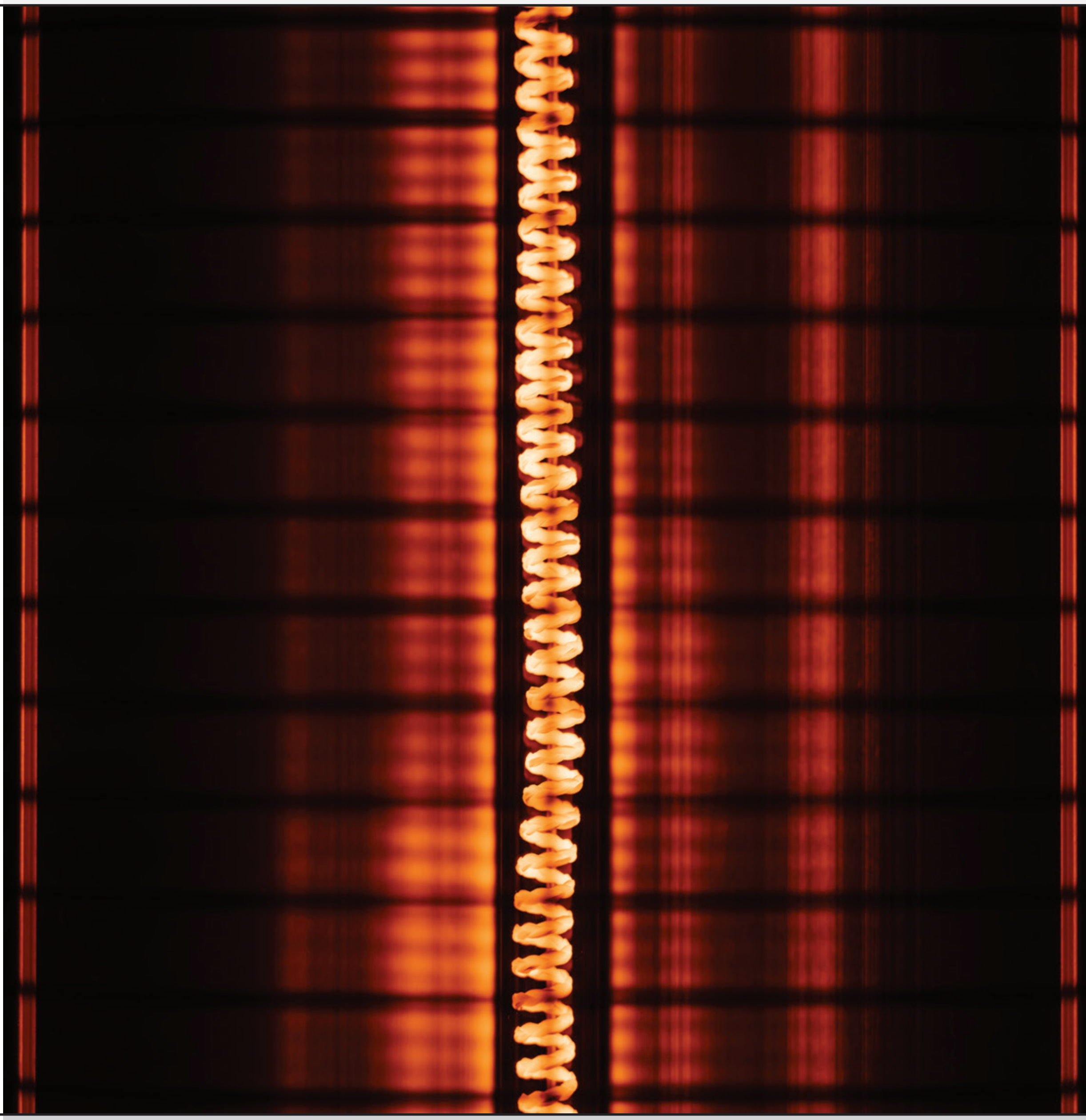
Energy Consumption and running costs of Electric Space Heating Systems



Professor John M Counsell
Advanced Control Partnerships (ACP) Limited

The author would like to thank Dr Yousaf Khalid, Cameron Downing and Connor Wright for their contributions to producing Stroma beta software results for SAP10.1 case studies presented in the report. The project also acknowledges the contribution in knowledge of energy system modelling from the open research outputs/publications produced by the EPSRC funded “Heat STRESS” project and the Advanced Control Partnerships Ltd sponsored EU Eco-innovation Masters of Research Project at the University of Chester, “Multi-Vector Energy Control Systems”, authored by Rhys Jones.

