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Energy retrofit of residential building envelopes in Israel: A cost-benefit analysis

Chanoch Friedman [a], Nir Becker [b, *], Evyatar Erell [a]

[a] Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Israel
[b] Tel Hai College, Tel Hai, Israel

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ABSTRACT

It is often taken for granted that thermal renovation of building envelopes not only conserves operational energy and reduces the environmental impact of generating electricity, but is also economically beneficial to the individual homeowner. While this may be true in cold climates, it may not necessarily be true in the case of Israel, most of which has a relatively mild Mediterranean climate but parts of which are hot and arid. This study, which sought to address this question, comprised two stages: a) Analysis of the direct economic benefits to the individual homeowner of different strategies for refurbishing the envelope of an existing building; and b) Examination of other (external) benefits to society arising from electricity conservation resulting from such retrofit. The analysis demonstrates that in Israel, given current electricity prices and building construction costs, insulating the roof is a cost-effective strategy – but the payback period is 15–30 years, making it unattractive to most homeowners. Insulating the external walls of a typical apartment results in electricity savings comparable to only one third of the retrofit cost, and is thus not economically viable. Accounting for the external benefits to society does make some marginal retrofits more attractive, but not sufficiently to justify most envelope retrofit options. This highlights the importance of adopting stringent standards for new construction, since the marginal cost of additional thermal insulation in new buildings is far lower than the cost of renovating them.

1. Introduction

Approximately 40% of global energy use is attributed to buildings – residential, office and commercial [1–5]. Residential buildings, in particular, are major consumers of energy in most countries [6–9] and homes produce about 25% of the CO_2 emissions of the EU [10]. Israel, where electricity consumption in residential buildings amounts to some 16 TWh annually, or about 30% of total consumption [11], is no exception.

Household energy consumption depends on the local climate, building properties and occupant behaviour [12]. The breakdown of domestic energy use into different end-use categories, such as air conditioning, water heating and appliances varies from country to country. HVAC (heating, ventilation and air conditioning) has been estimated at 25–50% of total residential energy [13], although there are substantial discrepancies among data sources even for the same country. McKinsey & Company [14] estimate that space conditioning (heating and cooling) comprises some 30% of residential electricity consumption in Israel as well.

It is thus clear that any plan to moderate the rate of increase in Israel's energy consumption and to meet its international obligations to reduce emission of CO_2 must address the energy required to heat and cool buildings. Furthermore, because new buildings comprise only a tiny proportion of the building stock – only about 1.6% is added to the building stock in Israel each year – existing houses must be renovated too [3,15]. However, refurbishing existing homes to promote energy efficiency may require different technical solutions to those available to designers of new buildings: Unlike a new home designed for energy efficiency, renovating a home must take into account existing construction features that cannot be modified easily [16].

The cost of renovation depends on numerous factors, including the current state of the building stock, local building practices in the construction sector, availability of materials and labour, and legal and regulatory constraints. Likewise, the benefits also depend on local characteristics (such as climate) on one hand and

* Corresponding author.
E-mail addresses: chanoch.friedman@gmail.com (C. Friedman), nbecker@telhai.ac.il, nbecker@econ.haifa.ac.il (N. Becker), erell@bgu.ac.il (E. Erell).

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behavioural components (such as thermal preferences and life style) on the other hand. The balance between the cost of retrofit and the expected benefits may determine whether a specific retrofit plan is carried out [17]. The economic approach to the study of retrofit typically examines the direct costs and benefits of the renovation using tools such as net present value, but studies may also consider the embodied energy [18]. In order to use economic tools, the lifetime of the project should be estimated and an appropriate discount rate for the period determined [19].

The potential for energy savings in residential buildings has been investigated in many studies [20–23]. Although a reduction of as much as 70–85% is possible in older, poorly built homes [10,24–25], the investment required may be very high. For example, the investment required to reduce residential heating and cooling bills by 80% from average 2010 levels may be as much as € 300 per m^2 in Germany [26]. It is unlikely that such an investment can be justified on narrow economic grounds.

Clearly, a larger investment is required to achieve successively higher levels of energy saving, because once savings from low-hanging fruit have been realized, further gains become relatively more expensive. The fact that some studies have demonstrated that building renovation is effective from the point of view of the individual renovator [19,27], while others have not [24,25] may thus be attributed to the extent of retrofit undertaken. Studies also differ in their methodology of assessing the cost of the energy retrofit. Some assume that improvements in the thermal envelope are only carried out in the course of 'normal' maintenance, and assign only the added cost of, e.g., thermal insulation [28], while others assign the full cost [19]. Galvin [19] showed that for Germany, retrofit to the lowest acceptable standard is an order of magnitude more cost-effective than retrofit to the highest level, in terms of both energy saved per euro invested and of the return on investment over the lifetime of the renovations, independent of fuel prices. Nevertheless, because several studies have shown that a long period is required to recover the investment in some types of energy-saving building renovation, the subject is worthy of further study. Soratana and Marriott [27], for example, reported that the payback period of renovating a typical low-income residence in the U.S. was nearly 35 years.

