Lifecycle cost and operational carbon of heating systems in a student accommodation application

Michael Lim PhD, BEng(Hons), CEng, MIMechE (michael.lim@aecom.com) and
SIMON LAW BENG(HONS), CENG, MCIBSE, AECOM LTD
Chris Goggin, BSc, MEnt, Rinnai UK Limited

Abstract
A real-life case study of a large student accommodation was carried out to investigate the combination of various gas and electricity heating solutions to determine the respective system capital costs and the lifecycle operational cost, fuel consumption and CO2 emission over a 20-year period.
The study demonstrated that the combination of continuous flow hot water heating with a range of gas and electricity space heating results in a relatively more efficient solution in terms of cost, fuel and CO2. The study also highlighted that distribution and storage heat losses present an opportunity for improvement.

The study also includes the impact of projected grid decarbonisation and changes in energy cost going into the future, giving useful insight on the impact of solution choice on lifecycle performance of building heating systems.

1.0 Introduction
A study was carried out to revisit some of the widely-applied conventions of system solutions to identify opportunities for improvement. This paper describes a joint-study to review the various heating systems typically encountered in the industry today.

The study is based on a real life large student accommodation where the application of various combinations of gas and electricity space heating and hot water systems were investigated to determine the respective system capital and lifecycle operational costs, fuel consumption and CO2 emission over a 20-year period.

2.0 Systems
The study compared the baseline system solution of Low Temperature Hot Water (LTHW) gas boiler for centralised space heating and domestic hot water (DHW) generation against alternatives of continuous flow water heaters, electric heating and air source heat pumps. Table 1 outlines the options that were considered.

Table 1 – Solution options investigated

	Space heating	Domestic hot water (DHW)
Baseline	LTHW with gas boiler	Indirect storage with gas boilers
Option 1	LTHW with gas boiler	Continuous flow water heater
Option 2a	Electric resistance	Electric resistance
Option 2b	Electric resistance	Continuous flow water heater
Option 3a	LTHW with air source heat pump (ASHP)	Air source heat pump (ASHP)
Option 3b	LTHW with air source heat pump (ASHP)	Continuous flow water heater

3.0 Building heating demand

The student accommodation block estimated space heating demand was generated using a dynamic thermal model, which equates to 445 MWh/pa excluding storage and distribution losses. The model was run with CIBSE Test Reference Year for London, and complies with the UK Building Regulations Part L 2013 requirements.

The pipe heat loss are applied to the corridors and risers and varied seasonally with the heating demand and adjusted for both mean corridor temperatures as well as for weather compensation. The daily DHW demand is based on a usage rate of 70 l/person/day and a total of 643 persons, amounting to 1733kWh/day (55K lift). The DHW demand varied seasonally corresponding to typical university term and the incoming cold water temperature is varied in-line with the average ground temperature at 1.5m deep. Overall, the annual demand for DHW is around 536 MWh/year, before allowing for storage and distribution losses.

4.0 Results

4.1 Initial and annual costs

Table 2 shows a high-level comparison of annual energy consumption and estimated capital and annual maintenance costs. The options have been ranked (in brackets) for best performance or most favourable solution (bold) and the overall optimal solution is "green" highlighted. A breakdown of the capital costs is shown in Figure 1. Costs are derived from Spon's price book 2017 (1) and data from manufacturers.

Table 2 – High level comparison of annual energy consumption and costs

	Natural gas (MWh/year)	Electricity (MWh/year)	Initial capital costs	Annual fuel costs	Annual maintenance costs
Baseline	1,503	14.8	£432,051 (4)	£50,079 (3)	£875 (4)
Option 1	1,415	13.4	£399,315 (3)	**£46,926 (1)**	£850 (2)
Option 2a	0	1,178	£241,506 (2)	£148,323 (6)	**£300 (1)**
Option 2b	759	450	**£198,474 (1)**	£81,614 (5)	£850 (2)
Option 3a	0	609	£849,595 (6)	£74,273 (4)	£1,575 (5)
Option 3b	759	210	£698,773 (5)	£49,413 (2)	£2,125 (6)