Contents

Page number

Introduction

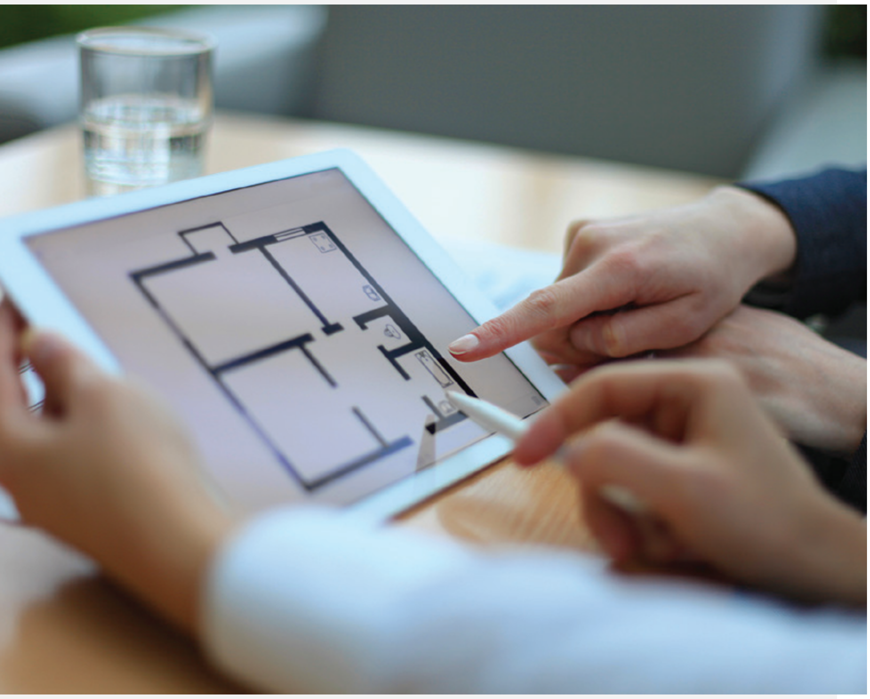
The purpose of this information paper is to provide a publicly available document for professionally informed decisions regarding the impact of the revision of Part L Building Regulations in England & Wales. This regulation uses an updated SAP2012 calculation method (2012 Edition rev Feb2014) [1] for SAP ratings and compliance testing of electric heating system solutions.

The proposed further revised calculation method is referred to by BRE Ltd as SAP10.1 [2]. NOTE: The calculations contained and subsequent results discussed in this report have been generated using a Beta released software FSAP by Stroma Ltd that has been checked for a sample of cases by method [2] validation calculations carried out in Microsoft Excel by Professor John Counsell. This software, as per BRE's SAP10.1 software which at the date of publication of this report had not been 100% verified by BRE. Professor Counsell of ACP Limited carried out independent verifications for the FSAP software calculations since that was possible as the FSAP software tool provided SAP10.1 worksheet calculations unlike the BRE software. In summary the space heating calculations were consistent with Professor Counsell's own calculations. Some inconsistencies in the calculation of domestic hot water usage were discovered, especially the quantity of hot water required for baths, thus it is proposed to update this report with a Version 2.0 supported by a final year undergraduate student's project at the University of Chester. This is expected to be completed in the Summer 2022. Further developments to be investigated are discussed in Section 7.

The report has been prepared by Professor John Counsell who is an independent researcher with over 30 years of experience in the design, development and assessment of electric heating systems and their controls. The running costs, CO_2 emissions, Primary Energy Factor (PEF) used in the comparison studies described in this paper have been estimated using SAP10.1 beta FSAP software aimed to replicate the calculation method: Standard Assessment Procedure 10.1 [2] (SAP10.1). SAP10.1 is a compulsory calculation required to comply with Part L of the England & Wales and is normally adapted for the Scotland & Northern Ireland building regulations. The study uses the full SAP10.1 as implemented by FSAP software calculations as per the latest BRE published revision SAP10.1 [2].

Key differences for Electric Heating in SAP10.1 compared with SAP2012

There are significant differences between SAP2012 and SAP10.1. In the main, for the electric heating systems, it is the increased complexity of domestic hot water modelling (i.e. to create a monthly energy use prediction) and the inclusion of monthly Carbon Emission (CO_2 Factor) and Primary Energy Factor (PEF) for the different electricity tariffs of standard, 10-hour off-peak and 7-hour off-peak tariffs. This leads to a lot of sensitivity to the choice of tariff and also lighting and domestic appliances as well as the choice of hot water and space heating solutions.



CO_2 Factor & PEF as per SAP 10.1 Table 12e [1]

SAP2012, emissions used a constant emissions factor for calculating CO_2 emissions annually. In SAP10.1 the CO_2 and the equivalent PEF have become increasingly complex as they need to be calculated monthly and as a function of the energy use split between high rate and low rate electricity. Thus, they have become dynamic with season and time of day. This has brought about some challenges:

a) The dynamic CO_2 emission and Primary Energy factors are based on the tariff option as the high and low rate fractions are dominated by the technologies responsiveness and ability to store energy. So linking these calculations to Tariff does produce some strange results, i.e. if you change the tariff you change the CO_2 emissions and PEF. That is not logical as changing a price should not affect a technical performance?

b) The modelling of tariff, high and low rates, has to be accurate to be able to prevent anomalies and so does the dynamic values for CO_2 emission factors and PEF have to be accurate to obtain a true picture. Initial observation in SAP10.1 have been very concerning.

   For example:

   Direct Electric Boilers are given the benefit of only 90% on high rate for E7 tariff yet direct electric convectors are penalised at 100%. Why? Perhaps if boilers had more inertia it could be justified, but both systems have a responsiveness of 1! Direct Electric on Standard and 10 hour have the same CO_2 and PEF, which is sensible but it increases on a 7-hour off-peak tariff. This should not be the case.

