Energy and Buildings 54 (2012) 160–168

Contents lists available at SciVerse ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Production efficiency of hot water for domestic use

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ARTICLE INFO

Article history:
Received 14 March 2012
Received in revised form 6 June 2012
Accepted 16 July 2012

Keywords:
Hot water storage
Domestic hot water
Solar water heating
Legionella

ABSTRACT

This paper examines the efficiency (in terms of energy use and carbon emissions) with which 5 different types of domestic water heating systems employed in the UK are able to produce hot water for sanitary use. A method of normalisation is employed allowing results from case studies with different systems and usage levels to be compared. Water heating appliances studied include gas boilers, a micro CHP, heat pumps, an immersion heater, and a solar thermal system. It is found that instantaneous production of hot water is much more efficient than delivery via tank storage for gas-fuelled systems. For electrical systems, an immersion heater is found to perform better in some circumstances than heat pumps and also has advantages when combined with a solar thermal system leading to the proposal that this combination offers the most potential as a low carbon method for domestic hot water provision in the long term. Opportunities are identified to improve the performance of all systems with storage through better control of heat inputs. Inconsistencies in, and problems of compliance with, established standards for mitigation of *Legionella* in hot water systems are also identified.

1. Introduction

Regulatory measures aimed at mitigating climate change and economic pressures from rising fuel costs are motivating increased energy efficiency within the UK residential sector, which accounts for 32% of UK final energy consumption [1] and a similar proportion of CO_2 emissions. Historically space heating has been the major use of energy in UK homes amounting to 61% of the total in 2009 (Fig. 1), while water heating, appliances, lighting and cooking comprise the balance. However, as standards of insulation improve with retrofit programmes initiated under the UK Low Carbon Transition Plan [2] this element can be expected to fall. Realisation of the policy goals in this plan such as 80% reduction in UK CO_2 emissions by 2050, with no emissions at all from the domestic sector, is therefore likely to require attention to these secondary energy uses. As the third largest element water heating is clearly worthy of detailed examination.

This paper focuses on the energy consumption involved in the production and use of domestic hot water for washing and other sanitary purposes, with the aim of comparing efficiency and carbon intensity across the range of water heating systems commonly installed and identifying opportunities for improvement and implications for policy. Table 1 provides a demographic summary of current fuel and system types derived from the 2009 English Housing Survey (Department of Communities and Local Government (DCLG) [3]. A critical distinction made in Table 1 is between those systems which include a tank for storage of hot water (55% of the total), and those where hot water is produced on-demand (45%). The existence of a tank provides opportunities for fuel diversity and optimisation of efficiency which are discussed later, but results in some level of unavoidable losses arising from a standing volume of hot water. Some other points of clarification to aid interpretation of the table are:

- “Economy 7” refers to a electricity tariff option available in the UK under which electricity is supplied within a 7 h overnight time window at a lower cost and also lower carbon intensity.
- “Combi” refers to a type of gas boiler which provides space heating by circulating hot water through a radiator network and heats water directly from the mains supply to deliver domestic hot water on demand.
- “Other fuels” comprise oil and solid fuels such as coal or biomass.

Because of the complexity of instrumentation and analysis required to quantify the amount of hot water used in a household and the energy consumed to provide it the approach adopted for the present work comprises a set of 7 case studies. Each case is a single household and water heating system for which hot water use and energy inputs have been analysed in detail for a sufficient

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0378-7788/$ – see front matter
http://dx.doi.org/10.1016/j.enbuild.2012.07.011

Table 1
Populations of different water heating methods in England [3].

System type	Storage (S) or instantaneous (I)	Number of dwellings (000s)	Proportion of total (%)
Electrically heated, on-demand	I	340	1.5
Electric immersion heater, normal tariff	S	612	2.7
Electric immersion heater, Economy 7	S	1673	7.5
Gas fired non condensing “combi” or water heater	I	5498	24.8
Gas fired condensing “combi”	I	4061	18.2
Gas fired non condensing with tank	S	7653	34.3
Gas fired condensing with tank	S	1331	6.0
Other fuels with tank	S	1122	5.0

number of days to estimate the performance of the system used. By performing this analysis across a range of system types it has been possible to draw some more general conclusions based on the inherent physics of the system engineering and results from other studies that have investigated patterns of hot water use. Some of the case studies include system types (micro CHP and heat pumps) which are relatively novel in the UK and for which comparative data on hot water production efficiency is useful to assess their potential benefits in larger scale use. All of the systems studied had been installed on a retrofit basis and had been in operation for at least two years so they exemplify performance currently achieved in practice rather than optimum performance for each system type.

