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Energy consumption modeling of air source electric heat pump water heaters

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ABSTRACT

Electric heat pump air source water heaters may provide an opportunity for significant improvements in residential water heater energy efficiency in countries with temperate climates. As the performance of these appliances can vary widely, it is important for consumers to be able to accurately assess product performance in their application to maximise energy savings and ensure uptake of this technology. For a given ambient temperature and humidity, the performance of an air source heat pump water heater is strongly correlated to the water temperature in or surrounding the condenser. It is therefore important that energy consumption models for these products duplicate the real-world water temperatures applied to the heat pump condenser.

This paper examines a recently published joint Australian and New Zealand Standard, AS/NZS 4234: 2008; Heated water systems – Calculation of energy consumption. Using this standard a series TRNSYS models were run for several split type air source electric heat pump water heaters. An equivalent set of models was then run utilizing an alternative water use pattern. Unfavorable errors of up to 12% were shown to occur in modeling of heat pump water heater performance using the current standard compared to the alternative regime. The difference in performance of a model using varying water use regimes can be greater than the performance difference between models of product.

1. Introduction

New Zealand has very low carbon emissions from electricity generation. Renewable sources led by hydro-electricity provide approximately 65–75% of annual requirements depending on rainfall patterns [1]. The standard water heater in New Zealand homes is generally an internally installed storage tank with an electric resistance element [2]. Newly installed product requires [3] thermal insulation to meet a stringent standing heat loss test to pass the required Minimum Energy Performance Standard (MEPS). There is therefore little scope for improvements in energy efficiency and greenhouse gas reductions from incremental improvements to this technology. Solar thermal systems have been tried in New Zealand for many years. These have been unsuccessful as a mass market product. Factors contributing to this include; domestic electricity tariffs' at a level where savings from solar will not payback capital cost over the equipment life making installation uneconomic, small market size, and a complete lack of standardization in house building methods resulting in almost every installation having some bespoke aspect. In addition to this there is an absence of meaningful government subsidies as the standard electric water heater accounts for minimal greenhouse gas emissions.

Air source electric heat pump water heaters (EHPWH) appear to be an attractive technology to make useful reductions in domestic energy use. Approximately two-thirds of the four million population of New Zealand live in temperate coastal climate areas suitable for this type of technology. These water heaters have recently received a raised profile in the New Zealand marketplace from a pilot subsidy scheme offered by the Energy Efficiency and Conservation Authority (of the Government of New Zealand). At the same time a local consumer-rights organization published a study of these products which reported mixed performance results [4]. Of five models tested, only one performed adequately for all climate zones in New Zealand, two were acceptable in warmer areas but on a par with electric storage in cold areas and of the remaining two, one switches to electric resistance heating at 7 °C so would provide useful savings only in warm areas while the other continued to operate at colder temperatures but at a COP of 0.5.

The mixed results of the consumer study highlighted how important it is for the performance of products to be able to be clearly determined by potential customers. There is currently no requirement for suppliers to represent their product in any particular manner. Some manufacturers use peak COP figures under favorable conditions to promote their products. Others use a seasonal COP

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Nomenclature

AS/NZS joint Australian and New Zealand standard
COP coefficient of performance
DR AS/NZS final draft of joint Australian and New Zealand standard not yet published
EHPWH air source electric heat pump water heater
HEEP household energy end-use project
MEPS minimum energy performance standard
TRNSYS University of Wisconsin transient system simulation program

modeled figure but for the heat pump unit only ignoring losses from the storage vessel.

The recent introduction of joint Australian and New Zealand standards for both the evaluation of EHPWH performance [5] and calculation of annual energy consumption provides a basis for comparisons to be made between products. It is important for consumers relying on the evaluations of these standards, that they provide a robust manner to compare not only different designs of heat pump water heater, but also heat pump water heaters with other technologies modeled using the same standard.

This paper examines the energy consumption modeling for air source EHPWHs, in particular "split" systems, where the heat pump is located outside and the storage vessel indoors which is typical for New Zealand dwellings [6]. The heat pump condenser consists of a heat exchanger with the refrigerant on one side and potable water drawn from the storage cylinder passed through the heat exchanger and returned to the storage cylinder by a circulating pump built into the appliance as shown in Fig. 1.

