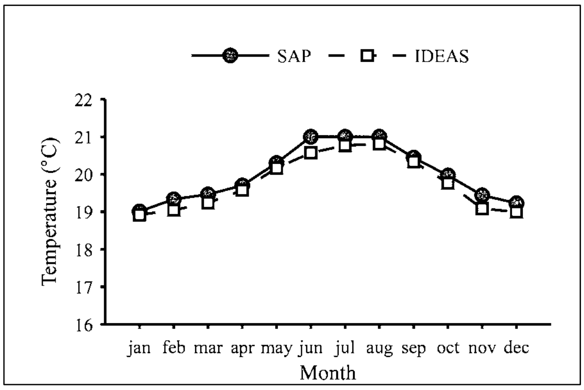

Figure 4. Standard Test Case – mean monthly zone temperature comparison

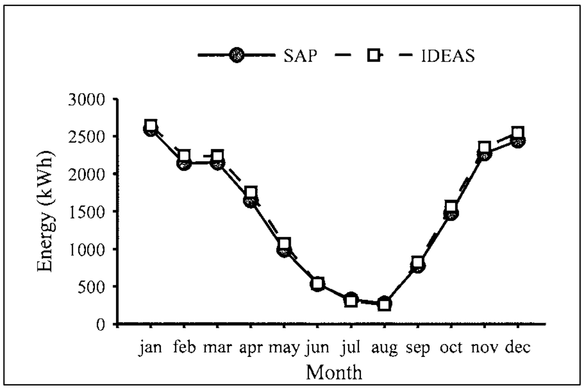

Figure 5. Standard Test Case – mean monthly energy estimation comparison

Performing a statistical analysis on the zone temperature data presented in Figure 4, we find that there is a coefficient of determination, or R^2 value, between the data (adjusted for a fourth order model) of 0.822. Similarly, for the energy consumption data given in Figure 5 we have an adjusted R^2 value of 0.9875. Based upon these results for the Standard Test Case of an unfilled cavity wall construction dwelling, there is a close match between the IDEAS model and SAP for both zone temperature and energy consumption estimation.

The Standard Test Case and calibration highlighted in Figure 4 and Figure 5 are based upon an external temperature profile for Manchester, as taken from the CIBSE weather data.

The Standard Test Case is used as a baseline for analysing the effect of varying external temperature on energy estimation calculations.

WEATHER ANALYSIS

Statistical data analysis

CIBSE Test Reference Years (TRYs) and Design Summer Years (DSYs) are available for 14 locations across the UK. CIBSE highlights the importance of weather data as they state, 'weather data has now become an essential component of virtually every new building design and major refurbishment' (CIBSE 2012).

Table 1 provides the results from a statistical analysis performed on the CIBSE weather data.

Table 1
Weather data statistical analysis

LOCATION	LAT. (°)	$\overline{T}$ (°C)	σ	CV
Glasgow	55.97	8.67	5.425	0.62592
Edinburgh	55.95	8.80	5.143	0.58425
Newcastle	54.98	9.60	4.930	0.51385
Belfast	54.62	9.18	4.967	0.54120
Leeds	53.81	10.2	5.565	0.54716
Manchester	53.48	10.0	5.269	0.52682
Nottingham	52.97	9.63	5.651	0.58713
Norwich	52.65	10.1	5.463	0.54085
Birmingham	52.48	9.89	5.872	0.59389
Swindon	51.56	9.88	5.535	0.56038
London	51.51	11.4	5.818	0.50855
Cardiff	51.47	10.4	4.887	0.46799
Southampton	50.93	11.0	5.445	0.49699
Plymouth	50.37	11.1	4.369	0.39354

The locations are ordered by their latitude from the top of the British Isles to the bottom. The latitude given is for the city, which is an approximate location of the actual CIBSE weather location. The standard deviation (σ) is provided to highlight the variability of the temperature of each location from its mean temperature ($\overline{T}$) over the year. Results indicate a reasonably large temperature swing from their mean, in line with the wide variance expected of British weather. The coefficient of variation (CV) is an indication of how the standard deviation relates to the mean. The closer the CV is to zero, the greater the uniformity of the weather. The results in Table 1 demonstrate that the weather is generally more varied in Scotland and the North of England as opposed to Wales and Southern England.

