PROJECTING ENERGY USE AND CO2 EMISSIONS FROM LOW ENERGY BUILDINGS

A COMPARISON OF THE PASSIVHAUS PLANNING PACKAGE (PHPP) AND SAP

"I was working as a physicist. I read that the construction industry had experimented with adding insulation to new buildings and that energy consumption had failed to reduce. This offended me – it was counter to the basic laws of physics. I knew that they must be doing something wrong. So I made it my mission to find out what, and to establish what was needed to do it right."

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Thanks also to David Olivier for some additional modelling

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1. INTRODUCTION AND BACKGROUND

1.1 The AECB is an independent membership organisation that was set up in 1989 to promote environmentally-sustainable building practices in the built environment sector. Its members are architects, builders, planners, energy and water consultants, developers, self-builders and many others. AECB members represent the whole supply chain and are also practitioners who have been involved in many high profile sustainable buildings in the UK.

1.2 In 2003, given the growing concerns about climate change, the AECB decided that it should encapsulate its expertise in the development and promotion of a suite of tools to assist with the design and construction of very low energy, low carbon buildings - the CarbonLite Programme (CLP). The CLP embodies the AECB's approach to low energy design and construction which can deliver real and significant CO2 emissions reductions cost-effectively.

1.3 At the core of the CLP are three energy standards, based around the PassivHaus standard developed by the PassivHaus Institut (PHI) in Germany in the mid 1990s. The PHI is an independent organisation set up with the sole purpose of developing an effective low energy building standard and promoting its application as widely as possible.

1.4 The AECB chose to adopt this standard because it has been proven against hundreds of homes and non-domestic buildings on mainland Europe, and studies have shown it to be effective. The standard is fast gaining credibility. The EU proposals for commitments to fight climate change and promote renewable energy[1] proposed that the PH standard be adopted in all EU countries from 2015. The PH standard is also consistent with the AECB's strategic approach, namely, that:

- it is essential to get the building fabric right;
- energy performance has to be improved at the whole building level, not just applying standards to the fabric but also aiming to minimise energy use and emissions from lighting, appliances and other equipment;
- the projected energy use and CO2 emissions must be expressed as clear targets - $kWh/m^2.yr$ and $kgCO_2/m^2.yr$ - that can be monitored.

1.5 Allied to these three principles is the need for a robust approach to projecting energy use – meeting a target of 15 $kWh/m^2.yr$ for space heating/cooling requires a minute attention to detail, where each kWh of heat loss – or gain - represents a significant proportion of the total target energy use.

1.6 To assist with the design of buildings to its standard, the PHI developed a software package – the PassivHaus Planning Package (PHPP). AECB decided to adopt PHPP to demonstrate compliance with its three standards. SAP, the UK compliance methodology for Building Regulations (and now the Code for Sustainable Homes) was originally produced as a simple common subset for a number of competing energy labels, and has not been optimised for very low energy buildings. It was thus considered less well validated for this purpose. There was also a concern that SAP might not be appropriate for calculating energy use in low energy buildings.

1.7 Further, the expression of Building Regulations and the Code levels as reductions in CO_2 emissions relative to a notional building make direct comparison of the AECB standards with UK regulatory requirements problematic.

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1 Published 10 January 2008

A Comparison of PHPP with SAP

1.8 The AECB recognised that promoting the use of new software as a compliance tool means that anyone adopting the AECB standards for building in the UK will be required to follow two parallel compliance regimes. However, the AECB believes that PHPP's focus on low energy buildings means that it has characteristics which software packages commonly used in the UK do not. The PHI has also used a significant programme of energy measurement to inform PHPP by using data from monitored buildings to try and close the gap between design intent and the reality of building energy use post-occupancy.

1.9 The AECB's three standards are designed to provide a practical and achievable stepped trajectory towards near zero carbon buildings, offering assistance to the design and construction industry to meet the government's objective of "zero carbon"[2] homes and non-domestic buildings by 2016 and 2019 respectively. This agenda requires progressive tightening of Building Regulations in 2010, 2013 and 2016[3], moving eventually towards the compliance regime covering total building energy use and emissions.

1.10 Alongside the revisions to Building Regulations, government has announced its intention to revise SAP as early as possible, both so that it can be used to demonstrate compliance with the 'zero carbon' standard by 2016, and to provide industry with the correct signals about the technologies to be manufactured and adopted. Industry has been consulted, and wider government policy objectives, such as developing the market for micro renewables, informs the detailed development and form of SAP. There are indications that, in the past, industry interests and wider government objectives may have had priority over the need for the software to be based on the principal objective of accurately modelling emissions and promoting cost-effective solutions for designers and specifiers.

1.11 The AECB decided therefore that it could make a useful contribution to policy-making in this important area by undertaking a comparison of SAP and PHPP, to establish and quantify the differences between them and, where one has better characteristics than the other, to make proposals for modifications to improve one or both tools. The ultimate objective is to provide a UK tool which assists with the design and delivery of buildings with low energy use and CO2 emissions, and that can be used as a compliance tool appropriate to very low energy, low carbon buildings.

1.12 It is over 25 years since BRE's Domestic Energy Model was first developed, and around fifteen years since energy efficiency became an objective of Building Regulations. Current government policy targets for new buildings are extremely ambitious, and represent a radical change in the requirements imposed on the industry that needs to deliver them. AECB believes that this therefore is an appropriate time for government (and industry) to step back and take a strategic overview of its compliance regime, and the tools used to deliver it. We therefore take the opportunity provided by this report to raise some wider questions of strategic

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2 The AECB welcomes the Government's initiative towards lowering carbon emission from new homes but believes that the target of zero emission on-site is ill-advised both technically and economically when the existing stock is still producing 95% of the stock emissions; reducing the CO_2 emissions from large numbers of existing homes by 80-90% would be a much more efficient use of resources.

3 In its publication, *Building Regulations: Energy efficiency requirements for new dwellings – a look forward at what standards may be in 2010 and 2013* the Department for Communities and Local Government quoted the AECB standards as having the potential to constitute the CO_2 standards for the revised Building Regulations in 21010, 2013 and 2016.

importance which we believe will contribute towards a more robust and practical regulatory regime appropriate to the challenges that lie ahead.

1.13 The analysis in this report is not intended to be a definitive list of differences between PHPP and SAP, but to provide an indication of where they differ in some key respects. Further analysis may well be rewarding, but we hope that this report will spark a lively debate.

1.14 Whilst we make reference to BREDEM, the original model on which SAP is based, our comparison is of SAP with PHPP. This is because SAP and PHPP are the two models used for comparable purposes.

2. OBJECTIVES

2.1 The primary objective of this study is to compare the outputs of PHPP and SAP when modelling a low energy building and to understand the reasons for the differences. We look at both pieces of software in terms of their underlying models, and how they are used in regulatory compliance mode and as design tools.

2.2 As a result of that work, we also aim to contribute to thinking about how the UK regulatory regime sets energy and CO2 requirements for new buildings because the policy framework is a key determinant of how effectively regulation is implemented.

2.3 There are a number of sub-objectives. These all relate in part to the AECB's own desire to understand and verify the methodologies adopted by both PHI and the UK government:

- to trace briefly the history of the development of PHPP and SAP, where and how they have been applied, and the impact of this history on their development;
- to explain what the software has been designed and used for (compliance, design or both) and how these different uses may impact on the methodologies and practices adopted;
- to identify key differences in methodology;
- to establish any differences in projected energy use and CO_2 emissions arising;
- to draw conclusions about the efficacy of the two packages measured against the criteria listed above;
- to make broad recommendations about the compliance regime for new buildings;
- to make recommendations modifications to SAP and/or PHPP to obtain the best tool for the new low carbon homes agenda;
- to comment briefly about the use of SAP within the methodology for the Code for Sustainable Homes and any issues arising.

3. HISTORY AND BACKGROUND

BREDEM

3.1 BREDEM – the Building Research Establishment Domestic Energy Model - is a method for estimating the energy used in dwellings for the provision of space and water heating, cooking, lights and appliances. It was based originally on technical energy monitoring work on hundreds of low energy homes in the Milton Keynes Energy Park in the late 1970s and early 1980s..

3.2 The first model, as described by Uglow[4], was a single zone model, whereas all the versions that followed were based upon two zones. A full description of the background and philosophy is available in a report by Anderson *et al*.[5]

3.3 There are three main versions of BREDEM:

- BREDEM-8 is a monthly model and was the original version in which the heating season was fixed at 8 months based on monitoring buildings in use for a whole year
- BREDEM-12 is the most comprehensive annual model, calculating total annual energy usage for space heating and hot water plus lighting, domestic appliances and cooking
- BREDEM-9 is a sub-set of BREDEM-12 and is used in the SAP worksheet calculation. It does not include location factors[6] or the ability to use anything other than standard occupancy. [The latest version is referred to as SAP 2005].

3.4 BREDEM-12 is also used to calculate the National Home Energy Rating and has been updated in NHER software. A degree day table with a variable base temperature lies at the heat of the space heating module of BREDEM 12, allowing the user to take account of heating season length, extended or shortened depending on the location within the UK.

SAP

3.5 The SAP (Standard Assessment Procedure for Energy Rating of Dwellings) is the UK Government's National Calculation Methodology for assessing and certifying the energy performance of new dwellings under the European Directive on the Energy Performance of Buildings (EPBD).

3.6 SAP uses BREDEM-9[7] and was constructed in such a way that it could be defined in a worksheet form (as opposed to a computer program). It aims to provide an assessment that is substantially more sophisticated than simple procedures such as design heat loss, but is markedly simpler than the use of detailed simulation models.