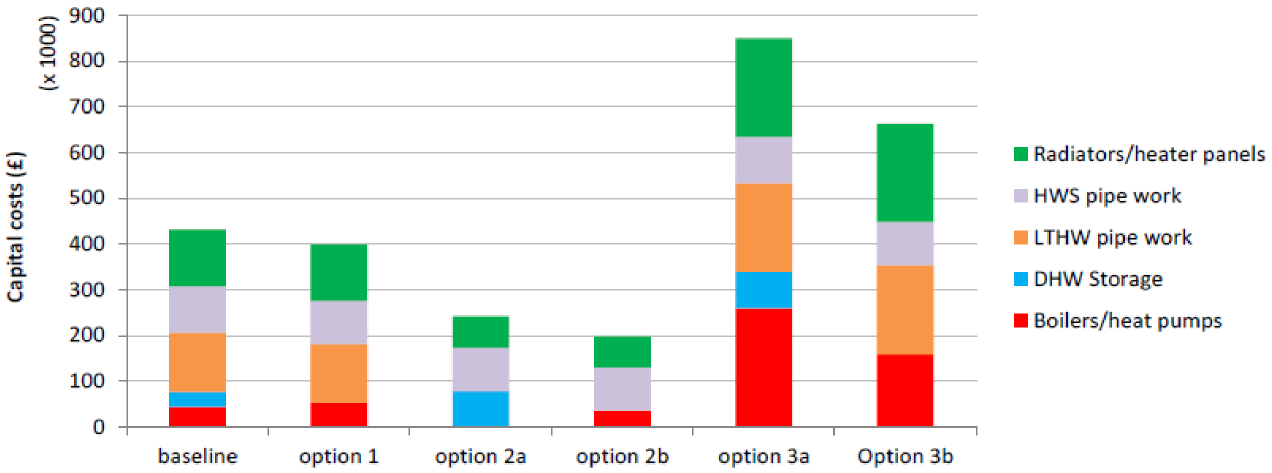

Figure 1 Breakdown of capital costs for each option considered

4.2 Lifecycle performance

The lifecycle comparison was carried out for a 20-year period based on the expected system service life prior to any replacement. The net present value (NPV) calculation was based on a discount rate of 3.5% (The GREEN BOOK - HM Treasury) and an inflation rate of 2% for servicing costs. The analysis also used projected retail fuel costs and equivalent CO2 emissions factors (CO2e) for electricity published by the Department of Energy and Climate Change (DECC).

As no reliable projections were found when carrying out this work, the equivalent gas CO2 emission factor was fixed at 0.184 kgCO2e/kWh based on the UK Government GHG conversion factors for company reporting. Table 3 compares the options in terms of lifecycle cost and operational CO2e emissions, where Option 1 has the lowest cost, while Option 3a has the lowest CO2e emission by a significant margin. However, Option 3b with ASHP and continuous flow water heater is shown to be the optimal solution in terms of overall lifecycle performance. From lifecycle cost point of view, 16% uplift results in 38% reduction in lifecycle CO2e emissions.

Table 3 – Net present value and CO_{2e} emissions over 20 years

	NPV	% savings	CO_{2e} (tonnes)	% savings
Baseline	£1,356,096 (2)	0%	5,439 (6)	0%
Option 1	**£1,265,765 (1)**	-7%	5,102 (5)	-6%
Option 2a	£2,756,263 (6)	103%	3,943 (3)	-38%
Option 2b	£1,625,863 (4)	20%	4,299 (4)	-25%
Option 3a	£2,103,487 (5)	55%	**1,974 (1)**	-69%
Option 3b	£1,573,411 (3)	16%	3,443 (2)	-38%