Figure 7 highlights the distribution spread of the CIBSE TRY/DSY weather files. The markers placed on Figure 7 correspond with the locations of the available weather data. It is clear that although the main population density areas of the UK are covered, there are large areas where there is no weather data available.

Figure 6 highlights the minimum and maximum external temperatures for each CIBSE TRY/DSY

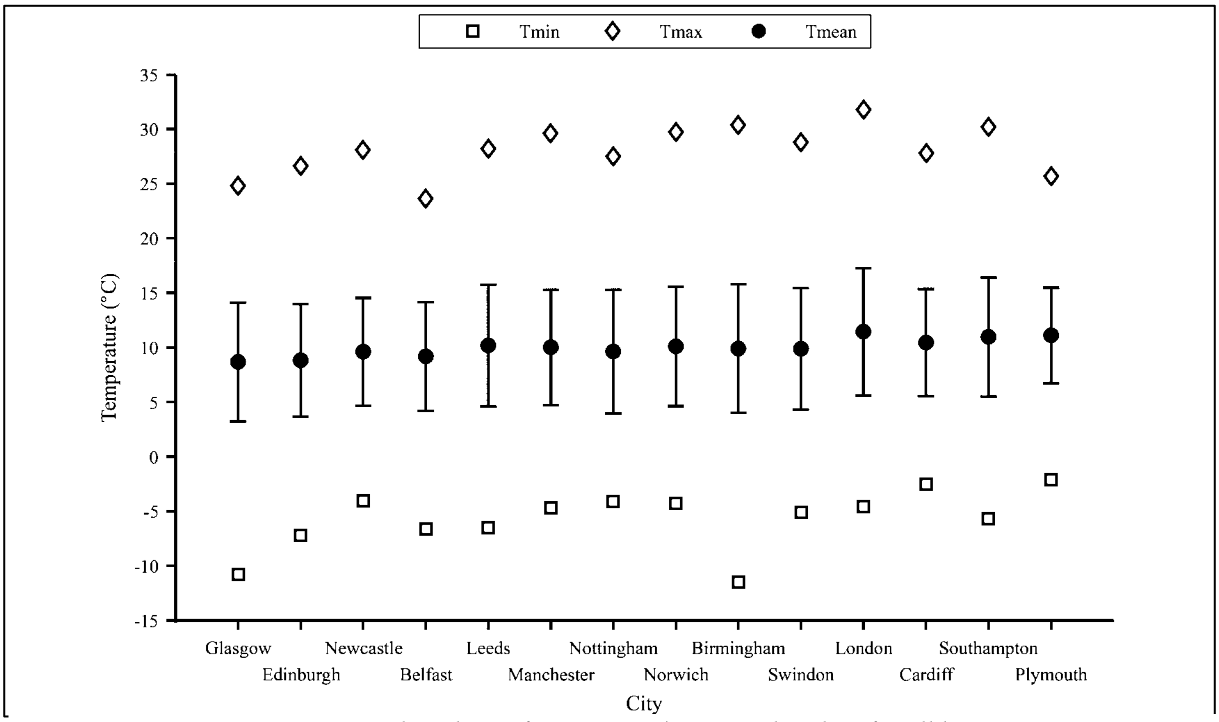

Figure 6. Statistical analysis of CIBSE TRY/DSY weather data for all locations

weather location. It can be viewed from Figure 6 that there is a variance of approximately 8ºC between the maximum temperatures and 9ºC between the minimum temperatures when comparing the weather locations as a whole.

