Energy Policy 65 (2014) 501–511

Contents lists available at ScienceDirect

Energy Policy

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

# Forecasting uptake of retrofit packages in office building stock under government incentives

Andrew Higgins [a,*], Mike Syme [b], James McGregor [c], Leorey Marquez [d], Seongwon Seo [b]

[a] CSIRO Ecosystem Sciences, Dutton Park, Brisbane, QLD, Australia
[b] CSIRO Ecosystem Sciences, Highett, Melbourne, VIC, Australia
[c] CSIRO Energy Technology, Newcastle, NSW, Australia
[d] CSIRO Computational Informatics, Clayton, Melbourne, VIC, Australia

## HIGHLIGHTS

- Diffusion model for uptake of building retrofits.
- Case study with New South Wales office buildings.
- Forecast uptake of government policy programs.

## ARTICLE INFO

*Article history:*
Received 12 November 2012
Received in revised form
26 July 2013
Accepted 14 October 2013
Available online 5 November 2013

*Keywords:*
Office buildings
Energy efficiency
Diffusion model
Incentives
Retrofit

## ABSTRACT

As government and industry plan to reduce energy consumption in building stock, there is a need to forecast the uptake of retrofit packages across building stock over time. To address this challenge a diffusion model was set up and applied to office building stock across New South Wales (NSW) in Australia, accommodating a high spatial resolution and temporal capability for projecting uptake of technology packages characterised by multiple variables. Six retrofit packages were set up for the diffusion model, which ranged from inexpensive services and manuals through to mid-priced packages involving energy efficient T5 lighting and solar hot water through to expensive packages such as chilled beams and Solar PV. We evaluated the model using a base case and two policy programs, representing the Green Building Fund and Environmental Upgrade Agreements. These were recent incentive programs funded by the Australian government to accelerate the uptake of retrofit packages, by providing financial support to upfront expenditures and removing barriers to retrofit. By forecasting uptake of each retrofit package to 2032 under each program, we demonstrate how the model can be a valuable resource in tailoring expensive government programs and increasing their effectiveness.



## 1. Introduction

Commercial buildings contributed to about 4.7% of gross energy consumption (or 277 pJ) in Australia in 2009 (ABARES, 2011) with stand alone offices representing a 25% share of this gross consumption (DCCEE, 2012). Office buildings have the highest energy savings opportunity compared to other commercial stock, with an estimated total energy reduction opportunity of 5142 GW h by 2020 (ClimateWorks, 2010), with the largest opportunities in rationalisation, insulation, HVAC, lighting and electronics. Realising these energy reduction opportunities is difficult since retrofitting existing buildings is more difficult than creating new green buildings, and requires the co-operation of a wide range of stakeholders such as landlords, tenants, contractors, local and state government. Also, whilst the technology may be available, issues such as cost and demand from landlords, tenants and policy makers will determine the priority and timeframe that existing buildings are retrofitted (Miller and Buys, 2008).

Various policy instruments can be used to promote the uptake of retrofit in existing buildings. These include: economic incentives that reduce the up-front cost barrier; regulations requiring that renovated buildings are equipped with energy efficient technologies or meeting star rating standards; and strategies that improve the transparency of energy use and installations. In Australia, government programs, such as the Green Building Fund (GBF) (AusIndustry, 2013) and Environmental Upgrade Agreements (EUA) (NSW Government, 2013) represent recent policies implemented to accelerate the adoption by landlords/tenants of retrofits that reduce energy consumption in office buildings. However such policies require substantial financial

* Corresponding author. Tel.: +617 3833 5738.
*E-mail addresses:* Andrew.Higgins@csiro.au (A. Higgins), Mike.Syme@csiro.au (M. Syme), James.mcGregor@csiro.au (J. McGregor), Leorey.Marquez@csiro.au (L. Marquez), Seongwon.Seo@csiro.au (S. Seo).

0301-4215/$ - see front matter 
http://dx.doi.org/10.1016/j.enpol.2013.10.041

outlay from the government (e.g. A$90million for GBF), and there is a need to tailor such instruments to increase their adoption and maximise their effectiveness. This requires an ability to estimate the likely future uptake of building retrofits by landlords and tenants with and without the incentive policies under consideration, along with the resulting energy reductions. A few studies have simulated future energy consumption in office buildings under an assumed behaviour (e.g. replace at end of life) or scenarios of when retrofits are likely to take place (Coffey et al,. 2010). Foliente and Seo (2012) forecasted energy consumption from commercial office building in Australia and models different reduction opportunities including solar PV. However, uptake of retrofit options varies depending on social, financial and geographical conditions. Estimating the likely uptake of retrofit packages across building stock over time is currently very difficult, and tools are needed to accommodate:

- The complex diffusion process of adoption over different time steps by spatial scales, demographics and building types;
- Variables that influence landlord and tenant actions in different locations, such as demographics, socio-economic indicators, income, debt levels;
- Evolution of building stock and demographics in different regions or precincts;
- A wide range of office building materials, sizes and usages, including mixed usage.
- Different incentive requirements for responsibilities for landlords versus tenants. Some retrofits are the responsibility of the landlord depending on the conditions of the lease agreement. In some situations, retrofits are dismantled by the tenant at the end of the lease.
- Several soft and hard barriers to adoption, which vary with retrofit package. The main barrier categories are: capital constraints and investment priorities; capital and implementation costs; market structures and supply constraints; regulatory structure and supply constraints; information gaps; and workforce and skill barriers. See Marquez et al. (2012) for a full description of these barriers.
- Electricity metering in some buildings can make it difficult to distribute cost savings to tenants to encourage adoption of energy efficient retrofit.