In summary the dynamic CO_2 modelling and PEF modelling needs careful analysis and thorough peer review. In results presented the CO_2 emissions of direct electric can be lower than High Retention Storage Heater systems (HRSH), which appears to be counter intuitive as off-peak electricity has significantly lower carbon intensity than peak time electricity. Also off-peak periods suffer roughly less than half the power distribution loses. Typically, low rate electricity in the winter is more than 30% lower in CO_2 Factor than high rate, but SAP10.1 tables do not reflect this and is therefore not a truthful representation of the facts. BRE have informed us there is a study to derive the monthly CO_2 and PEF factors, but this has not been published for peer review at this time It is essential it is allowed to be reviewed.

Reduced Lighting and Appliance Gains

In SAP2012, the heat gains from lighting, appliances, metabolic rates from occupants and cooking were if anything on the generous side and in the main linked to the home's floor area. In SAP10.1 and specifically for NEW BUILD, these gains can be much reduced by choosing low energy appliances and lighting, thus giving rise to more heating energy being needed in some cases despite the better insulation and air tightness improvements. This increases electric heating running costs compared with gas central heating and increases the electricity consumption of resistive electric heating compared with heat pumps. On the plus side for all electric heating it improves the electric heating solutions' CO_2 emissions relative performance to gas. The studies in this presentation use energy from appliances and lighting as calculated by the FSAP software.

Furthermore, the DHW utilised volume of hot water is very sensitive to the number of expected baths and the number of installed electric showers. At present Stroma's FSAP software seems to be understating the quantity of hot water used in baths. This is under investigation and will be updated as soon as possible.

Figure 1 shows the methodology adopted by Prof John Counsell to verify the accuracy of the FSAP software results contained in the worksheets linked in Appendix A. This was done by example sheet calculations done in Microsoft Excel using the BRE documentation for SAP10.1 [2]

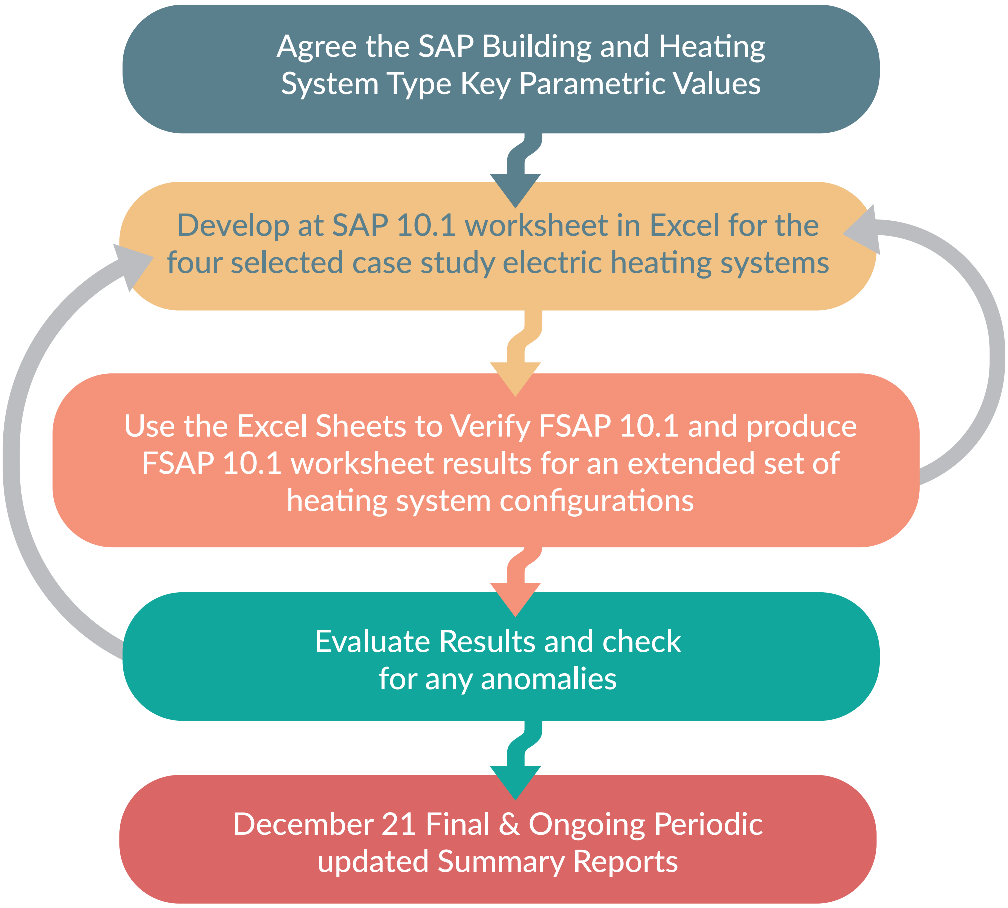


Figure 1: FSAP software results validation process flow

SAP 10.1 Case Study Buildings

The study used three types of home: One Bedroom Single Storey Ground Floor Flat, Two Bedroom Single Storey Ground Floor Flat and a 3 Bedroom Two Storey Semi-detached house. They were all modelled using SAP10.1 default region of Sheffield which is consider as a median of the UK Climate. The parameter settings for the three home types are described in Tables 1, 2 and 3 respectively:

Table 1 Ground Floor Single Storey One Bedroom Flat SAP10.1 key parameters

1 Bed Flat	
Total Floor Area (m^2)	$40m^2$
Floor Height (m)	2.4m
Sheltered Walls	2
U Values; External Wall, Window Glazing Area Floors	0.15 (W/m^2k, 0.8 (W/m^2k, 0.11 (W/m^2k)
Infiltration	0.39ac/hr
If tank used	120ltr, 40mm insulation

Table 2 Ground Floor Single Storey Two Bedroom Flat SAP10.1 key parameters

2 Bed Flat	
Total Floor Area (m^2)	$65m^2$
Floor Height (m)	2.4m
Sheltered Walls	2
U Values; External Wall, Window Glazing Area Floors	0.15 (W/m^2k, 0.8 (W/m^2k, 0.11 (W/m^2k)
Infiltration	0.32ac/hr
If tank used	120ltr, 40mm insulation

Table 3 Three Bedroom Semi-Detached House SAP10.1 key parameters

3 Bed House	
Total Floor Area (m^2)	$90m^2$
Floor Height (m)	2.4m
Sheltered Walls	2
U Values; External Wall, Window Glazing Area Floors	0.15 (W/m^2k, 0.8 (W/m^2k, 0.11 (W/m^2k)
Infiltration	0.29ac/hr
If tank used	120ltr, 40mm insulation

For each house type the electricity tariff's unit prices p/kWh, Carbon Emission factors $kgCO_2$/kWh and PEFs kWhs are derived from SAP10.1 [2] tables 12e and f.

Electric Heating Systems to be modelled

The modelling of DHW Heating SAP10.1 is significantly more detailed than in SAP2012, involving many more options for new technologies and hybrid solutions. The domestic hot water use is also driven by the number of baths, mixer showers and electric showers and the size of any hot water tank as opposed to SAP12 water demand which was just based on occupancy levels/total floor area only. There are different domestic hot water solutions that have been modelled as follows:

1. Direct Instantaneous Point- of -Use Electric DHW

This type of solution has the lowest kWh use and its best tariff option in SAP12 and SAP10.1 is the 10-hour tariff as opposed to Standard Rate, however results shown are for Standard Tariff.

2. Single Immersion Heated 120ltr Capacity Hot Water Tank

This solution uses an insulated (level specified in Tables 1, 2 and 3) hot water tank sized sensibly for the property modelled and suffers from tank standing heat loss and distribution of hot water losses compared with heated at point of use solutions. Results shown for 7-hour off-peak Tariff only.

3. Dual Immersion Heated 120ltr Capacity Hot Water Tank

This solution uses two immersion heaters, the lower one operated at low rate electricity in an insulated hot water tank sized sensibly for the property modelled and again suffers from tank standing heat losses and distribution of hot water losses compared with heated at point of use solutions. Results shown for for 7-hour off-peak Tariff only.

4. Insulated 120ltr capacity Hot Water Tank heated by an Air Source Heat Pump hydrodynamic system (ASHP)

Results are for a Hot Water tank heated by a wet system that is also used for space heating.

The specific combinations of electric space heating and DHW technologies modelled in FSAP10.1 software as follows:

Type 1: Direct Electric Heating (not underfloor) with Direct at point of use DHW

Type 2: Direct Electric Heating (not underfloor) with single immersion heated tank for DHW

In the SAP methodology these heating systems are type 3 for zone control, zero offset penalty in temperature control accuracy and have a responsiveness of 1.0. Their best tariff option in SAP10.1 is the 10-hour off-peak tariff as opposed to Standard Rate, however results shown for a Standard Tariff.

Type 3: Underfloor in timber floor or immediately below floor covering Direct Type Electric Heating with Direct at point of use DHW

Type 4: Underfloor in timber floor or immediately below floor covering Direct Type Electric Heating with single immersion heated tank for DHW

These heating systems are type 2 for zone control and have a responsiveness of 1.0 when assumed under timber/laminate. Their best tariff option in SAP10.1 is the 10-hour off-peak tariff as opposed to Standard Rate, however results shown for Standard Tariff.

Type 5: High Retention Storage Heaters (HRSH) Electric Heating with Direct at point of use DHW

Type 6: High Retention Storage Heaters (HRSH) Electric Heating with single immersion heated tank for DHW

Type 7: High Retention Storage Heaters (HRSH) Electric Heating with a dual immersion heated tank for DHW

These heating systems are type 3 for zone control and have a responsiveness of 0.8 with zero offset for temperature control accuracy. Their best tariff option in SAP10.1 is the 7-hour off-peak tariff which is used in FSAP modelling.