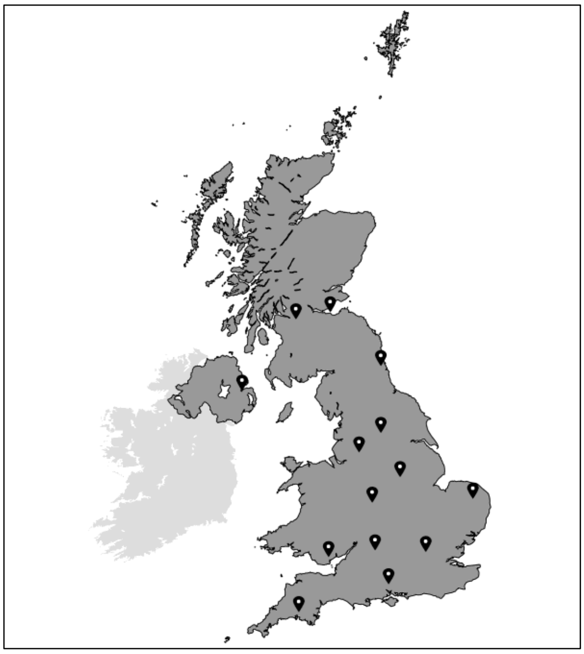

Figure 7. CIBSE weather data distribution

RESULTS

Energy consumption analysis

Table 2 presents the results of 14 IDEAS simulations based upon the Standard Test Case dwelling. The CIBSE weather locations are sorted by the yearly energy required for the Standard Test Case dwelling to meet the standard SAP temperature demand profile (Figure 2).

Weather location 8, Manchester, is taken as the weather location most representative of that used in SAP. Therefore the variation of each weather location from the Manchester data is presented. It was found that the weather locations where most energy is required is Glasgow and Edinburgh. The location where the least energy is required is London. It might have been expected that Southampton, Plymouth and Cardiff would require less energy due to their more southerly location. However, London's mean temperature is the highest out of all of the CIBSE weather locations (see Table 1) and this will have a major influence on the predicted energy consumption.

Table 2
Yearly energy consumption for each weather location

NO.	LOCATION	ENERGY (kWh)	VAR. FROM (8), kWh	VAR. FROM (8), %
1	Glasgow	20199	2598	14.76%
2	Edinburgh	19918	2317	13.16%
3	Belfast	19097	1496	8.50%
4	Nottingham	18551	950	5.40%
5	Newcastle	18376	775	4.40%
6	Birmingham	17913	312	1.77%
7	Swindon	17885	284	1.61%
8	Manchester	17601	0	0.00%
9	Leeds	17422	-179	1.02%
10	Norwich	17411	-190	1.08%
11	Cardiff	16519	-1082	6.15%
12	Southampton	15725	-1876	10.66%
13	Plymouth	15117	-2484	14.11%
14	London	14985	-2616	14.86%

Implications for SAP and EPC generation

The SAP calculated energy consumption is used in the regulatory process to determine the values which are then used in the production of the EPC. If a dwelling is located in a substantially more northerly location in comparison to the weather location used to assess it in the regulatory process, then the EPC will suggest that the building will use less energy than will be the case in reality. For trust to be engendered regarding the regulatory process, the most accurate results possible must be produced.

The current method of SAP, SAP 2009 (BRE 2012) generates EPCs for dwellings in the UK based upon a notional centre of the UK – the East Pennines location. This is taken as a representative location for the UK as a whole. Mean external temperatures are derived from this location. From Table 2 location number 8, Manchester is the most applicable CIBSE weather location for the SAP East Pennines region. The results for Manchester can be seen to be centrally distributed between the other weather locations: this is to be expected based upon the approximately central location of Manchester.

Table 2 highlights that there is a 15% difference between results when the SAP UK average Manchester location and Glasgow is compared. Therefore, when an EPC is produced at present for a dwelling in Glasgow its SAP calculated yearly energy and hence EPC rating is actually 15% better than it would be if a more localised weather location was used. Similarly, there is a 15% difference in results between the SAP calibrated Standard Test Case with the SAP UK average Manchester location and the London weather. Therefore a London dwelling modelled in SAP will be penalised by 15% due to the use of non-location specific weather data.