4 Uglow, C. E. (1981).The calculation of energy use in dwellings, Building Services Engineering Research Technology 2(1), pp. 1-14.

5 Anderson, B., Clarke, A.J., Baldwin, R., and Millbank, N. O. (1985). BREDEM - BRE domestic Energy Model: background philosophy and description, BRE Report BR 66. Watford: BRE

6 Dwellings assessed using SAP are assumed to be located in the East Pennines degree-day region, just west of Derby.

7 This is effectively defined by the various SAP publications, the latest of which is SAP 2005 version 9.81.

3.7 The first version of SAP was published in 1995, to be replaced by updated versions in 1998, 2001 and 2005. The latest version is referred to as SAP 2005[8].

3.8 It calculates the typical annual energy consumption for space and water heating per square metre and, from 2005, for lighting. The cost of this energy consumption and the CO2 emissions can also be calculated.

3.9 Since 6 April 2006, SAP 2005 has been used as the basis for checking new dwellings for compliance with building regulations in the United Kingdom requiring the conservation of fuel and power (England & Wales: L1 Approved Document), 1 November 2006 (Northern Ireland Technical Booklet F1) and 1 May 2007 (Scotland Technical Handbook 6, Domestic).

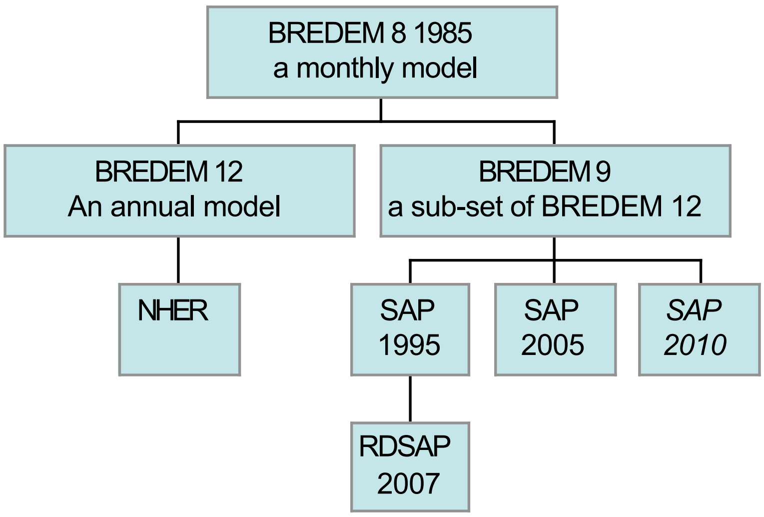
3.10 In the 2006 regulations, the U-value was replaced as the primary measure of energy efficiency by the Dwelling Carbon Dioxide Emission Rate (DER), an estimate of carbon dioxide emissions per m² of floor area. This is calculated using the SAP 2005.

3.11 A simplified version of SAP 2005, RDSAP, has been under development since 2003, and from 2007 has been used to produce the energy report and Energy Performance Certificate in Home Information Packs (HIPs).

3.12 The SAP Index 0 – 100 is used for rating all new homes, and reflects the notional annual cost/m² of providing energy for heating and domestic hot water in a dwelling - the lower the energy cost the higher the rating. Bands were subsequently superimposed on the index to provide energy labeling consistent with the European Performance of Buildings Directive.

3.13 A new document was published by the UK Government in 2007, looking towards SAP and energy standards in the future. Already, a monthly version of SAP, based on EN13790, is planned for 2010.

The BREDEM family



8 Available at: http://projects.bre.co.uk/sap2005.html.

BREDEM and SAP

3.14 SAP is funded by DEFRA which is the government department with responsibility for decisions about the final version published. However, SAP it is a tool largely used by the Department for Communities and Local Government for establishing compliance with the Building Regulations and the Code for Sustainable Homes, and for home energy labeling under the European Performance of Buildings Directive.

3.15 Oversight of the development SAP lies with the Building Regulations Advisory Committee (BRAC) which, in turn, is advised by the Part L Technical Working Party WPTL). The WPTL is made up of individuals with technical expertise in this area from consultancies and industry.

3.16 The Building Research Establishment, as a government agency, was responsible for building the first version of BREDEM in the 1980s and BRE has retained overall responsibility for the calculation procedure under contract to government. Decisions made by BRAC are therefore implemented by BRE.

3.17 The calculation procedure for SAP is published by BRE for implementation by others; it was last updated in 2005. SAP software used for demonstrating compliance with the Building Regulations and the Code for Sustainable Homes must be approved by BRE. Several BRE-approved and some non-approved implementations of SAP are available. The National Home Energy Rating scheme (NHER) is a BRE-approved implementation of BREDEM 12 published by National Energy Services, which cover whole home energy use.

3.18 Communication between the teams responsible for policy in the different departments is imperfect. Even within departments, different teams pursue different agendas. Within CLG the team responsible for Building Regulations (particularly Parts L and F) is different from the team responsible for the Code for Sustainable Housing. Each of these teams has its own separate team of technical advisors, but these teams are neither paid, nor expected, to communicate with each other.

PHPP

3.19 PHPP is owned and developed by the PassivHaus Institut under the control of its PHPP Development Group. Because PHI is independent, it is not accountable to any external body but is influenced its constituency which is represented by users of its methodology.

3.20 PHPP is the standard tool developed by the PHI to assist with the design of low energy buildings and to certify buildings designed to the standard. The first energy model was developed as SIA 380/1 in 1988, with the first edition of PHPP, drawing on the work in SIA 380/1, published in 1998.

3.21 Subsequent releases of PHPP were made in 1999, 2002, 2003, 2004, with the most recent edition published in 2007. The PHI's developers' group makes changes to the package based on the outcome of experience fed back by users and buildings with measured energy results.

3.22 PHPP is available for purchase from the PHI and its re-sellers. Accreditation assessments are validated by the PassivHaus Institut prior to certification of the compliance of dwellings with the PassivHaus standard. The contracts for those wishing to use PHPP to accredit buildings to the PH standard requires users to attend an annual meeting.

3.23 Around 500 PH buildings have been monitored over the last ten years, mainly when funding has been made available through an EU programme.

4. METHODOLOGY

Overall approach

4.1 We describe the two packages in outline qualitatively, the main features they have in common and their main differences by comparing SAP and PHPP, listing in a table for ease of comparison:

- overall philosophy, application and implementation;
- conventions;
- what's included and excluded;
- the use or otherwise of assumed input variables and their levels;
- how the steady-state heat loss is calculated and how the annual heat loss is derived from that;
- the treatment of solar gains - how carefully they are estimated, and how they are deemed to be utilised;
- the treatment of internal gains - how carefully they are estimated, and how they are deemed to be utilised;
- how building plant is calculated to deliver energy to meet the calculated load – eg boiler efficiency, system losses, pumps, solar fans etc.

Specific approach for establishing quantitative differences

4.2 The consultants undertaking the analysis are frequent users of both SAP and PHPP and have become familiar over time with some of the differing results obtained when modelling various aspects of buildings[9]. They also have many years of experience in the design of low energy buildings and this in itself is an important factor in their appreciation of where differences in the outputs of SAP and PHPP are important or relatively trivial.

4.3 On the basis of this understanding, and because to model every difference would be too time-consuming, the analysis concentrated in the first instance on the following key features:

- floor area measurement and heat loss calculations for building junctions
- windows, including U values and solar gains
- thermal mass
- ventilation and infiltration
- internal temperatures
- internal heat gains
- hot water distribution– demand, losses, gains
- greenhouse/CO_2 ratios

4.4 We used the following process:

- we set up a PHPP model of a UK standard developer semi-detached house altered to reflect the fabric and other elements required to comply

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9 Peter Warm and Alan Clarke - Peter Warm was involved with the original development of BREDEM and has delivered SAP assessor training' Alan Clarke is a building services engineer who uses both SAP and PHPP in making energy assessments.

with the PassivHaus standard of 15kWh /m^2.yr for space heating (see Appendix 1);

- we then set up a SAP model of the same house to compare results;
- we used the consultants' own spreadsheet implementation of the SAP 9.81 worksheet to compare the results and the intermediate calculation steps. Using a spreadsheet for SAP meant no restriction to SAP default values. The spreadsheet was also checked against an NHER SAP worksheet;
- comparing SAP and PHPP at the output stage showed significant differences in heating energy demand, but no clear explanation of why there was a difference;
- we therefore introduced SAP assumptions (where they differed from PHPP ones) into the PHPP model individually to see what impact they had on the end result.

4.5 Doing this gives an insight into which differences are major and which are minor, and which send the result one way and which send it the other. The next stage was to try and set up parallel SAP and PHPP models with these differences eliminated to see of there is still a difference in the results. Finally, we looked at the cumulative impact of the differences and drew conclusions about the overall effect of variations between the two models.

5. OVERALL PHILOSOPHY, APPLICATION AND IMPLEMENTATION

Principles of energy projection software design

5.1 Energy projection software is used to assist with the design of buildings to calculate and minimise their energy use as well as to demonstrate compliance with regulatory regimes related to energy.

5.2 These two purposes – regulation and design– are different from one another and impose different requirements on the software. Essentially, software developed for regulatory purposes needs to focus on constrained options, and on imposing regularity and conformity so that results are comparable; software developed for design purposes needs to provide flexibility to allow for refinements of a design across a range of variables.