Type 8: Air Source Heat Pump (ASHP) Electric Heating and Zone Control with Direct at point of use DHW

Type 9: Air Source Heat Pump (ASHP) Electric Heating and Zone Control with single immersion tank for DHW

Type 10: ASHP Electric Heating and Zone Control with Indirect DHW cylinder
These heating systems are type 3 for zone control and have a responsiveness of 1.0. The ASHP has a default efficiency of an equivalent of 170% (including DHW cylinder if used). Its best tariff option in SAP10.1 is a 10-hour low-rate tariff; however, results are shown for a Standard Tariff for better comparison with direct acting system

Type 8MCS: MCS Certified ASHP Electric Heating and Zone Control with Direct at point of use DHW

Type 9MCS: MCS Certified ASHP Electric Heating and Zone Control with single immersion tank for DHW

Type 10MCS: MCS Certified ASHP Electric Heating and Zone Control with indirect DHW cylinder

These heating systems are type 3 for zone control and responsiveness of 1.0. With MCS certificate its system's Seasonal Performance Factor is 219% for Space Heating and 190% for DHW. Again, the best tariff is a 10-hour low-rate tariff, but results are shown for a Standard Tariff for comparison with direct acting electric systems.

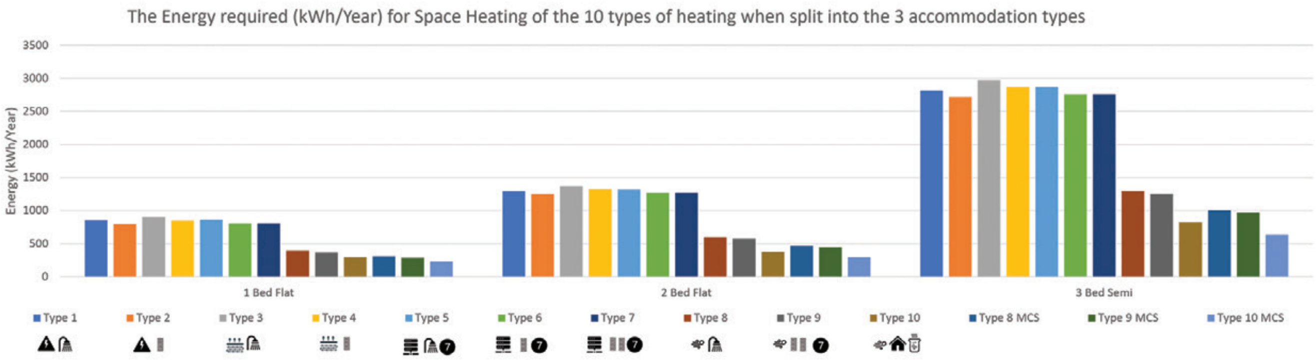
FSAP 10.1 Software Results

Heating Types	
Type 1	Direct Electric with at point of use (@PoU) Domestic Hot Water (DHW) on a Standard Electricity Tariff
Type 2	Direct Electric and Single Immersion Heated Tank on a Standard Electricity Tariff
Type 3	Direct Underfloor (under carpet/timber) with @PoU DHW on a Standard Electricity Tariff
Type 4	Direct Underfloor (under carpet/timber) and Single Immersion Heated Tank on a Standard Electricity Tariff
Type 5	High Retention Storage Heaters (HRSH) with @PU DHW on a 7-hour off-peak Electricity Tariff (E7)
Type 6	HRSH and DHW Single Immersion Heated Tank on E7
Type 7	HRSH and DHW Dual Immersion Heated Tank on E7
Type 8	Air Source Heat Pump with @PU DHW on a Standard Electricity Tariff
Type 9	Air Source Heat Pump and DHW Dual Immersion Heated Tank on E7
Type 10	Air Source Heat Pump for Space Heating and DHW on a Standard Electricity Tariff
MCS	Microgeneration Certification Scheme. Applied to Types 8, 9 and 10

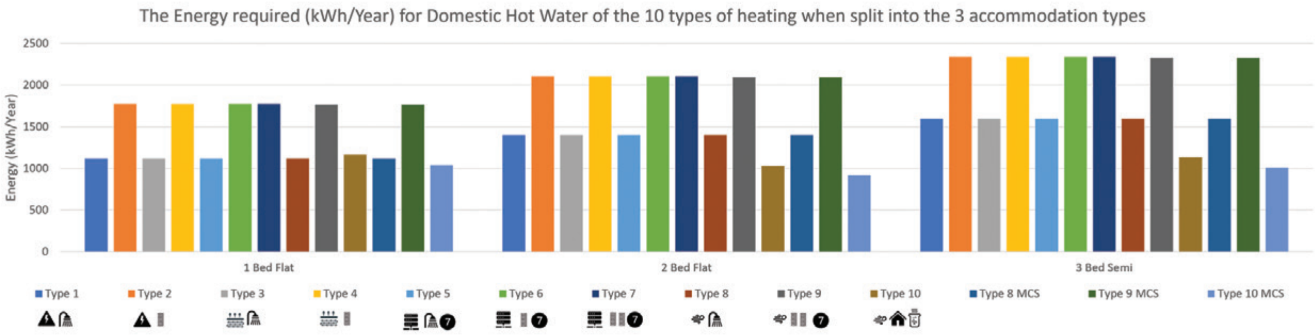
Relative Electric Heating Systems' Energy Performances in kWh (Space Heating / Domestic hot water / Combined)