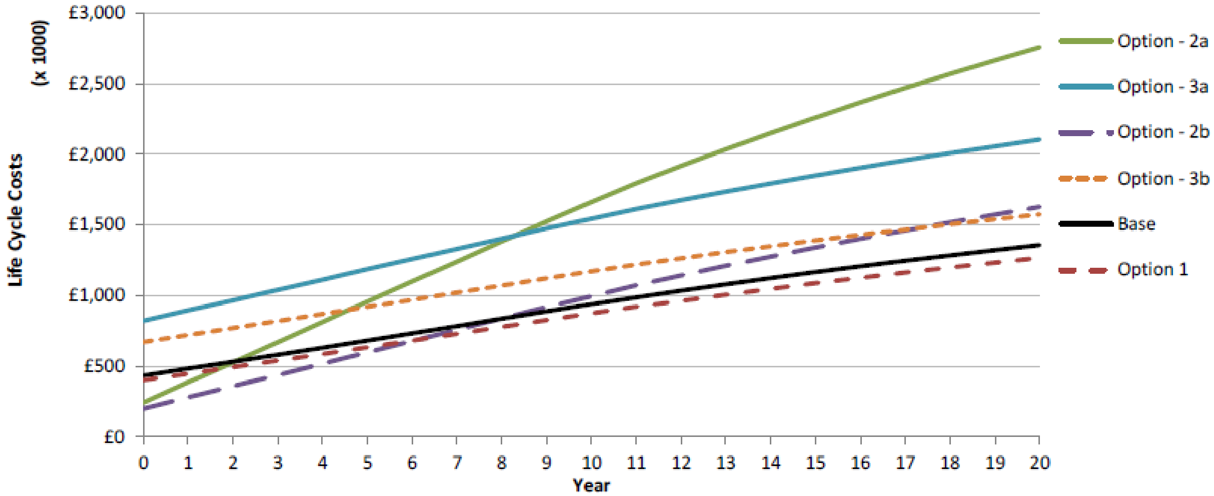

Figure 2 – Comparison of NPV trajectories between each option considered

5.0 Discussion and concluding remarks

Despite much lower capital cost, electric panels in Option 2a and 2b have led to high operational cost and hence higher NPV against baseline. In both cases of electric panel and heat pump space heating, Option 2b and 3b demonstrated improved NPV when using continuous flow water heaters instead of electric-based water heaters.

In terms of energy performance and costs, separating the space heating and DHW allows each system to operate more efficiently. In both the base case and Option 1, there are modulating condensing boilers with weather compensation, but whenever there is simultaneous requirement for space heating and DHW, the base case boilers will not operate as efficiently because the DHW results in higher return water temperatures to the boilers. The seasonal efficiency of the base case boilers doing both heating and DHW is around 89%, compared to the seasonal efficiency of the space heating boilers in Option 1 at around 91%, while the continuous flow water heaters is around 95% as these are optimised for hot water generation.

A similar effect is seen between the options with heat pumps, where Option 3a with ASHP providing both space heating and DHW has a Seasonal Coefficient of Performance (SCoP) of around 2.4, compared with 3.1 in Option 3b where the ASHP only provides space heating.

The costs of distribution pipework generally dominates the capital costs, which is why the options with electric panel heating have the lowest capital costs (at the expense of high energy costs and overall lifecycle costs). Between systems with hot water storage and those with continuous flow water heating, the capital cost is generally in favour of the latter due mainly to the savings from not requiring storage cylinders.

The operational CO2e emissions over 20 years show dramatic differences between gas and electric based heat sources, with Option 3a generating around a third of the CO2e of the base case, with electric-based heating shown to be lower carbon over the medium/long term than gas-based solutions. The projected changes in CO2e intensity seems fairly optimistic and would require continual investment and the uptake in renewable technologies over the longer term to deliver the projected grid decarbonisation, which will be highly dependent on political and economic pressures. Furthermore, in practice, there is unlikely to be sufficient capacity for major shifts in heating fuel from gas to electric due to the limited capacity of the national grid, unless this is supported by urgent aggressive investment in the relevant infrastructure.

The analysis of the annual heat losses in the distribution pipe work show that the heat loss through the space heating pipes is between 22% and 25%, while for DHW pipe work it varies from 35% to 39%. This indicated potential savings could be achieved through distributed instead of centralised generation, both in terms of energy and capital costs due to reduction of distribution pipework.
se and greenhouse gas emissions for appraisal, 7 June 2017

The study has shown that the various parameters considered vary significantly depending on system type and hence for a more informed view, a lifecycle approach is required. It is prudent to revisit and review the compatibility of current system solutions, accounting for lifecycle factors such as the projected shift in grid carbon content and energy costs, so to be able to make any noticeable improvement in the long term resource efficiency of the built environment.

Acknowledgement
The authors would like to acknowledge input and funding provided by Rinnai UK Ltd.

References
(1) AECOM, *Spon's Mechanical and Electrical Services Price Book 2017*, CRC Press
(2) *The Green Book*, HM Treasury, 2003
(3) *Data tables 1-19, The Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal*, 7 June 2017