5.3 Software for estimating the energy use and CO_2 emissions for new buildings needs to perform in certain ways in order for it to be an effective tool. Ideally, all software would fulfil criteria in the following areas:

a) *accuracy of the underlying model* – robust against a thorough understanding of energy technologies, systems and building physics representing physical reality as closely as possible, being based on first principles rather than guesswork;

b) *be evidence-based* - validated against a statistically significant number of real buildings and installed energy technologies with systematic and regular monitoring and feedback from buildings post-occupancy to ensure that the underlying model continues to reflect reality;

c) *designed for ease-of-use without compromising the underlying accuracy* - a user-friendly interface to simplify the use of the underlying complexities in the model and thereby reduce errors made in its use. The higher the number of users and the more legally accountable the outcome, the more important ease-of-use becomes. A designer working to a specific energy target is likely to invest more effort and care in modelling a building to achieve the desired design outcome; a compliance tool has to be usable by many more, probably less expert users so reducing the number of entries and simplifying the process to avoid data entry error becomes more important; equally, it is essential that simplification (through the application, for example, of assumed variables to avoid the need for complex calculations) does not compromise the accuracy of the results.

d) *auditable within software and across versions* – transparent in its workings, assumptions made and reasons for them, All versions of the software must be fully documented for changes, authorship of changes and sources of data. Where there is a software family, there needs to be a consistent hierarchy for making changes throughout to retain auditability – from parent to child, avoiding the creation of ‘orphaned children’ (subsidiary software packages which are altered without altering the foundation software). Each member of the ‘family’ should provide answers consistent with the others.

e) *clear and independent accountability for its development* – there must be confidence in the results from the software and its results, that the software is independent of any vested interests, and with arrangements which subject it to regular peer review.

f) *flexible in use:* an ability to operate at varying levels of details allowing both strategic rapid exploitation of the "space" of solutions and detailed modelling of the performance of specific designs.

5.4 Conformity with the above criteria should ensure that the software encourages value-for money solutions in terms energy saved (as well as water), that any unintended paradoxical consequences are avoided and, ideally, that good creative design is rewarded rather than a tick-box mentality to compliance.

5.5 In summary, the essence of a good design and compliance-demonstration tool is that it distils and packages detailed knowledge of the energy performance of buildings (in this case dwellings) into a form that facilitates the rapid testing of design and specification options for their effect on overall performance and compliance.

Expressing the regulatory measures

5.6 Compliance with energy and CO2 targets for building design can be expressed in a variety of ways.

5.7 PHPP uses two headline targets – delivered energy and primary energy. The principal target is 15kWh of useful space heating energy, which reflects the primary aim of the PassivHaus standard, i.e. to design an extremely energy-efficient thermal envelope. The secondary target is a primary energy limit of 120 kWh, which aims to ensure the most efficient use of scarce resources, including those related to non-fabric energy use. There are other secondary targets such as an overheating limit.

5.8 UK Building Regulations targets % reductions in CO2 compared to a notional dwelling for the fabric and lighting; 'discretionary' energy (for non-fixed lighting and appliances) features only in CSH Level.

5.9 While the targets are not fundamental to the models and should not impact on how they are used to demonstrate compliance, the headline measure(s) may influence designers' approaches, and some ways of expressing targets may have unintended consequences. The specific targets in PHPP relate more closely to the reality of measurable energy use than the UK's regime of % reductions.

Comparing the approaches of PHPP and SAP

5.10 The following table sets out the philosophical approaches of PHPP and SAP, and how these are applied and implemented.

5.11 The characteristics of any piece of software arise from the context in which it is developed, its objective(s) at the outset, and any changes in either context or objective over time. Understanding and tracking this history is important if we are to appreciate the reasons for certain features, which in a new context may seem puzzling but which at their origins had a clear rationale.

5.12 It is worth noting here that it is important to distinguish between *regulatory* and *design* modelling modes. BREDEM is the design model, SAP is the regulatory model based on BREDEM, but with limits imposed on the acceptable data inputs. Similarly, the PHPP software has two modes: Design and Verification. Verification is the regulatory model – it has fixed inputs (internal gains), whilst PHPP Design is the design model, allowing some linkages with, for example, actual (rather than standard) occupancy.

5.13 In general, the regulatory model removes individual people's effects and uses the average occupancy numbers and pattern to calculate the loads/gains from all fuel uses. Design models generally have fewer restrictions on the inputs, to allow the analysis of more what-if scenarios.

Overall philosophy, applications and implementation

	PHPP	SAP	Comments
Beginnings	PHPP was designed specifically for buildings with low energy performance. PHPP assumes that buildings are heated throughout to a uniform temperature, consistent with the principle of highly insulated fabric.	BREDEM, of which SAP is a sub-set, was developed in the early 1980s. It aimed to model accurately the energy consumption of homes built to a higher energy standard than was then the norm - roughly equivalent to Building Regulations Part L1995, as well as the existing housing stock, from which it was calibrated. This was an era when whole home heating was not the norm, so it is a two-zone heating model. The two-zone model converges to a one-zone model as HLP is reduced.	Since BREDEM was developed, whole home heating has become the norm. It may therefore not be appropriate to apply the two-zone model to both the existing and new stock, as the new stock becomes significantly more energy-efficient. We may need to retain the two- zone model for existing un-insulated stock, before upgrade. Buildings with a highly-efficient thermal fabric are more likely to develop a uniform temperature so that a single zone approach is more appropriate (provided that buildings are completed to the quality required by the PH standard). If energy prices rise significantly as projected, the two-zone model will remain relevant to the existing stock because home-owners will not be able to afford to heat all rooms.
Theoretical basis .	Monthly or annual degree day model based on EN13790.	Annual degree-day model developed by BRE in the 1980s (pre-dates EN13790); a monthly version (BREDEM 8) exists but has not been implemented or updated.	A monthly version of SAP, based on EN13790, is planned for 2010.

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Core methodology	PHPP's initial target is configured to ensure that the building fabric reaches a minimum (high) standard of thermal efficiency. The type of heating system is not included at this stage. The heating load is derived from calculating the total heat loss and subtracting a standard figure for all incidental gains including hot water.. The detail of the heat loss is therefore considered carefully, and solar gain is calculated in considerably more detail than in SAP. In addition to building heating energy demand PHPP examines total primary energy (and carbon emissions) for a house, including appliances. Standard figures are provided for these, but more accurate data can be used if available.	SAP combines consideration of the building heat loss with the heating type, and control. Heat loss and heating control are combined to derive an estimate of average internal temperature with which to calculate heating energy consumption. Incidental gains are included as standard figures; hot water gains include a selection of figures depending whether primary pipework is insulated or not, and include calculated heat loss for the indicated level of hot water cylinder insulation. SAP aims to provide a total running cost for the building as built, so figures for electrical use by pumps, fans and lighting are added to the heating and hot water figures.	
Main applications	Europe-wide accreditation of low energy buildings (mostly dwellings), by the PassivHaus Insitut; UK accreditation of designs for low energy buildings	Demonstration of compliance of new dwellings with Building Regulations Part L1A, and of some works to existing dwellings with Part L1B; assessment of	SAP is essentially a regulatory compliance tool which is also used extensively as a design tool by architects, engineers, house-builders and specialist consultants, for both new dwellings and improvements to existing

	against the AECB CarbonLite standards; also used as a specialist design tool for low energy buildings.	energy efficiency against the standards in the Code for Sustainable Homes; certification of the energy performance of new and existing dwellings (EPCs) in accordance with the EPBD; housing stock profiling.	dwellings.
Differences between validation and design applications	In validation mode, PHPP fixes the internal gains from hot water, appliances, hot water and people at 2.1 W/m^2. In design mode, changes can be made to this fixed assumption to reflect real conditions.	In validation mode, SAP assumes gains from hot water and appliances based on standard occupancy.	The PHPP limit on internal gains from people and appliances maintains the standard to which the fabric is designed. In SAP, higher internal gains can be set against a lower standard for the thermal envelope.
Implementation	Microsoft Excel workbook sold by the PassivHaus Institut; German and English versions last updated 2007. The calculation procedure is published with the workbook in the PHPP Technical Manual.	The calculation procedure is published by BRE for implementation by others; last updated 2008. SAP software used for demonstrating compliance with the Building Regulations and the Code for Sustainable Homes must be approved by BRE. Several BRE-approved and some non-approved implementations of SAP are available. The NHER is a BRE-approved implementation	The quality of SAP software varies; there are several user-interfaces for different applications; some implementations offer other features (e.g. U value calculators)..

		of BREDEM 12, a more detailed version of BREDEM, but this software also calculates BREDEM 9 (SAP) for regulatory purposes.
Philosophical approach to achieving accuracy	In validation mode, PHPP assumptions default to a higher thus making compliance harder to achieve. This incentivises the user to use the software as a design tool. In this mode, it provides a lot of flexibility so that improvements can be made to the default assumptions – but they require the designer to invest effort into finding more energy-efficient solutions – and rewards them accordingly.	Some of the assumptions in SAP default to a more energy-efficient answer than the likely reality, making compliance easier. This detracts from its use as a design tool for low energy buildings. For example, the default frame and g value factor for windows provides for more solar gain than is likely to occur in many cases. The y-value approximation for thermal bridges can under-estimate heat loss and gives no incentive to designers to calculate the correct figure. The default assumption for lighting is that most will be tungsten which creates higher internal gains leading to a reduced predicted heating demand.