	SH (kWh/Year)			DHW (kWh/Year)			Total (kWh/Year)		
Heating Type	1 Bed Flat	2 Bed Flat	3 Bed Semi	1 Bed Flat	2 Bed Flat	3 Bed Semi	1 Bed Flat	2 Bed Flat	3 Bed Semi
Type 1	851.96	1295	2818.05	1118.45	1399.59	1599.53	2041.53	2799.62	4563.48
Type 2	797.37	1250.99	2715.96	1775.73	2106.47	2341.71	2644.22	3462.49	5203.57
Type 3	902.29	1370.79	2974.46	1118.45	1399.59	1599.53	2211.86	2995.41	4839.89
Type 4	845.27	1324.26	2868.49	1775.73	2106.47	2341.71	2812.12	3655.76	5476.1
Type 5	862.54	1318.68	2865.29	1118.45	1399.59	1599.53	2052.11	2823.3	4610.72
Type 6	806.51	1272.65	2760.17	1775.73	2106.47	2341.71	2653.36	3484.15	5247.78
Type 7	806.51	1272.65	2760.17	1775.73	2106.47	2341.71	2653.36	3484.15	5247.78
Type 8	392.3	596	1293.24	1118.45	1399.59	1599.53	1701.87	2220.62	3158.67
Type 9	367.97	576.14	1248.01	1766.69	2095.13	2328.78	2325.78	2896.3	3842.69
Type 10	292.13	377.11	820.55	1166.74	1030.27	1134.38	1649.99	1632.41	2220.83
Type 8 MCS	304.11	462.02	1002.51	1118.45	1399.59	1599.53	1613.68	2086.64	2867.94
Type 9 MCS	285.25	446.62	967.45	1766.69	2095.13	2328.78	2243.06	2766.78	3562.13
Type 10 MCS	226.46	292.33	636.09	1041.73	919.88	1012.84	1459.31	1437.25	1914.82

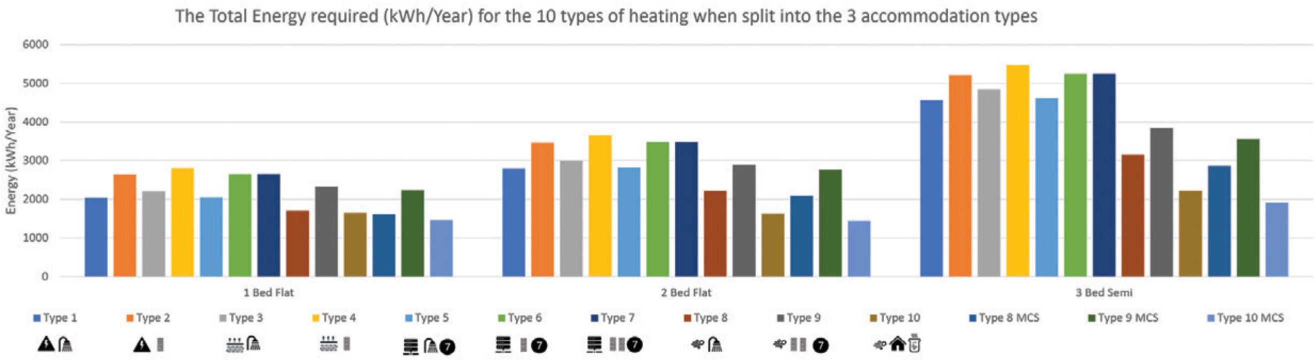
Relative Electric Heating Systems' Space Heating Energy Performances in kWh for each House Type



Relative Electric Heating Systems' DHW Heating Energy Performances in kWh for each House Type



Relative Electric Heating Systems' Total Heating Energy Performances in kWh for each House Type

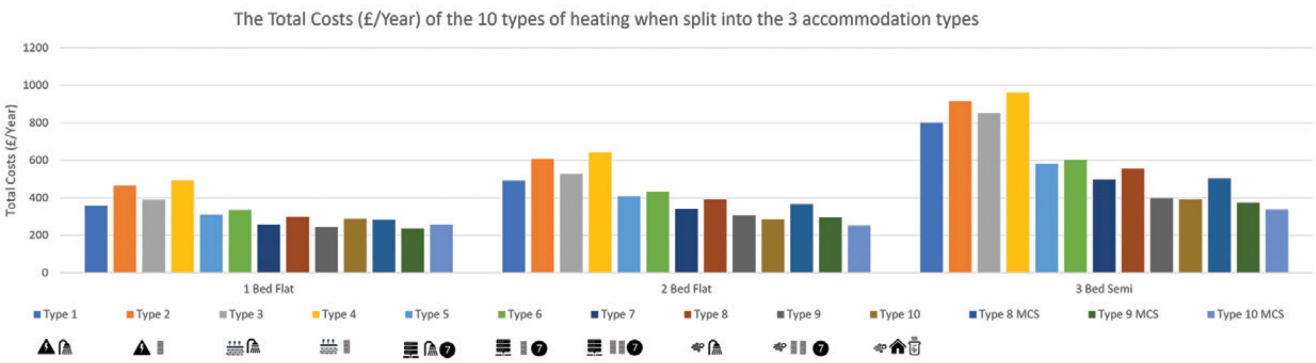


Relative Electric Heating Systems’ Running Cost, CO_2 and PEF Performances as Modelled by FSAP

