Energy and Buildings 68 (2014) 696–702

Contents lists available at ScienceDirect

Energy and Buildings

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

Towards the development of new energy performance indicators for the external walls of residential buildings

Larry Bellamy*

School of Property, Construction and Project Management, RMIT University, GPO Box 2476, Melbourne, VIC 3001, Australia

ARTICLE INFO

Article history:
Received 24 January 2013
Accepted 27 August 2013

Keywords:
Wall
Energy
Performance
Indicator
U-Factor

ABSTRACT

This paper assesses nine types of dynamic and equivalent *U*-factors for their ability to predict the relative energy performance of different types of external walls, with varying levels of insulation, thermal mass and solar absorptance, when used in housing. A simulation analysis is undertaken to determine the energy performance of different wall designs at eight cities, and to determine the dynamic and equivalent *U*-factors of those walls. The results show that there is a strong correlation ($R^2 > 0.7$) between wall energy performance and the equivalent *U*-factor at all but the coldest of the locations. The equivalent *U*-factor shows promise as a wall energy performance indicator for global housing.

1. Introduction

The *U*-factor and *R*-value are used in building regulations around the world to prescribe minimum levels of insulation in building envelopes deemed to have acceptable energy performance. Due to their legal status these metrics have become deeply embedded in the building industry and are routinely used in building design. Further, it appears they are treated as de-facto indicators of the energy performance of building envelopes. However, they are ill-suited for this purpose because they do not account for the effects of thermal mass and solar heat gain on energy performance [1]. Nor do they provide information about the nonlinear relationship between insulation level and energy performance, let alone the possibility that performance may actually reduce with increasing insulation [2].

The aim of this research is to identify a metric that can be developed into a useful wall energy performance indicator for housing worldwide. The dynamic *U*-factor, which is the inverse of the dynamic *R*-value [3], and the equivalent *U*-factor [4] are assessed in this paper. These metrics were selected because they satisfy important criteria: they are simple; they account for the effects of thermal mass, solar heat gain and insulation on heat transmission through the building envelope; and they can be determined by experimental or analytical methods. Further, the *U*-factor is widely understood, which should help these metrics to be accepted by the building industry if they prove suitable for use as energy performance indicators. The objective of this paper is to determine the ability of dynamic and equivalent *U*-factors to predict the relative energy performance of different wall designs in different types of climates.

* Tel.: +61 3 99253907; fax: +61 3 99251939.
E-mail address: larry.bellamy@rmit.edu.au

2. Dynamic and equivalent *U*-factors

2.1. Definitions

The dynamic *U*-factor of a wall is defined as its apparent *U*-factor. Over a period of n hours the mean dynamic *U*-factor, U_D, may be found from:

$$U_D = \frac{\sum_{i=1}^{n}(Q_{w,i}/\Delta T_i)}{3600 A_w n} \ (\mathrm{W/m^2\,K}) \quad (1)$$

where $Q_{w,i}$ (J) is the conduction at the wall's interior surface (+ve towards the exterior) during the *i*th hour, A_w (m^2) is the wall area and ΔT_i (K) is the mean indoor–outdoor air temperature difference during the *i*th hour.

The equivalent *U*-factor of a wall is defined as its apparent *U*-factor when the adjacent building space requires auxiliary heating or mechanical cooling. This metric should be superior to the dynamic *U*-factor because it is based on conduction during heating and cooling events. The mean equivalent *U*-factor, U_E, over a period of n hours may be found from:

$$U_E = \frac{\sum_{i=1}^{n} a_i (Q_{w,i}/\Delta T_i)}{3600 A_w n_{aux}} \ (\mathrm{W/m^2\,K}) \quad (2)$$

where n_{aux} is the number of hours during which auxiliary heating or mechanical cooling is required and a_i equals 1 if auxiliary heating or mechanical cooling is required during the *i*th hour, otherwise it

0378-7788/$ – see front matter
http://dx.doi.org/10.1016/j.enbuild.2013.08.057

Table 1
Interior boundary conditions.

Boundary type	Solar irradiance (W/m^2)	Indoor air temperature (°C)			
		00–06 h	06–12 h	12–18 h	18–24 h
C20	0	20	20	20	20
V18	0	18	20	22	20
V16	0	16	20	24	20

Table 2
Dynamic and equivalent *U*-factor variants.