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Achieving technical accuracy	PHPP is designed for use by those with a good knowledge and understanding of low energy buildings and their services and requires extensive data entry consistent with achieving low energy designs. Certification to the PH standard can only be delivered under the auspices of organisations accredited by the PHI; certification assessments are validated by the PHI prior to certification of the compliance of buildings with the PH Standard.	Certified SAP assessments may only be delivered under the auspices of 'authorised' energy rating schemes that have ISO-9001 quality assurance procedures in place; such procedures typically involve training, examination, registration and technical updating of SAP assessors, and sample monitoring of assessments. Authorised energy rating schemes are currently being replaced by accreditation schemes for SAP Assessors.	Data requirements for both SAP have been reduced, and conventions simplified, as far as possible, to minimise errors associated with data availability (estimation), measurement and entry by non-expert users. Certified SAP assessments are monitored to demonstrate that the accuracy standard is being met. PHPP's extensive and complex data requirements may lead to inaccurate data collation and entry if carried out by untrained users.
User interface	Microsoft Excel workbook with 34 worksheets requiring detailed input data. Conventions for measurement, etc, are explained in the Technical Manual, not always clearly.	A variety of user-interfaces exist in different software implementations. User-interfaces vary according to the type of application and the source of input data (e.g. drawings and specifications of un-built dwellings, or surveys of existing dwellings). The conventions for measurement and representation of dwelling features, etc, from drawings and specifications and from surveys, are defined and published by BRE.	The SAP user-interface is used where data are obtained from drawings and specifications. The Reduced Data SAP (RDSAP) user-interface is used where data are obtained from surveys of existing dwellings.

A Comparison of PHPP with SAP

Training	There is no formal user training requirement. The PHI, the AECB and other organisations offer short training courses for PHPP users, typically two days in duration. On mainland Europe there are hundreds of consulting firms - either in the field of building physics, or interdisciplinary practices - which are trained in the use of PHPP.	User-training is considered essential if the accuracy standard is to be met. A variety of training courses are available for SAP Assessors; duration varies from two to five days, and usually includes a test of competence.	Certified SAP assessments (for EPCs) may only be delivered by accredited SAP Assessors (OCDEAs) who have been trained and then passed a test of competence in accordance with National Occupational Standards (NOSs). In the UK, the AECB (in association with PHI) is developing a process for PHPP user accreditation, including a test of competence, a system of double-checking to ensure repeatability, and access to a user forum.
Validation	PHPP is calibrated against measured fuel use data from over 500 buildings built to the PassivHaus standard, since the 1990s.	Calibrated during the 1980s against detailed monitored data from several hundred dwellings built to better than the Building Regulations standards of the time.	Neither SAP nor PHPP have been resourced to ensure that they can regularly and systematically monitor buildings to ensure the accuracy of the models.

Conventions used

PHPP and SAP use a number of different conventions which can make direct comparison of their outputs difficult. The main conventions are set out in the table below.

	PHPP	SAP	Comments
Dimensions and areas	Building dimensions for the calculation of heat loss areas are measured to the external surfaces of the insulation layer to allow for geometric thermal bridges and allow	All building dimensions and areas are measured internally. The floor area includes all habitable floorspace within the heated envelope, including plant rooms and	The difference between the two conventions results in the TFA entered into PHPP being typically around 10% less than *total* the floor area entered into BREDEM. The Total Floor Area (TFA) of SAP can be 5-15% larger than PHPP, the larger figure applying to

	simplified data entry where thermal bridges have a psi value less than 0.01. The total floor area (TFA) is calculated from internal dimensions, net of internal partition thicknesses, to count actual useable floor area; plant rooms and stairwells are omitted. The TFA is also adjusted to take account of spaces that are less than full height. (This is consistent with the methodology applied by German surveyors to calculate usable living space).	the area occupied by internal partitions; the areas of stairwells are included on every floor. Opening areas include the frames.	dwellings with multi-storey designs, the smaller to bungalows (stair area is significant)
Treatment of linear thermal bridges at junctions between elements	Elemental areas measured externally. The psi-values quoted relate to external dimensions and can be negative.	Elemental areas measured internally. The psi-values quoted relate to internal dimensions.	
Location	PHPP assessments are location-specific; temperature and insolation data are available for a variety of European locations, including five sets of UK weather data from	SAP assessments are independent of location; all assessments assume that the dwelling is located in the East Pennines degree day region, near Derby. However, the	

	Plymouth to Glasgow. The exposure of the dwelling to wind, and local solar overshading, are taken into account. Entered data on wind exposure are used to adjust the infiltration rate derived from the airtightness data (see below).	exposure of the dwelling to wind, and local solar overshading, are both taken into account. Entered data on wind exposure are used to adjust the infiltration rate derived from the entered air permeability (see below).	
Measurement of air infiltration	Air leakage rate in air changes/hour @ 50 Pa – can be converted to permeability.	Air permeability in m/h @ 50 Pa. However, the worksheet uses this figure as if it were the air changes per hour figure that PHPP uses.	These should not change the predictions. Both methods, if applied correctly, should yield the same result. However SAP appears to confuse air permeability and air changes per hour. Although the difference is small with typical surface area:volume ratios, and natural ventilation, it can be significant with atypical house forms, and where heat recovery ventilation is employed.
Actual air infiltration	Uses a default factor of 0.07 in line with recent international guidance. Gives guidance for the use of lower or higher factors in very sheltered locations and very exposed situations; e.g., high-rise flats and rural locations without tree cover.	Uses a factor of 0.05 to relate annual average air infiltration to air flow in the pressure test.	

Occupancy	Standard occupancy in persons/m^2 for all sizes of building, or a level specific to that building.	UK standard occupancy only; persons/m^2 varies slightly with dwelling floor area; smaller dwellings are assumed to have higher density occupancy than larger dwellings.	SAP default assumptions may be more realistic in relation to larger dwellings.
Party walls and floors	Party walls and floors are not considered as heat loss elements; the spaces on the other sides are assumed to be at the same temperature as the dwellings being assessed. However, for calculation of the maximum heating demand a temperature difference of 3°C is assumed across party walls and floors.	Party walls and floors are not considered as heat loss elements; the spaces on the other sides are assumed to be at the same temperature as the dwellings being assessed.	Recent research by LMU on the Stamford Brook development in Manchester has suggested that UK party walls of cavity construction transfer heat to the roof-space by convection, and can have effective U values as high as 6.0 W/m^2K. If this is the case then both PHPP and SAP seriously underestimate heat losses via this type of party wall. On the other hand, as this type of building is not low energy because it breaks one of the basic low energy maxims that there should be no voids in the structure, it may be a design characteristic not used in PH buildings. In the case of renovations, both SAP and PHPP neglect the fact that a poorly insulated house adjoining a well-insulated one will tend to have a lower average internal temperature. The heat loss through an un-insulated party wall may be highly significant in this case.

What's included and excluded

Water evaporation	Included	Excluded	PHI measurements on the four Kranichstein Passive Houses at Darmstadt, 1992-96 calculated that the useful space heating requirement would increase by 2.8 kWh/m^{2}yr as a result of this.
Heating up of incoming mains water (e.g. en route through the building and stored in toilet pans and cisterns)	Included	Excluded	PHI measurements on the four Kranichstein Passive Houses at Darmstadt, 1992-96 calculated that the useful space heating requirement would increase by 0.6 kWh/m^{2}yr as a result of this.
Use of A+, A++ or similar appliances	Can be modelled	Not modelled	
Thermal capacity and efficiency of utilisation of passive solar and internal gains.	Included. PHPP is calibrated by reference to results of previous dynamic thermal simulations	Excluded. SAP uses a default value for thermal capacity, which cannot be changed.	
Boiler efficiencies	Can model a particular boiler brand and model number.	Can model a particular boiler brand and model number.	
Lighting	Lighting energy is modelled as a whole and includes both fixed and plug-in lighting.	Models fixed lighting only; treatment of plug-in lighting by CSH is very unclear - may take historic energy	

		use data for lighting, including plug-in lighting. Allows choice of % low energy, but assumes all plug-in will be incandescent.
Compact plumbing layouts	Can be modelled	Not modelled
Highly energy-efficient MVHR systems	Can model particular systems and takes account of the design of the system as a whole including duct lengths and their insulation. Heat transfer between the heated space and the ductwork connecting the MVHR can significantly reduce the effective efficiency of the heat recovery.	In SAP 9.81 this can be done within software, drawing systems down from a Products Database. Multiplies efficiencies by 0.85 to allow for inefficiencies of installation. SAP makes no provision for the length and insulation of ductwork at different temperatures from the surroundings. Efficient design is not rewarded and inefficient design is ignored.
Treatment of windows and solar gain	PHPP requires detailed consideration of the shading of each window from remote obstacles as well as reveals and overhangs. The actual dimensions of each window are used including all frame elements so actual glazed areas are derived for individual windows. There are no default figures for glazing g-vlaues – manufacturers' actual figures are used along with glazing unit U-values.	SAP treats the windows on each aspect of a building as a single area of glazing. The U value of windows is taken to be that of the standard window size, rather than that actually installed. For solar gain, a frame factor is applied, though the defaults which may be used generally give a favourable level of solar gain compared with the frame factor that can be achieved in practice. SAP does allow for average actual frame factors to be

		used, but not on a window-by-window basis. Shading by reveals and overhangs is not calculated specifically; general shading by surrounding obstacles is considered in broad approximations. The thermal bridges associated with window installation, such as lintels, are not included with window heat loss and are instead subsumed into the overall y-value for the building.	
Impact of window area on electricity use for lighting	Excluded	Included	SAP treatment of window size in this respect is likely to be more accurate than PHPP though we have not modelled it.