Retrofit of buildings may deliver benefits both to the occupants, directly, and to society at large. The former are manifested in the form of the reduced cost of building heating and cooling, as well as in improved internal environmental quality. SBS (Sick Building Syndrome) is a well-recognized phenomenon and many new air conditioned buildings exhibit few, if any, of the effects associated with it, but many older homes still suffer from poor air quality. Improved living conditions may result in potentially large savings to the individual and to society [16], and are particularly significant for disadvantaged populations [2,9]. Such societal benefits are more difficult to quantify because they are 'non tradable goods', and as such are difficult to translate into financial terms. Studies in the US [2] and New Zealand [29] found that about three quarters of the benefit from renovation comes from reducing energy consumption. As much as one quarter is attributed to improved thermal conditions in the buildings, especially in the case of low-income families who cannot afford to heat or cool their dwellings to acceptable levels (fuel poverty) [30,31]. Additionally, because there are few metrics to evaluate the overall contribution of societal effects to an individual's quality of life, they are rarely reflected explicitly in the market value of an apartment and there is little incentive to take them into account. Hence, they generally do not affect economic decisions by the individual [2,32], although there is some evidence of a developing market willingness to pay for societal benefits (or at least for the appearance of promoting them), as indicated by a premium for commercial 'green buildings' that are certified according to various voluntary schemes such as LEED or BREEAM [33].

Building retrofit may address various deficiencies in the building and its systems. Substantial research has been carried out on refurbishment of heating systems, which often delivers substantial savings and is characterized by short payback periods, but most buildings in Israel are heated by electricity. Studies in the US have shown that retrofit of such buildings, which deals mostly with the envelope (sometimes referred to as the 'shell') typically has payback periods in excess of 20 years [34]. Nonetheless, thermal insulation is a basic element of the building, and has thus been the object of incentive programs in several countries. Unlike minor actions such as weather stripping which are cheap, effective and easy to implement, installing thermal insulation is typically a complex and expensive task and is unlikely to be undertaken by homeowners without government incentives.

In view of the above, our purpose in this paper is twofold: First, we intend to examine whether in Israel, a Mediterranean country whose climate is relatively mild, thermal renovation of the building envelope is economically beneficial to the individual homeowner (considering only the direct benefits of reduced energy consumption); Second, we intend to assess the economic benefits from a societal point of view, when market failures are internalized and are taken into account as well. Such analysis may inform debate on environmental as well as other external issues and justify potential government policy intervention. One such policy is examined through a closed tax system that covers the cost of carrying out a retrofit of all roofs in the country.

2. Methods

Several renovation strategies for the envelope of residential buildings were selected for evaluation. The benefit of each strategy was assessed by comparing the energy requirement for climate-conditioning of typical apartments before and after retrofit, by means of computer simulation. The cost of each retrofit action was obtained from a sample of construction companies, and compared with the direct economic benefit from energy conservation for each of the retrofit options. The other external benefits of reduction in electricity demand, such as avoided air pollution, were then expressed in monetary terms to internalize external costs and to provide an estimate of the overall benefit to society from energy-saving retrofits.

2.1. Identifying energy-effective retrofit techniques

As noted above, the relative contribution of various retrofit scenarios to the buildings' energy efficiency was quantified by comparing the existing configuration (referred to as the 'base case') with a series of improved configurations incorporating various improvements. Renovation alternatives examined retrofit of three types of building envelope elements:

Walls: Thermal insulation of various thicknesses was studied, applied either to the external surface of the walls or on the building interior. While the former is technically more complex and requires cooperation among all apartment owners in a building, the latter is simpler to install but slightly less thermally effective for a given thickness of insulation, and comes at the expense of valuable internal space. In the case of external insulation, the cost included stucco rendering and paint as well as erection of scaffolding, in addition to polystyrene insulation boards of different thicknesses. For internal insulation, the cost estimate included, in addition to mineral wool batts, gypsum boards on a metal frame, new window frames and painting – but not relocation of plumbing or electricity sockets.

Roof: Two alternatives were examined for improving the energy performance of flat roofs: painting the roofs white or installing