DISCUSSION AND FUTURE WORK

Weather Data in Regulatory Frameworks

The main focus of this study was to determine the effect of different external weather data locations on the energy estimation calculations. Specifically within the UK government's Standard Assessment Procedure - SAP.

The analysis of the CIBSE TRY/DSY weather locations did raise a number of queries. The distribution spread (Figure 7) highlighted that there is a lack of climactic data for large areas of the British Isles. For example, no weather data exists for areas north of Scotland's Central Belt. Future work could take weather data from another source, such as Meteonorm, for areas such as Aberdeen, Scotland and analyse this accordingly. These results could suggest if additional climactic regions should be considered for conclusion in the main CIBSE TRY/DSY dataset. Comparative analysis using international weather datasets could also be carried out to determine if a common trend exists between weather data sets used in other countries.

The building design vs. building performance gap will increase the importance of tools used to model buildings in the future. Recent research demonstrates the importance of SAP and its current place in the regulatory framework (Zero Carbon Hub 2010). This highlights the dwelling design versus dwelling performance gap and the importance of rigour in methods such as SAP.

Commercial Building Regulations

IDEAS was developed in order to assess the dynamic behaviour of domenstic buildings while still producing results that correlate with those produced by SAP. Therefore, the model development and subsequent iterations have been based on the SAP environment and its own development. As such, if IDEAS was to be used to assess the impact of different weather profiles on the energy estimation of commercial regulatory processes, modifications would have to be made to the model with respect to commercial building regulatory processes.

One of the commercial regulations that the model could be adapted for is the European Standard for the energy performance of buildings – EN 15265 (Standards 2007). The purpose of this European Standard is to ensure that the calculation of energy needs for space heating and cooling of a room in a building computed by a model are accurate. Work has been conducted (Allison and Murphy 2013) that has reformed the IDEAS method for this purpose and successfully validated this modified model with the European Standard with accurate results across all test cases.

In order to achieve this several modifications had to be made to the model that increased its complexity. The number of temperature nodes were increased from 4 to 5 – which represent the air within the zone and each of the enclosure elements in a building zone i.e. the internal walls, roof/ceiling, floor, and the external strucutre. There is also the addition of radiation heat transfer to and from each of the enclosure elements. Ventilation heat transfer was added, as well as further modifications to include solar radiation distribution across the nodes. Convective and radiative heat transfer from the internal loads such as lighting, people and IT equipment is also accounted for. Where the convective portion affects the air temperature immediately, while the radiative portion is distributed among the enclosure element nodes.

Similarly to SAP, only a single weather location is available to use for validation purposes. In this case climatic data (external air temperature and solar radiation) is provided for Trappes, France. Climactic data played a significant role in the simulation of the office due to the use of Trappes, France weather data, with significant changes to energy estimation when solar shading was implemented. An interesting extrapolation of this work would be to use various climactic data from throughout Europe to ensure that the European Standard produces validated models throughout the continent.

The modelling approach introduced here could be followed by other dynamic models wishing to calibrate against International Standards. This method could also extend methods such as the Simplified Building Energy Model (SBEM) (Tuohy 2009; Hitchin 2010) by simply estimating the potential transient impact of innovative technologies to energy estimation and regulation. SBEM is used as a compliance tool for building regulations for non-domestic buildings in the UK. This modified model could be used to help assess the impact of weather data upon simulation in regulatory processes which are commercially focussed.

Future Work in Regulatory Frameworks

Future work can be carried out by making use of the solar data available in the CIBSE TRY/DSY weather data, as solar gain can also be an important factor in assessing the energy performance of a building. Further work is also required to compare weather commonly used in simulation to determine the data variation and impact on simulation results.