	Interior boundary (see Table 1)	Heating balance temp. (°C)	Cooling balance temp. (°C)
Dynamic U-factor			
U_{dC20}	C20	–	–
U_{dV18}	V18	–	–
U_{dV16}	V16	–	–
Equivalent U-factor			
$U_{eqC20\text{-}10}$	C20	10	22
$U_{eqC20\text{-}15}$	C20	15	22
$U_{eqV18\text{-}10}$	V18	10	22
$U_{eqV18\text{-}15}$	V18	15	22
$U_{eqV16\text{-}10}$	V16	10	22
$U_{eqV16\text{-}15}$	V16	15	22

equals 0. The equivalent *U*-factor may be interpreted as the *U*-factor of a massless wall that, in the absence of any solar heat gains, has the same energy performance as the actual wall.

The energy performance of a wall is defined here as the thermal load imposed on heating and mechanical cooling equipment due to conduction within the wall.

2.2. Hourly conduction

Hourly conduction $Q_{w,i}$ is determined using prescribed boundary conditions at the wall's interior and exterior surfaces. This approach standardises the method for determining the dynamic and equivalent *U*-factors and makes them independent of building design and indoor conditions. The outdoor climate over a typical year is attributed to the exterior surface of a wall when $Q_{w,i}$ is found from a simulation analysis. It is not clear what conditions should be attributed to the interior surface, so the dynamic and equivalent *U*-factors are assessed with three different types of conditions, shown in Table 1.

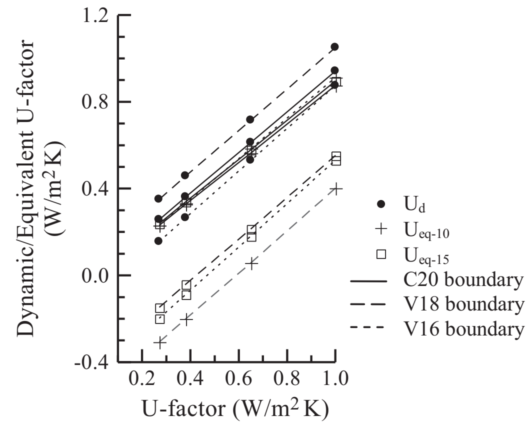

Fig. 1. Dynamic and equivalent *U*-factors versus *U*-factor for unshaded south-facing PCE wall (see Fig. 2) at Christchurch (43.5°S). Solar absorptance = 0.4.

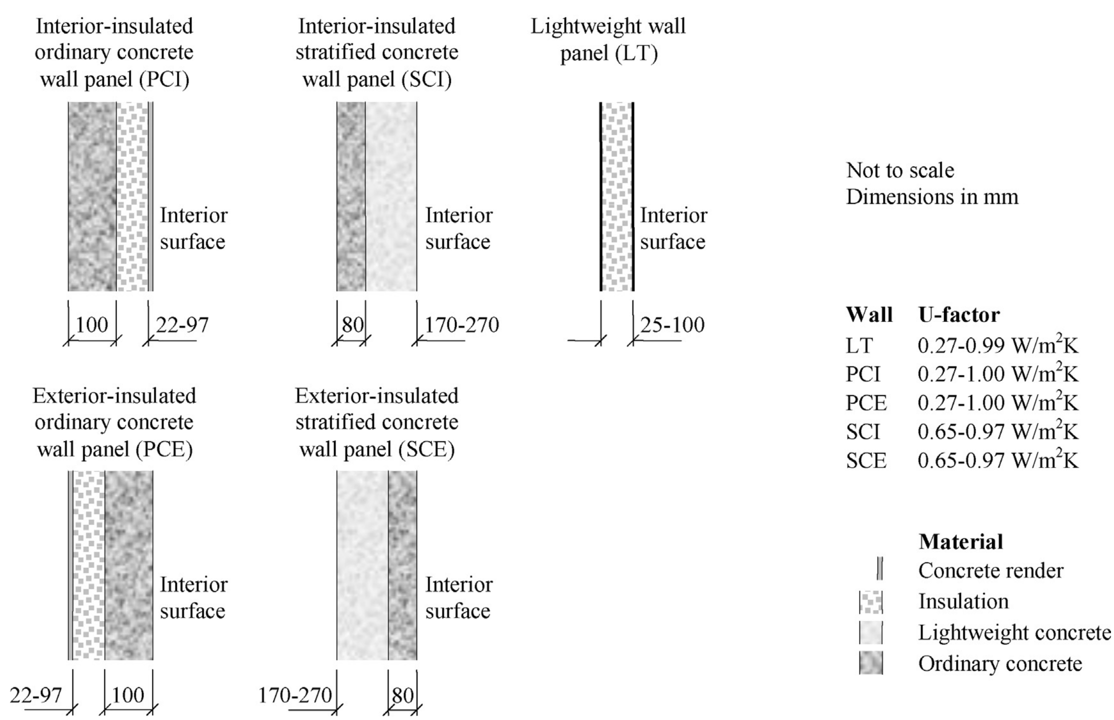

Fig. 2. External walls.