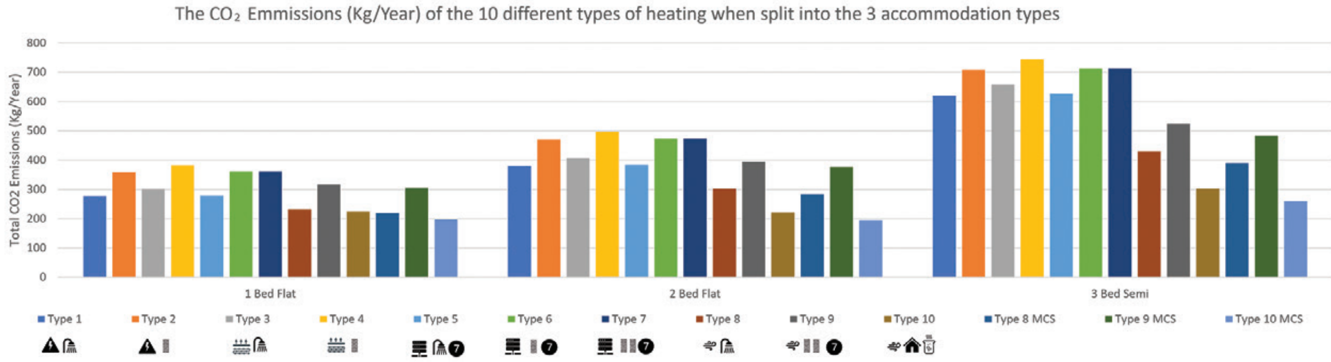
Relative Electric Heating Systems’ Running Cost, CO_2 and PEF Performances as Modelled by FSAP

	Total Cost (£/year			CO² (kg/Year)			PEF (kWh/Year)		
Heating Type	1 Bed Flat	2 Bed Flat	3 Bed Semi	1 Bed Flat	2 Bed Flat	3 Bed Semi	1 Bed Flat	2 Bed Flat	3 Bed Semi
Type 1	358.49	491.61	801.35	277.65	380.75	620.63	3064.34	4202.21	6849.79
Type 2	464.32	608.01	913.75	359.61	470.9	707.68	3968.96	5197.19	7810.55
Type 3	388.4	525.99	849.88	300.81	407.38	658.23	3320	4496.1	7264.68
Type 4	493.81	641.95	961.6	382.45	497.18	744.75	4220.98	5487.29	8219.62
Type 5	309.63	408.02	580.63	279.09	383.97	627.06	3080.21	4237.76	6920.69
Type 6	335.1	432.63	600.55	360.86	473.84	713.7	3982.69	5229.7	7876.91
Type 7	256.62	340.04	498.03	360.86	473.84	713.7	3982.69	5229.7	7876.91
Type 8	298.85	389.94	554.66	231.45	302	429.58	2554.51	3333.13	4741.17
Type 9	243.46	305.65	397.14	316.31	393.9	522.61	3490.99	4347.38	5767.88
Type 10	289.74	286.65	389.98	224.4	222.01	302.03	2476.64	2450.25	3333.46
Type 8 MCS	283.36	366.41	503.61	219.46	283.78	390.04	2422.14	3132.02	4304.79
Type 9 MCS	236.73	295.12	374.33	305.06	376.29	484.45	3366.83	4152.97	5346.76
Type 10 MCS	256.26	252.38	336.24	198.47	195.47	260.41	2190.43	2157.30	2874.16

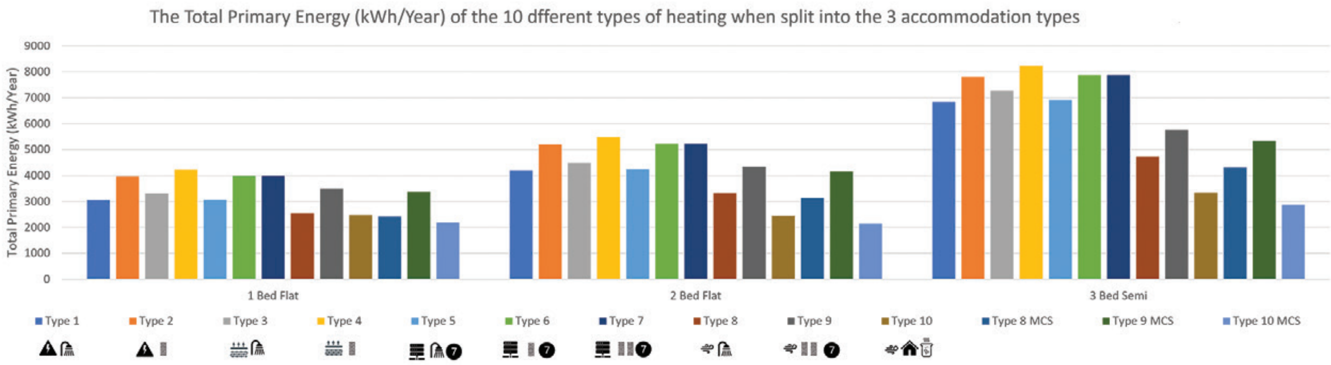
Relative Electric Heating Systems’ Running Cost in £/Year by House Type