The effect of rain on U-values of structures could also be assessed using the IDEAS method. This is a large development task but one which can be addressed in IDEAS by the use of dynamically varying U-values, which is another aspect where IDEAS can be used to extend simplified methods such as SAP.

SAP is currently being updated to incorporate a greater degree of distribution spread for climactic data but it is unclear until the final version is released what updates have been agreed upon. Once an updated version of SAP is released the results presented in this study could be replicated to compare with new SAP predictions. SAP is a steady state methodology which produces monthly results. This compares to the CIBSE weather data used which is hourly and the IDEAS model time-step of 1 minute. Further work could assess the benefit of steady state regulatory methods such as SAP being updated to incorporate a greater level of dynamics and making use of more granular data. A dynamic version of SAP could also be used as a design tool; this would highlight the use of simulation to help drive better building design.

CONCLUSION

Results suggest that use of localised weather data can have a noteworthy effect on energy estimation and can play an important role in the regulatory process. The use of CIBSE TRY/DSY weather files has been shown to provide a wide variation of results, with energy consumption generally increasing the higher the geographical latitude of the CIBSE weather location.

The spread and variation of the CIBSE weather files has been highlighted - the most accurate weather data to use is that which is closest to the location where the modelled building exists or will exist. The CIBSE weather file spread is good and most major population centres have been well covered but there are large geographical areas of the British Isles where no weather data exists.

For benchmarking of energy consumption of buildings in the regulatory processes, internal heat gains and building location are becoming more important at the design stage and once a building is occupied. The research here has highlighted that weather data can have a significant bearing on simulated kWh/year output - a swing of $\pm 15\%$ in calculated energy consumption can be seen based purely upon the external temperature variation simulated in IDEAS from the 14 CIBSE weather locations.

Methods such as IDEAS can be an important part of the regulatory processes in the future and can suggest how steady state methods such as SAP and SBEM could evolve in future iterations.

NOMENCLATURE

c	specific heat capacity, J/(kg·K)
m	mass, kg
T	thermodynamic temperature, K
U	thermal transmittance, W/(m^2·K)
ϕ	heat flow rate/thermal power, W

Subscripts

c	cavity
e	external
free	free disturbance heat gains
H	heating
i	internal
im	internal mass
in	inside
o	outside temperature
out	outside
s	structure
si	internal structure
se	external structure

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APPENDIX

Table A
Building parameters for Standard Test Case

PARAMETER	VALUE	CORRELATION
m_{zone}	13561 kg	Value from SAP
m_{si}	15181 kg	Value from SAP
m_{se}	15181 kg	Value from SAP
m_{im}	13327 kg	IDEAS calibration parameter
$\dot{m}_{\mathrm{v}}$	0.0377 kg/s	Value from SAP
c_{zone}	1129 J/(kg·K)	Value from SAP
c_{s}	949.5 J/(kg·K)	Value from SAP
c_{im}	1000 J/(kg·K)	IDEAS calibration parameter
c_{a}	1005 J/(kg·K)	Standard Value
U_{w}	1.5 W/(m^2·K)	Value from SAP
U_{f}	0.7 W/(m^2·K)	Value from SAP
U_{r}	2.3 W/(m^2·K)	Value from SAP
U_{im}	2.5 W/(m^2·K)	IDEAS calibration parameter
U_{d}	2.1 W/(m^2·K)	Value from SAP
U_{s}	1.05 W/(m^2·K)	Value from SAP
A_{w}	16.9 m^2	Value from SAP
A_{f}	44.4 m^2	Value from SAP
A_{r}	44.4 m^2	Value from SAP
A_{im}	133.3 m^2	IDEAS calibration parameter
A_{d}	3.8 m^2	Value from SAP
A_{s}	81.8 m^2	Value from SAP
h_i	7.69 W/(m^2·K)	Standard Value
h_e	25 W/(m^2·K)	Standard Value
k_w	0.303W/(m·K)	Value from SAP
d_w	0.2375 m	Value from SAP