6. RESULTS OF QUANTITATIVE ANALYSIS

Introduction

6.1 This comparison focuses on the actual numbers resulting from the algorithms, rather than the presentation of the two models and what they look like. SAP is defined through a worksheet listing the calculation steps, although you would carry out a SAP assessment with a dedicated computer program designed to make it user-friendly. PHPP is defined by a set of spreadsheet worksheets, and PHPP assessments are carried out using a copy of the spreadsheet.

6.2 Fundamentally though, both models do much the same thing. Given details of the heat loss of a house, the windows and ventilation, they estimate annual heating energy consumption for “standard” occupancy and weather (though PHPP has weather data for locations all over Europe, including several locations in the UK). In the first instance, the analysis focused on the heating, which is the primary output of the models.

6.3 Despite the fact that the two models use the same basic principles – steady state heat loss multiplied by degree-days, with internal and solar gains subtracted – we find when comparing models of well-insulated houses that the results are very different.

6.4 This section describes the analysis undertaken in respect of key variables – areas and heat loss, windows, thermal mass, ventilation and infiltration, internal temperature, internal gains and overall impacts. The dwelling used was a standard developer form of a two-storey, three-bed house.

Areas and heat loss

6.5 SAP and PHPP use different conventions for measuring areas; PHPP measures internal area to reflect actual living space, although this is harder to measure than the gross internal floor area used in SAP. We ignored this difference by simply concentrating on total kWh for the house, and using the same floor area.

6.6 Then PHPP looks at external heat loss areas, SAP at internal. The PHPP practice eliminates the geometric thermal bridge at corners and, given good practice, the extra material thermal bridges at corners are balanced by the slight over-estimation in heat loss that this method gives. The psi value calculations need to be done to ensure that they are within limits but PHPP gives reliable results for heat loss from thermal bridges without having to measure the lengths of the linear thermal bridges.

6.7 SAP uses the y-value to avoid the need to conduct detailed thermal bridge calculations. If we include full psi value calculations in both SAP and PHPP we get the same heat loss figure, as the basic derivation of the psi values (internal or external) is simply the difference between the internal- or external area-based estimation of heat loss and the more accurate numerical 2D figure for heat loss – which includes fabric thickness in its calculation.

6.8 However, our calculations have shown that a standard y-value of 0.08, which can be applied if the designer states that Accredited Details have been used, cannot be completely accurate when the total thermal bridge depends on number of window openings etc. In some cases it is an overestimate and in some an underestimate.

6.9 To simplify things we have found that for PassivHaus-type junctions a y-value of 0.03 is appropriate for this house, and using this value we have derived the same overall heat loss in terms of watts per degree K in both SAP and PHPP.

Windows

6.10 PHPP models windows in detail, since they are the largest single element of heat loss and are also likely to be the largest element of heat gain in a passive solar house. Individual U-values are calculated for each window with each pane of glass considered separately, coupled with its frame or frame elements (window surrounds and bars), which are stored in a standard library within PHPP. Once the glazing and frame dimensions have been entered, PHPP calculates the window U values. In PHPP, window-opening thermal bridges are included in the window U-value.

6.11 In fact, PassivHaus design favours large single pane windows, i.e. glazing without window bars, which makes this easier. Psi values are also calculated and included in the total heat loss calculation because measuring external areas does not eliminate the impact of window installation thermal bridging.

6.12 The calculations of U-value for windows in SAP follow the same method and, by discounting the psi value element, the same U-values are arrived at when comparing the UK "standard" window. However, frame factors in UK windows vary significantly, from below 0.5 to 0.8[10]. Triple-glazing fitted into standard frames has a big effect on U-value; for the PassivHaus standard windows considered in this example, the difference between the conduction of the frame and the glass is smaller so the difference in overall U-value wasn't significant. However, a difference in solar gain can be expected, as frame factor is very important in this.

6.13 The PHPP model base case has a heating demand of 15 kWh/m² and this was with the windows on the drawings modelled in detail in PHPP (only as double or triple casements though, "Georgian"-style glazing bars on one elevation were assumed to not exist. PHPP gave the frame factor as 0.5. Adjusting the frame width to give the SAP standard figure of 0.7 reduced the heating demand by over 2 kWh/(m2.yr). This is because the assumption about the higher glazing element increased the solar gain heating input by approximately 40%. This is an example with relatively small window areas so this variation driven by the differences in frame factor could lead to large differences in assumed losses/ gains related to windows.

6.14 SAP does allow actual frame factors to be used, but specifically not window by window:

"Note: If known, the actual frame factor can be used instead of the data in Table 6c provided that it is obtained either for the standard window configuration defined in BR 443 or it is an area-weighted average of all windows in the dwelling."

6.15 This is still different from the PHPP method in that it insists that a whole-house average is used; this is not so precise but important because, in a passive solar design, very large windows are installed on the south (with high-glazed fraction) and small windows (with small-glazed fraction) on the north. The SAP methodology may be to reflect the way BRFC ratings are done, but it does not help optimise the design of passive solar gain in houses.

6.16 SAP also allows for the use of the default value. It seems likely that default values will be used because either designers (or those using SAP for compliance-testing)

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10 The frame factor is defined as the proportion of the total window area that is glazed.. SAP makes standard assumptions of typical frame factors for several different window types, e.g. aluminium and timber-framed windows. If the ratios between glazing and frame are significantly different from the default U values, heat loss and solar gain calculations will be inaccurate.

will gain nothing from doing the additional work of entering actual frame factors, or because they are not aware of this significant differences in heat loss/ gains that will arise.

6.17 PHPP also requires specific data on the solar heat transmission of the glazing, or g value. The SAP methodology provides for input of actual values, but also defaults to a standard figure for the number of panes in the glazing unit. Using the default for triple glazing reduced heating demand by around 0.5 kWh/(m2.yr) although this could be discounted as a difference as SAP does allow correct values to be used. Again, the outcome turns on whether users of SAP are seeking to optimise their building or demonstrate compliance with a relatively relaxed performance standard.

Thermal mass

6.18 SAP takes account of thermal mass in respect of heating system response. PHPP takes account of thermal mass in respect of incidental gains. It considers the total mass of the fabric inside the thermal envelope, and derives a time constant by dividing the total mass by the heat loss of the building,. This is used to adjust the utilisation factor calculation for thermal gains in accordance with a correlation with dynamic thermal models.

6.19 The utilisation factor is calculated for each month as it depends on the relative levels of internal gain and heat loss. SAP also uses a utilisation factor, but just a single figure for the whole heating season. The utilisation factors are similar in PHPP and SAP, but with very small residual heat loads and gains providing over two-thirds of the heating, a small difference in utilisation factor has a large effect on the final heating demand figure.

6.20 With the base case PHPP model, varying the thermal mass to reasonable limits changed the heating demand by 0.5 kWh/(m2.yr). With higher gains, say from increased window area, this variation becomes more significant.

Ventilation and infiltration

6.21 Both models use air change rates at 50 Pa in their calculations to determine the infiltration heat loss. For some reason, however, SAP asks users to input the permeability figure instead of the air change rate. For this particular house, using an alternative metric does not make a large difference, but it seems odd to introduce this inconsistency. To eliminate this difference, we simply used the air change rate figure in both models.

6.22 There is a difference in the determination of average infiltration rate from the pressure test figure; the SAP algorithm results in heating demand being reduced by around 0.5 kWh/(m2.yr)

6.23 Our model uses mechanical ventilation with heat recovery, as is standard for PassivHaus designs. SAP has been revised in 2008 to reflect some recommendations from Approved Document F, that suggest that the infiltration rate is taken into account when determining the design mechanical ventilation rate. This is not traditional HVAC practice - wind-driven infiltration cannot be relied upon all the time, and will not be adjusted by opening and closing windows as is the case in a purely naturally-ventilated house. We would expect the MVHR to be designed to a specific figure irrespective of the actual air tightness test result, which won't be known when the design flow rates for the MVHR are calculated.

6.24 In fact, the assumptions now made in SAP for increasing MV rates are not actually a requirement of part F, and in practice a PassivHaus building could be designed without the SAP increase and still comply with Part F.

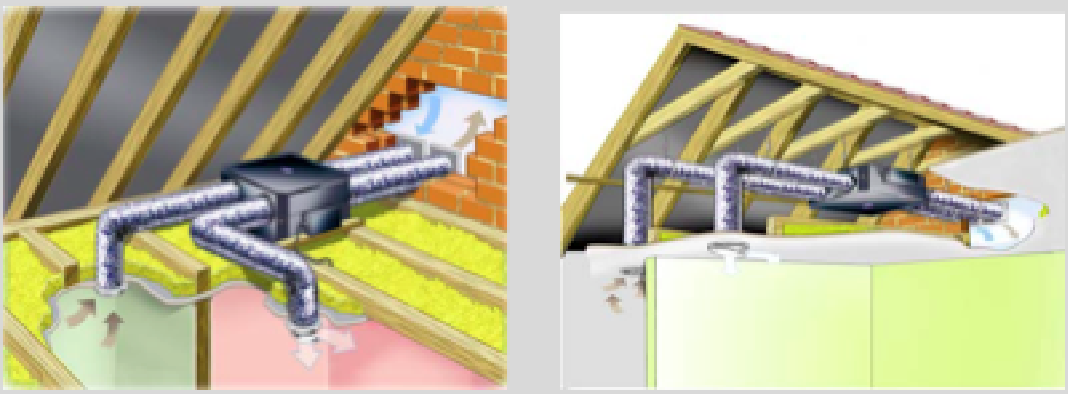
6.25 The SAP assumptions have the peculiar effect of indicating a minimum energy use at a pressure test result of around 3 air changes per hour, when actual experience shows that increasing airtightness delivers further energy savings. (This may be a consequence of assumptions made for Part F which create an anomaly in dwellings with high levels of airtightness).