Relative Electric Heating Systems' CO_2 Emissions in kg/Year by House Type



Relative Electric Heating Systems' Total PEF in kWh/Year by House Type



The hypothesis that underpinned this study was that for small, well insulated flats and apartments built to the latest building regulations, if fitted with electric resistance heating, the running cost and CO_2 emissions, although in percentage terms would be higher than if fitted with a heat pump, in absolute terms the impact on the occupant's heating system total costs would be marginal.

The results demonstrate that for a typical one- or two-bedroom flat or apartment built to the latest building regulation standards, and with a floor area of up to $65m^2$, the running cost differential between a house fitted with an electric resistance heating system compared with an MCS certified heat pump can amount to as little as £73 per year or £2 per week.

Given that electric resistance heaters systems have an average lifespan of in excess of 25 years, the contention is that for properties of this type, the capital cost premium to fit a heat pump instead of electric resistance heating, combined with the servicing cost and replacement cycle differentials make the economic justification extremely difficult.

However, for the larger 3 bed property which was modelled, the choice of a heat pump for space and water heating in preference to electric resistance heating, in economic and emission terms, is demonstrably more defensible.

The results also clearly show that for the smaller property types, domestic hot water plays a very significant role in total heating cost and CO_2 emissions, in most cases overshadowing the space heating contribution. Significantly, aside from when using certain heat pump systems, employing instantaneous water heating such as electric showers instead of stored hot water, offers a notable reduction in costs and emissions in every situation, and this advantage is carried over in SAP which rewards instantaneous over stored hot water for small property applications.

Professor Counsell's Observations and Discussion (A Constructive Criticism of SAP10.1)

To model underfloor electric heating the "in timber floor, or immediately below floor covering" application in SAP is used. This models the system with a responsiveness of 1.0, but zone control is restricted to Type 2. However it would seem that the underfloor solution needs to be better modelled to:

> First take into account the large warm surface area thermal comfort benefit. This requires a dynamic simulation analysis to prove the energy efficiency benefits of a large warm surface enabling an air temperature reduction to achieve a thermal comfort temperature of 21°C. This needs discussion with BRE using the Appendix Q process.

There is concern regarding Tables 12e and 12d values in SAP 10.1 for monthly high and low rate electricity prices, CO_2 Factors and PEF showing for different tariffs. As previously stated, this is a somewhat strange approach as ability to take advantage of grid reflective incentives is a technology not an electricity pricing impact. i.e. it is the ability of a technology to store energy and control its utilisation, not the electricity's price, this is consequence not a cause.

Furthermore, the tables are not numbers that relate closely to today's (i.e. 2021) national grid figures taking into account electricity transmission losses and any standby generation. The derivation of these figures should be openly and peer reviewed before use. If they are based on predictions, this should be challenged as DECC/BEIS predictions of national grid energy mix and demand trends have been extremely poor on a 10 year forward looking horizon. It would be safer and more accurate to update the tables annually based on a previous 3-year moving average. For example, according to government department's electricity demand of the national grid was estimated in 2009 to have now doubled by 2012, when in actual fact it is down more than 30% on 2009 levels. There is clear danger in regulating on what might be rather than what is!

Future Updates and further modelling to assist with SAP2011

The Excel and FSAP models created in this study have been and will continue to be shared openly with the University of Chester's Digital Energy and Control System research group DECS. The group will continue the work with the following activities and updates:

1. **FSAP10.2 software result updates**
2. **A thorough revision of sensible air change rates used especially in flats.**
3. **Addition of 10-hour tariff results and analysis.**

A further research study will use Chester's iDEM dynamic modelling method to investigate the impact on system responsiveness and control accuracy of modelling the impact of large warm surfaces on thermal experience. This study will also result in a journal paper submission in Summer '22.

Author’s Biography

ADVANCED CONTROL PARTNERSHIPS

Professor John M Counsell is the Managing Director of Advanced Control Partnerships Limited and Director and Professor of Digital Energy and Control Systems Research Group at the University of Chester. He was previously BRE’s Chair for Energy Utilisation at the University of Strathclyde and a member of the SAP Scientific Integrity Group. He was the R&D group manager for advanced domestic electric heating solutions for the electricity industry at EA Technology 1994 to 1997 and was awarded the Churchman Prize for his business and innovation leadership and invention of Control ELECTric (CELECT, now used in SAP) for introducing Demand Side Response (DSR) measures in to electric heating in 1995/6.

Author’s signature

Professor John M Counsell MIET.
Advanced Control Partnerships Limited
54 Grange Cross Lane
Wirral
CH48 8BQ
Email: JohnC@advancedcontrol.co.uk

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