Models such as the classic Bass or logistic *S* curve have been the primary means of representing uptake of technologies by landlords/tenants. They have been particularly applied to forecast national or regional level uptakes of solar PVs (Masini and Frankl, 2002; Guidolin and Mortarino, 2010; Higgins et al., 2011, 2013) in residential building stock. However, solar PVs represent the case of first time purchasers of a new technology without replacing an existing appliance. Choice modelling is commonly used in cases such as water heaters (Higgins et al., 2013), where the building always has the appliance and the primary decision is the choice of alternative technologies (e.g. heat pump, solar-electric boost, gas) upon replacement. Extensions of the basic diffusions model have been made to incorporate replacement (Oslon and Choi, 1985; Islam and Meade, 2000), where a statistical distribution of failure is used to represent replacement time. However, replacement of building retrofits also depends on the price and savings (and other variables) that would influence the landlord/tenant decision to replace prior to failure. There have been numerous extensions to diffusion and choice models to incorporate utility functions of variables that effect consumer choice of technology (e.g. Horne and Jaccard (2005) for electric vehicles) and population of first time purchasers at a given time (Horksy, 1990; Higgins et al., 2011). By modifying values of these variables (particularly upfront and ongoing cost), one can test the sensitivity of adoption rates to different government incentives. A novelty of our current paper is the application of such diffusion model features to the uptake of retrofit packages in office buildings under various government funded policy programs, with a case study of office buildings in New South Wales (NSW), Australia. The diffusion model has a high spatial resolution for forecasting uptake of technologies characterised by multiple variables, where Local Government Areas (LGA's) define the geographical locations. Our methodology integrates multiple building typologies, usage characteristics and financial and non financial features. It allows the stock of buildings to be partitioned into category combinations of location (LGA) by height and age etc., which are then linked to the drivers of the landlord/tenant actions to uptake. This allows us to better understand the full range of potential impacts and opportunities that can arise with policy packages from different stakeholder perspectives (government, landlords, tenants). As a result, more complicated policies can be tested, such as those found in the government rebates, behaviour change programs and uncertainty in future energy and technology price.

## 2. Model outline

The primary goal of the model is to forecast the stock of retrofit options realised by landlords and tenants of office buildings at incremental time intervals (e.g. 3-monthly) through to a target date. In each time interval, the number of purchases is represented by a logic demand model, with a utility function of the different variables that influence whether a landlord or tenant in a given location will choose a particular retrofit package. The number of landlords/tenants eligible to purchase a technology option in a given time period, is a utility function of the variables that influence the probability of adopting the retrofit package along with the average lifespan to replace existing technology. For example, building tenants are much less likely to replace one year old lighting with a more energy efficient option than if the lighting has reached its practical life span.

The model is an adaptation of that used by Higgins et al. (2011), to forecast the uptake of solar PVs and water heaters in residential housing stock of Queensland and NSW in Australia. In these applications, adopters were assumed to be households, where one house dwelling contains a household. For office buildings, we assume an adopter is a landlord or the tenant of the building. Technologies for adoption are different energy efficiency packages, six in total for this paper, ranging in price per $m^2$ and ability to retrofit. A landlord or tenant may purchase more than one retrofit package (and a package can be a composite of multiple energy efficiency technologies) over the planning horizon, and the purchase of one package is treated independently of others.

To describe the model several indices need to be defined. A building type by location category is represented by *d*. For the case study in this paper, *d* will represent a category in the typology of buildings by LGA, by height and by age. Retrofit packages available for adoption are represented by *o*. Time intervals within the planning horizon are represented by *t*. Intervals are three monthly for the case studies in this paper. Let *j* represent the criteria that a landlord or tenant consider (e.g. upfront cost, energy savings, incentive) when deciding whether to adopt a retrofit package. Input parameters to the model are defined as follows:

$A_d^o(0)$=stock of retrofit package *o* for building category *d* at the beginning of the planning horizon ($t$=0). This is an input parameter to the model. The main outputs from the diffusion model are:

$A_d^o(t)$=total stock of retrofit package *o* for category *d* at time *t*

Hence $A_d^o(t)-A_d^o(t-1)$ is the net interval increase in stock of package *o* in category *d* between times *t* and $(t-1)$.