6.26 The usual ventilation rate used in PHPP is 0.3 air changes per hour. This has been found to be more than sufficient to avoid high humidity in a well-insulated thermal bridge-free construction; there are also recommendations to avoid over-ventilating as this will lead to unhealthily low humidity levels at the consistently 20+ room temperatures found in PassivHaus buildings.

6.27 SAP uses a ventilation rate figure of 0.5 air changes per hour, as this has been historically found to be beneficial for dealing with condensation in less well-insulated houses. This assumption increases energy use by 0.5 kWh/(m2.yr) (as well as increasing fan power). In houses with MVHR the 0.5 ach is taken to be a combination of MV and average wind driven infiltration.

6.28 Duct losses are calculated in detail in PHPP as it can be seen that they can be nearly eliminated or that, with careless design, they can halve the efficiency of the heat recovery element of the system. SAP (new edition) applies crude "in-use" factors which don't even consider insulating the ducts connecting the MVHR unit to outside – crucial in PassivHaus design. The variation is over 2kWh. The diagram below is from the Installation Guide for Appendix Q and shows an MVHR system installed outside the insulation envelope and with un-insulated ducts.

Figure 2 Sample Mounting Positions



Internal temperature

6.29 SAP uses a simple two-zone heating model, assuming that the living room is warmer than the rest of the house. It arrives at the assumed air temperature by calculating the average temperature across the two zones and accounting for poor controls. PHPP assumes modern heating and high levels of insulation will lead to uniform temperatures throughout the house. Both assumptions are probably correct, in some cases, but the end result is that, in our example, the average room temperature is assumed to be 19 in SAP and 20 in PHPP. The resulting difference is around 2 kWh/(m^2.yr).

6.30 Monitoring of low energy houses in Europe shows that actual temperatures tend to be higher than both these figures, as people take advantage of very low heat loss to increase their comfort.

6.31 SAP has a more involved consideration of heating system control and response than PHPP; the justification for the simplifications in PHPP are that the very low heat inputs required for PassivHaus buildings and the long time constants of the buildings mean internal temperatures fluctuate very little.

Internal gains

6.32 This element of the calculations leads to the biggest difference between the two models, although it is not a fundamental difference in the algorithms themselves. PHPP assumes best practice in appliance and lighting choice and in hot water system design, thus deriving a low figure for internal gains. SAP assumes inefficient appliances, tungsten lighting and un-insulated hot water pipes, and comes up with a high figure. The W/m^2 rate varies slightly with floor area but in our example the SAP gains were nearly four times those of PHPP.

6.33 At the level of heat demand set by PassivHaus buildings, the SAP levels of internal gains practically eliminate the need for heating, reducing it by more than 10 kWh/(m^2.yr) in the PHPP spreadsheet.

6.34 Furthermore, PHPP decouples the magnitude of the internal gains from non-fabric sources, by the simple expedient of fixing internal occupancy gains of 2.1 W/m2 in regulatory mode (residential), so that a poorly designed hot water system cannot regain some credit by heating the building in winter.

Hot water system design

6.35 SAP and PHPP differ in a number of ways regarding hot water system energy consumption. Both take 25 l/person per day as a basic consumption level, but SAP adds 38 litres per household to this. Also, the area per person in PHPP is assumed to be 35m^2, but in SAP varies depending on total floor area, from 30m^2 for a total floor area, increasing gradually with increasing floor area. The net result is notably higher hot water consumption per m^2 in SAP than in PHPP, particularly in smaller dwellings where the SAP hot water consumption figure is twice that estimated by PHPP.

6.36 Hot water cylinder heat loss can be entered as the manufacturer’s figures in both PHPP and SAP; SAP also calculates heat loss depending on insulation thickness and cylinder size. PHPP allows for the possibility that the hot water cylinder may be outside the heated envelope (more common in Germany).

6.37 For primary circuit heat loss, SAP has standard figures for insulated and un-insulated pipework (and also uncontrolled hot water heating). PHPP requires pipe lengths and insulation specification to enable an accurate heat loss calculation. For secondary distribution SAP assumes losses will be a percentage of total use. PHPP requires pipe lengths, diameters and, in the case of secondary circulation systems, the insulation and periods of pump operation. This enables a calculation to be made on the basis of the actual pipe lengths and draw-off volumes when the system is run to a standardised water draw-off regime.

6.38 In return for this detailed information, PHPP credits designers of compact pipe work systems with short deadlegs and of well-insulated circulation pipes with low energy consumption.

6.39 Research at Stamford Brook showed that heat loss in poorly designed hot water systems can have a significant impact on building energy consumption and was identified as one reason why the houses studied did not perform as predicted.

CO_2 emissions

6.40 The basic data are clearly different between SAP and PHPP, for example, the CO_2 emissions factor for gas in PHPP is 0.25kg/kWh, whereas in SAP it is 0.19kg/kWh.

Fuel	PHPP kg/kWh	SAP kg/kWh
Oil	0.31	0.265
Natural gas	0.25	0.194
LPG	0.27	0.234
Hard coal	0.44	0.317
Wood	0.05	0.025
Electricity-mix	0.68	0.422
Electricity from Photovoltaics	0.25	-0.146

6.41 The reasons for the differences include:

i) PHPP uses net efficiencies, UK uses gross - this has the effect of, for example, increasing the UK gas figure to 0.22 kg/kWh, if German boiler efficiency data are used.

ii) PHPP uses GEMIS, a full lifecycle analysis of emissions – the UK figures use a more limited estimation of associated emissions. This may explain differences between the figures for energy-intensive extraction, such as coal and wood.

Other differences are:

iii) SAP electricity figures are different from the DEFRA UK data figure of 0.527 for recent years.

iv) The photovoltaic figures show a very different approach – PHPP assumes significant losses, so that the calculated kWh doesn't equate to the same reduction in generation. SAP seems to credit PVs with much higher CO2 reductions per kWh than any analysis of UK generation. This is supposed to reflect the CO2 emissions of marginal generation in the UK, but its effect is to be rather generous to PVs.

Overall effects

6.42 In the several ways described above, SAP underestimates the heating needed for a low energy house compared with PHPP. Underestimating heating need can lead to the erroneous conclusion that improving insulation levels is not important or economic. In fact, once internal energy wastage is brought under control and free sources of heating are eliminated, the argument for increasing levels of fabric performance is made again.

6.43 PHPP provides feedback on the design of particular elements significant to a PassivHaus building, namely ventilation duct insulation and solar heat gain, by requiring more of them. SAP fixes duct heat losses as a percentage allowance of poor insulation so poor practice is likely to predominate; the gains are likely to be lower than SAP predicts and the losses higher. An effect of this is to reduce the predicted benefits of MVHR where installed well.

6.44 An anomaly on ventilation (possibly derived from Part F) is the expectation that MVHR systems will increase in airflow when a building is made more airtight. This leads to the erroneous conclusion that making buildings more airtight than 3 ach at 50Pa may increase energy consumption. This only seems to hold when the internal heat gains are so high that the total requirement for heating, and hence benefit of MVHR are very low, as predicted by SAP modelling of a PassivHaus dwelling. In other cases there is more a situation of diminishing returns than an absolute minimum in CO_2 emissions. Note that energy consumption still reduces, but electricity use (fans) is increasing and heat (gas) reducing, so CO_2 reduces far less or starts to increase.

6.45 The results of the modelling are given in Figures 1 and 2 below.

Figure 1: The effect of the changing the assumptions in the PHPP model to SAP assumptions