The performance of a product to be modeled is first measured using DR AS/NZS 5125 [7] over a heating cycle from cold under four specified sets of initial water temperature, ambient temperature and ambient humidity conditions. AS/NZS 4234: 2008 [8] is then used to determine the standardized annual energy consumption. This standard employs TRNSYS [9] to model the annual energy consumption using typical meteorological year data (TMY) for the region being considered, the characteristic equations of individual product performance generated by DR AS/NZS 5125, and standardized hot water use information contained within AS/NZS 4234 for dwellings with varying numbers of occupants.

The determined energy consumption is compared with the energy consumed by a baseline product under similar load and atmospheric conditions. For electric products this is a storage water

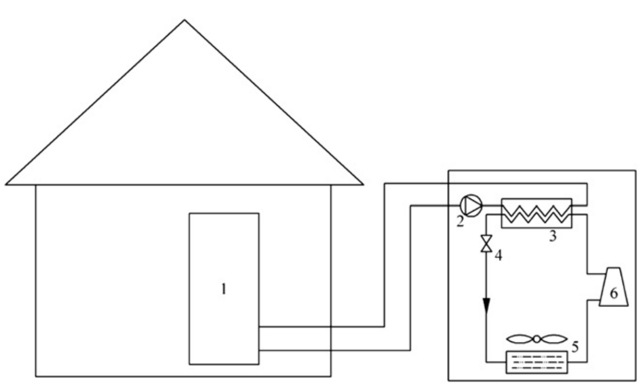

Fig. 1. Schematic of a "split" air source electric heat pump: (1) storage vessel; (2) circulating pump; (3) condenser/heat exchanger; (4) expansion valve; (5) evaporator; (6) compressor.

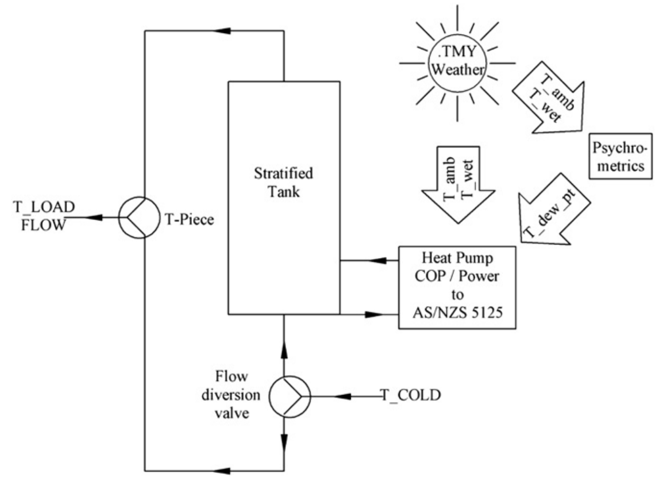

Fig. 2. TRNSYS energy consumption model schematic for EHPWH.

heater with a resistance heating element and for products incorporating supplementary gas heating, a gas storage water heater. The savings shown by the comparison can be used as the basis for government subsidy and consumer marketing. The standardized hot water loadings specified by AS/NZS 4234, the T_LOAD (load temperature) and FLOW parameters of Fig. 2, are examined in this paper to determine the effect on modeled product performance. For the purpose of this study, comparisons were confined to the requirements for a medium size dwelling (4–5 occupants) in the North Island of New Zealand. A similar effect could be expected for other climate areas, however variations are likely to be less with fewer occupants and correspondingly greater for larger house sizes.

2. Standard water use profile

Appendix B of AS/NZS 4234 sets out the water use information for the various dwelling sizes. The maximum net energy delivered from the outlet of the water heater on the peak day of the year is defined. This has been determined to be in August for New Zealand. Each other day of the year then has its energy consumption scaled with reference to this peak day. These values were established by the standards committee with assistance from an analysis [10] of the New Zealand Household Energy End-use Project (HEEP) data by the Building Research Association of New Zealand. The established annual energy use for a medium size dwelling of 11 GJ/annum is broken down into daily time of use data using the information shown in Tables 1 and 2. The standard specifies water should be delivered from the storage cylinder at a temperature of no less than 45 °C. When pipe losses between the storage vessel and fixtures are

Table 1
Standard water use parameters for modeling.

Month	Cold supply (°C)	Hot delivery (°C)	Seasonal scaling	Peak day energy use (MJ/day)
Jan	20	45	0.51	39
Feb	21		0.58	
Mar	19		0.60	
Apr	17		0.72	
May	15		0.83	
Jun	12		0.89	
Jul	11		0.99	
Aug	11		1.00	
Sep	13		0.90	
Oct	15		0.83	
Nov	17		0.76	
Dec	19		0.65	