The rest of the paper is organised as follows. Section 2 summarises the user demand patterns and regulatory requirements applicable to hot water systems in the UK, drawing out a particular issue concerning protection against *Legionella* risks. Section 3 describes the systems studied and the methodology for normalisation of results. Section 4 presents results in terms of energy efficiency and carbon dioxide emissions for the fuel-using systems when operated on their own and in combination with solar hot water heating. Sections 5 and 6 discuss the implications of these results and the conclusions for policy and installation practice.

2. Background

2.1. Hot water use

A detailed investigation of current patterns of domestic hot water use in the UK was performed by the Energy Saving Trust (EST) who monitored 120 dwellings in 2008 [4]. They found average hot water consumption per household varying from less than 25 L/day to over 300. They were able to derive a model relating daily volume used in litres V to the number of occupants N:

$$V = 46 + 26N \quad (1)$$

with standard errors of ±22 on the intercept and ±7 on the slope. This model is used later to assess the suitability of each system type for different household sizes. It is reasonably consistent with

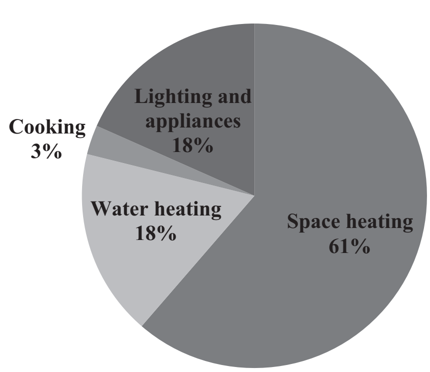

Fig. 1. UK domestic energy consumption by end use in 2009 [1].

an alternative simple model of 53 L per occupant per day proposed by Yao and Steemers [5] but seems more plausible since there will tend to be some economy of scale for larger households.

The UK’s strategy for water provision “Future Water” (Department for Environment, Food and Rural Affairs, DEFRA) [6] seeks to drive down overall domestic water consumption from 150 L per person per day to 130 L by 2030. Measures include the Code for Sustainable Homes [7] which specifies hot water saving features such as aerating showers and taps for new buildings. However Critchley and Phipps [8] identify trends for increased hot water use in existing homes through more frequent showering and installation of shower pumps. The introduction of universal metering by 2030 envisaged by DEFRA [6] and the development of standards for water consuming products under the Market Transformation Programme [9] are aimed at mitigating these trends.

2.2. Safety requirements

The critical mandatory safety requirements for provision of domestic hot water in the UK are specified in Building Regulations Part G [10]. These focus on preventing water boiling anywhere in the system through safety cut-out mechanisms controlling all heat sources that operate independently of thermostatic control. They also seek to prevent scalding from delivery of water at too high a temperature at the tap by requiring mixer valves to be employed such that the distribution temperature is limited to 60 °C and the water emerging from a bath tap does not exceed 48 °C. More detailed interpretations of the law and implementation recommendations are given in British Standard 6700 [11] invoked by [10] which also introduces the need for hot water systems to include measures to reduce risks from bacteria particularly *Legionella*. Paragraph 5.6.3 includes the commentary “In order to reduce the risk of colonisation . . . hot water should be stored and distributed at a temperature of not less than 60 °C”. Clearly a practical system with temperature tolerances on mixing valves and thermostats would be unable to satisfy both this requirement and Part G. Since the commentary is taken from a Health and Safety Executive Code of Practice [12] for controlling *Legionella* in workplaces and public buildings it is perhaps not surprising that it is not easily applied to the domestic environment.

None of the systems monitored for this study maintained hot water continuously at 60 °C and for systems with storage, draw-off volumes per day were often greater than the volume of the tank. Since no part of the storage volume was maintained permanently at 60 °C, none of the systems could assure that all water delivered had at some time been raised to 60 °C. System hot water delivery temperatures (i.e. prior to any mixing for avoidance of scalding) ranged from 40 °C to 68 °C. The EST study [4] also found that delivered hot water temperatures ranged from below 42 to above 62 with a mean of 52 °C, with “combi” systems having a lower average temperature (49 °C) than systems with tank storage (53 °C). These temperatures cover both the range at which references such as [12] advise *Legionella* flourish (35–45 °C) and that where they are killed