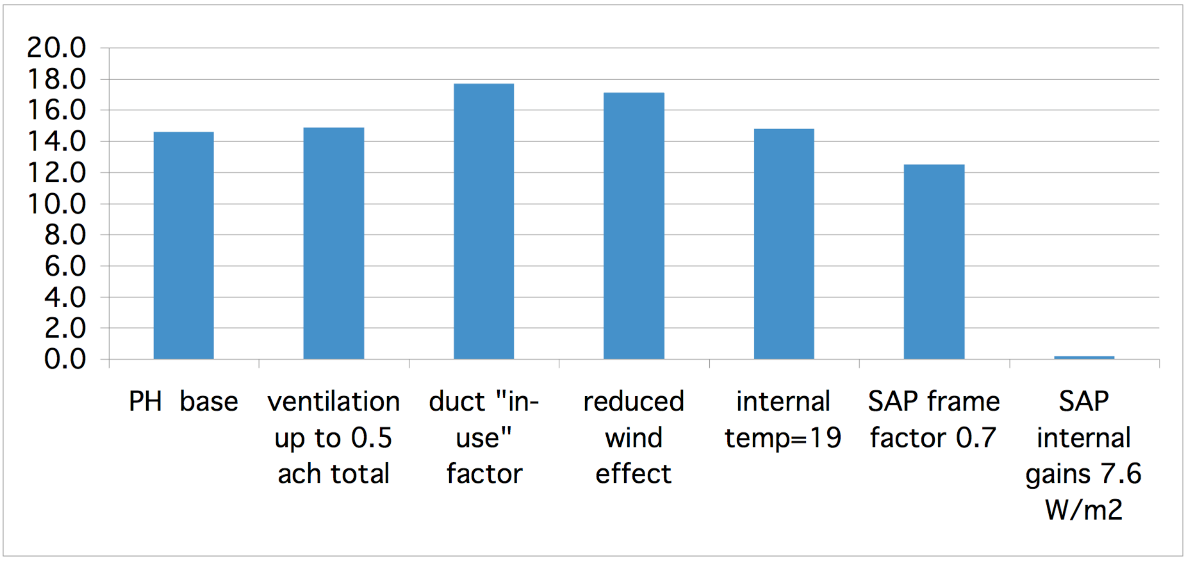


Figure 2: The total of heat losses and gains in SAP and PHPP modelled dwellings

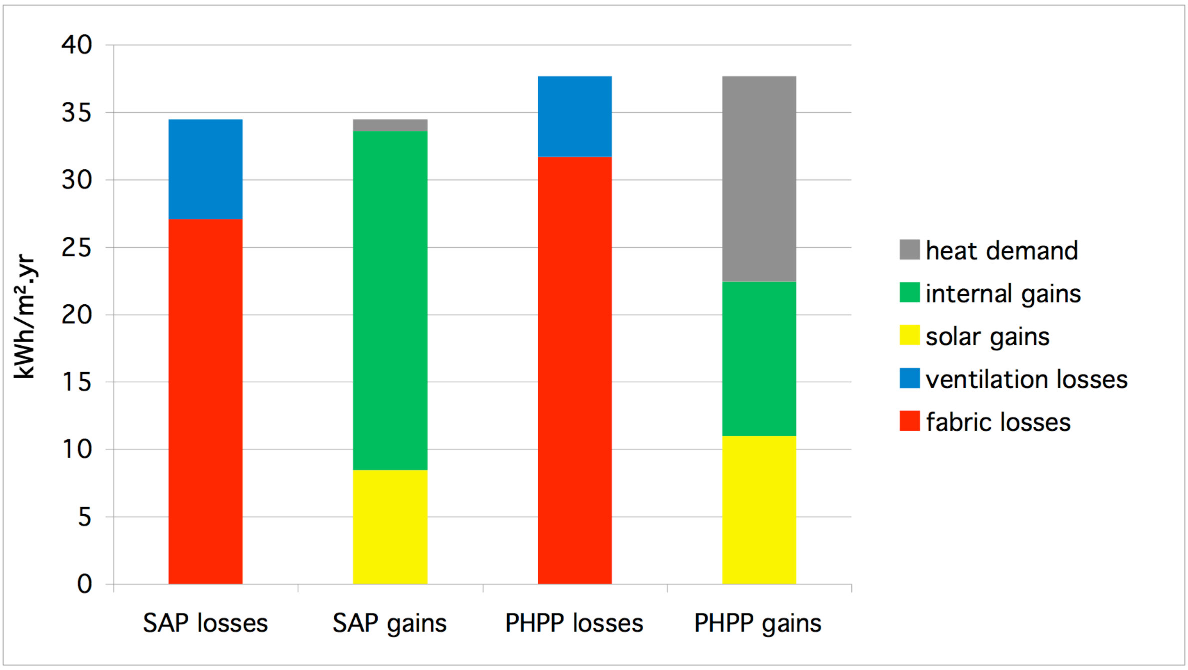
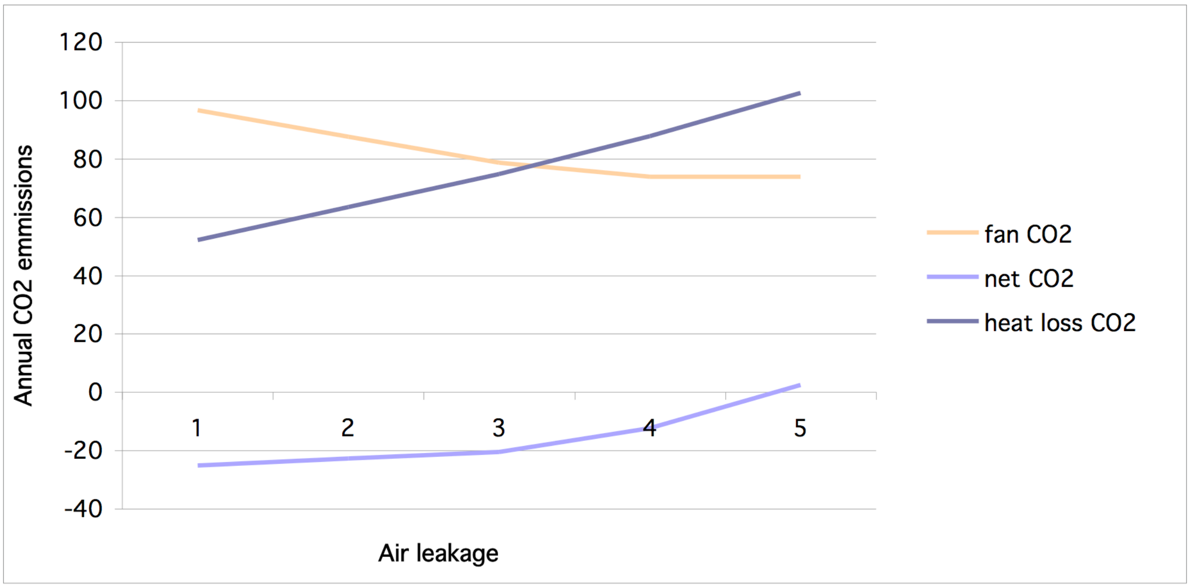


Figure 3: Example of the impact of SAP assumptions on CO2 emissions arising from the use of MVHR below 3 ach (where the relative position of the heat loss line depends on how much heating is needed)



7. CONCLUSIONS

Impact of the way in which the regulatory regime is expressed

Building Regulations and Code for Sustainable Homes

7.1 The basic calculation used for Building Regulations and the Code is to take the design as drawn, apply old elemental U-values to derive a reference heat loss, and then specify a percentage reduction to the calculated carbon emissions. This applies for basic part L and for Levels 3 and 4 of the Code for Sustainable Homes. In theory, this leads to actual reductions in energy use (and CO_2 emissions) by the percentages specified. In practice it does not.

7.2 This is because the more energy-efficient the basic design is, the harder it is to achieve the necessary percentage reduction – SAP assumes some fixed costs, such as pumps, which cannot be reduced, so the smaller they are relative to the total, the easier it is to achieve compliance. This encourages designers to make the base case less efficient, building detached rather than terraced homes for example. If that option is not available, it is possible to introduce a high carbon heating system, such as electricity. This increases the heating element of the total carbon emissions, and the percentage reductions come more easily. As a result, the total carbon emissions remain higher for CSH3 achieved this way than basic Building Regulations using gas heating.

Principles of energy projection software design

7.3 SAP and PHPP differ in the extent to which they match up to criteria for quality software:

a) *accuracy of the underlying model*:

- both models are fundamentally accurate, with the differences in results caused by different assumptions and default values;
- SAP assumptions are not always consistent with low energy dwelling design;

b) *be evidence-based*:

- PHPP is based on more recent evidence of post-occupancy energy results than SAP;
- neither model is updated on a regular and systematic basis;

c) *design for ease-of-use without compromising the underlying accuracy*:

- SAP has a much more user-friendly interface to simplify the use of the underlying complexities in the model but may thereby also be compromising the results;
- SAP does not make a clear enough distinction between design and regulatory modes;
- the PHPP spreadsheet is daunting even to experts in low energy buildings, though once the reason for some of the complexity is understood, the additional effort required to use it is rewarded;
- AECB current practice for achieving reliable and repeatable results is much more expensive; this is expected to change as consultants become expert in PHPP;

d) *auditability within software and across versions*:

- both SAP and PHPP would benefit from clearer explanations of how certain algorithms or assumptions were derived;

e) *clear and independent accountability for its development*:

- as an independent organisation PHI is accountable only to itself and its constituency of users. As the software becomes used more widely throughout Europe, it will become increasingly important to create a formal process of change management;
- there are no formal management or accountability processes for SAP other than BRE's contract with government and the advisory role played by the Building Regulations Advisory Committee.

f) *flexible in use:* an ability to operate at varying levels of details allowing both strategic rapid exploitation of the "space" of solutions and detailed modelling of the performance of specific designs.

SAP and PHPP outputs

7.4 SAP and PHPP use the same basic principles – steady state heat loss multiplied by degree-days, with internal and solar gains subtracted. However, we find when comparing models of well-insulated houses that the results are very different.

7.5 PHPP considers building energy in two stages. First, the building fabric is considered in isolation from the heating system, by assessing the annual heating energy demand. For this, the internal gains from appliances and hot water systems are assumed to be minimised according to best practice design. Treating the fabric in isolation recognises that heat sources can be changed much more easily than the building fabric. Then PHPP calculates total primary energy consumption, and associated carbon dioxide emissions. This include the particulars of heating and hot water system design, and also considers particular appliances and lighting where these are specified, though defaults are an option.

7.6 SAP aims to integrate all the energy consumption associated with heating, ventilation, lighting and hot water into a single figure for running cost and carbon emissions. To simplify data entry, a significant proportion of the information this result is based upon comes from default figures, such as for hot water primary losses, pump energy, boiler electrical use and MVHR duct heat losses.

7.7 The main purpose of Building Regulations is to set fabric standards without regulating those elements of building energy use regarded as 'lifestyle dependent'. This means, for example, that it is assumed that occupants will install energy-inefficient appliances and incandescent light bulbs where they are given a choice. This means that when SAP is used to model well-insulated houses, the assumed values for internal gains are comparable in magnitude to the total heating demand despite being very crudely estimated in comparison to the care with which the fabric is considered.

7.8 Because Building Regulations now set compliance targets in terms of carbon emissions, SAP allows the fuel type to take precedence over building fabric, although fuel availability and emissions factors are likely to vary considerably over the life of the building. Once a decision to use an expensive low-carbon heat source is made, then cuts are usually made in the performance of the building fabric.

A Comparison of PHPP with SAP

7.9 Overall, SAP plays down the significance of insulation and airtightness, and assumes high levels of internal gains, leading designers to believe they have reached a sensible lower limit on heat loss when in fact they have not.

7.10 SAP does not provide well for passive solar design in that windows and shading are not modelled in detail and the effects of thermal mass are not included. In particular, using SAP as a model does not permit the use of efficiency measures in electricity use, such as efficient pumps. Where a set level of carbon emissions is to be met this rules out efficiency measures in favour of electricity generation technologies such as photovoltaics.

7.11 SAP was developed in the 1980s from a study of homes with relatively poor levels of insulation and therefore high levels of heat loss. It is not precise about areas that become critical in very well-insulated dwellings where a heat loss of, say 3kWh/m².yr, represents one-fifth of the total allowed for space heating of 15 kWh/m².yr in a PassivHaus standard dwelling. PHPP was created to assist with the design of comfortable, healthy homes using the minimum amount of energy. These divergent histories are the reason for the fundamental differences in the outputs of the two models.

7.12 The estimation of CO_2 emissions in SAP is significantly lower than in PHPP, even allowing for differences between the electricity systems in the UK and Germany.

8. RECOMMENDATIONS

Compliance regime

8.1 The UK should move to a compliance regime that explicitly regulates the energy-efficiency of the building fabric independently of the heating fuel carbon intensity and CO_2 emissions.

8.2 Standards and compliance (Building Regulations, the CSH, EPCs and DECs) should all be expressed in clear and specific targets to conform to the Energy Performance of Buildings Directive namely kWh/m^2.yr and kgCO2/m^2.yr.

8.3 Both SAP and PHPP should move to standard EU-wide conventions for common characteristics, e.g. measurements of floor area, air leakage rates, local climate effects.

8.4 Place the implementation of SAP into the hands of an independent not-for-profit company with the resources to gather evidence for real-world performance of building fabric and energy technologies.

8.5 Both SAP and PHPP would benefit from the setting up of a programme for the systematic measurement of post-occupancy energy use and CO_2 emissions, supplemented by case studies, to inform the software.

8.6 For CSH purposes, fix the energy and CO_2 emissions in the base case so that games cannot be played on worsening the base case to ease compliance.

8.7 PHPP should include an explicit CO_2 target.

Principles of energy projection software design

8.8 SAP and PHPP differ in the extent to which they match up to criteria for quality software:

a) *accuracy of the underlying model*:

- SAP assumptions should be modified to ensure that the model outputs are consistent with low energy dwelling design;

b) *be evidence-based*:

- both PHPP and SAP should be supported by a continuous programme of monitoring of energy results for buildings in use to inform revisions to the model to ensure that they
  - a) reflect reality, and if necessary
  - b) modify the compliance regimes to ensure that the overall objectives of reducing energy use and climate change emissions are adhered to;

c) *design for ease-of-use without compromising the underlying accuracy*:

- PHPP would benefit greatly from the addition of a user-friendly interface;
- SAP needs to establish on a line-by-line basis that the default assumptions and simplifications made to render SAP user-friendly do not compromise the objectives of reducing energy and CO_2 emissions;
- SAP should allow for improvements to the design of hot water and ventilation systems by allowing users to model the losses associated with a specific design, rather than assuming a standard level of efficiency.

d) *auditability within software and across versions*:

- both SAP and PHPP would benefit from clearer explanations of how certain algorithms or assumptions were derived;
- both SAP and PHPP would benefit from clearer, more detailed and systematic audit trails for the changes made between versions and the reasons for those changes.

e) *clear and independent accountability for its development*:

- PHI should create a process of change management, including an oversight board which formally represents the users of its methodology;
- responsibility for SAP development should rest with a not-for-profit company that is independent of government, whose role and responsibilities are public and transparent;.

f) *flexible in use*:

- SAP should be modified to render it appropriate for use as a detailed design tool, as well as a compliance tool.

Result of quantitative analysis

8.9 The recommendations that follow apply only to SAP as this project was not seeking to establish changes that need to be made to PHPP outputs.

General principles

8.10 Ensure that all default values are designed to provide a worst-case answer.

8.11 All default values should be flexible to all users to enter more accurate data where they have it. There should be benefit to the designer from using more detailed and accurate assumptions than the defaults.

Specific changes related to this study

8.12 Re-visit SAP taking the perspective of minimising energy use and CO_2 emissions by improving the fabric and ensuring that all other energy uses are as efficient as possible. Changes would need to include:

- *heat loss calculations*: to avoid the ‘fudge’ of a ‘y-value’ add an automatic calculation of sigma (psi x length). This could be achieved by using on-line database of building details which have been subjected to an institutional framework and a robust procedure for ensuing that the numbers in the databases represent what is achieved in the real world;
- *windows:* accurate calculation of solar gains for window design – numbers, orientation, actual frame factors and solar heat transmission;
- *thermal mass*: calculation utilisation factors month-by-month during the heating season;
- *ventilation* correct the apparent discrepancy between the metrics for describing air infiltration in the model and the data input sheet; amend the algorithm to reflect traditional practice determining the design mechanical ventilation rate by excluding the infiltration rate;
- *temperature*: increase the default design temperature from 19 deg C to 20 deg C and establish through research the current average temperatures to which UK homes are heated;
- *internal gains:* assume best practice for energy efficiency in lighting design and appliance choice; ensure that all the compliance targets

represent energy-efficient solutions (e.g. minimising MVHR ductwork and requiring it to be insulated);

- *hot water system design*: require heating and water system pipe lengths to be input, and incentivise their insulation;
- *CO_2 emissions:* amend the CO_2 emissions factors to reflect the reality of the UK electricity system and other primary fuels.

Beyond this study

8.13 This study undertook a relatively limited comparison[11] of PHPP and SAP, highlighting those areas were the consultants expected to find significant differences. However, there are other areas which we believe would bear further scrutiny:

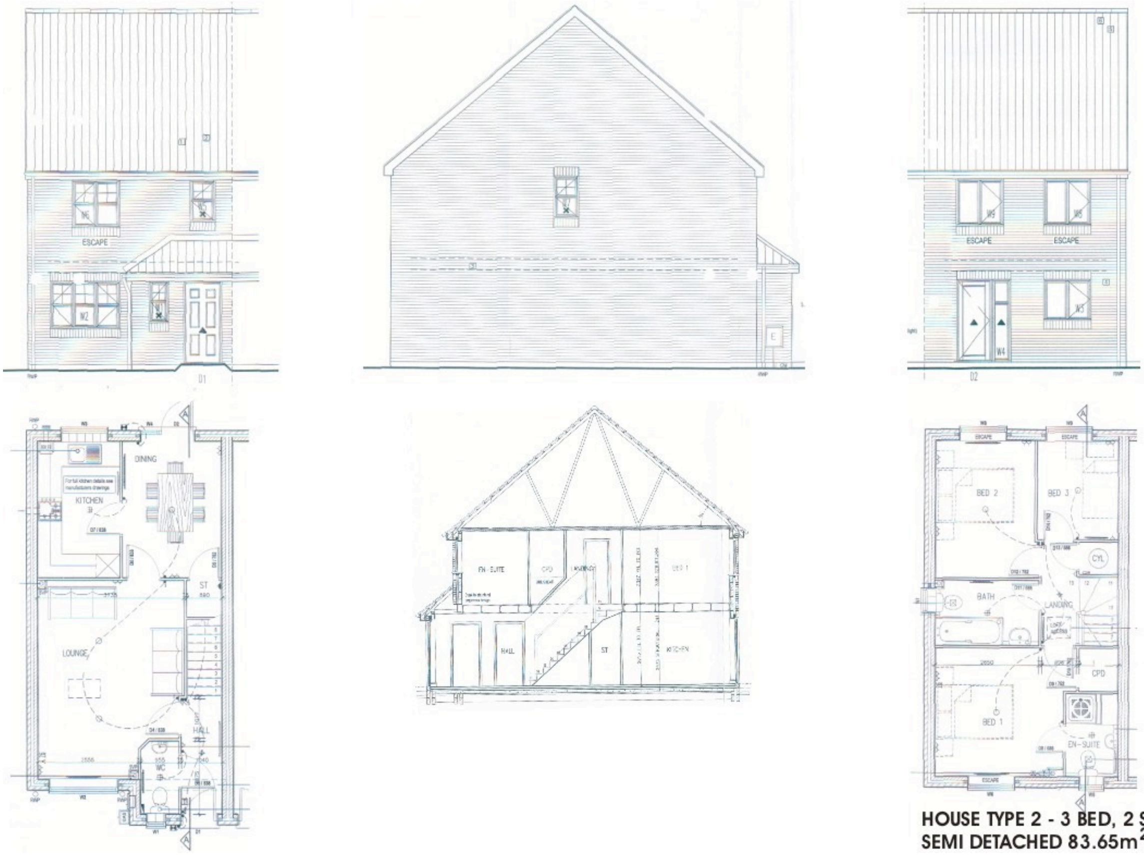
- the treatment of overheating
- the impact of orientation
- the impact of location

8.14 Some of the changes referred to in this study might easily be made by reintroducing those elements of NHER that have been dropped by SAP.

8.15 Draft a guidance document to accompany revised SAP which explains the impact of even small changes in heat loss, heat gains and energy demand on the design of low energy buildings.

11 Limited time, limited budget.

APPENDIX 1: THE HOUSE THAT WAS MODELLED



HOUSE TYPE 2 - 3 BED, 2 STOREY SEMI DETACHED 83.65m^2