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Are passive houses economically viable? A reality-based, subjectivist approach to cost-benefit analyses

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ABSTRACT

The 'passive house' (PH) is a specific, pan-nationally recognised building standard designed to consume 15 kilowatt-hours of space heating energy per square metre of living area per year (kWh/m^{2}a), significantly less than most countries' current standard for a conventional house (CH). Most PHs cost some 5–15% more to build than a CH of equivalent size and layout. Investor-households therefore often enquire as to whether building a PH is economically viable: will the extra cost pay back in the long-run through fuel savings? A number of studies have offered cost-benefit analyses to address this, usually based on modelled heating consumption figures and prescriptive approaches to setting values for unknowable variables such as future fuel price rises and the investor's discount rate. This study offers a novel 'reality-based, subjectivist' approach. It uses empirically derived (i.e. real rather than modelled) consumption figures for PHs and CHs, and allows flexibility in setting fuel price increase and discount rates according to investor-households' subjective judgments. Drawing on a wide range of data from peer-reviewed and non-peer-reviewed studies, it presents sample results in terms of years to amortisation against PH–CH consumption differences, and offers an 11-point decision-making process for would-be investor-households.

1. Introduction

This paper develops a 'reality-based', 'subjectivist' approach to deciding whether it is economically viable to build a passive house rather than a conventional house. It is 'reality-based' in that it uses the particular investor-household's likely *actual* heating energy consumption in the cost-benefit equation, rather than modelled values based only on the physical characteristics of buildings. It is 'subjectivist' in that it accepts that the values of some of the parameters in the cost-benefit equation are unknowable and must be posited by the investor-household according to their own tastes – rather than assuming there are correct values for these parameters and deferring to experts to find out what they are.

It is widely agreed that there is considerable potential in residential buildings for reducing energy consumption, mostly by increasing the energy efficiency of space heating. In part this can be achieved through thermal upgrades of existing homes, and in part through replacement of old buildings with new, energy-efficient models. Although there are considerable practical and economic problems in executing these goals [1–4] there is almost always an opportunity to opt for high energy efficiency when an existing dwelling is undergoing major maintenance or a new home is being built.

Guided in part by the EU Energy Performance of Buildings Directive [5], EU countries set minimum thermal standards for new builds, including maximum permissible energy consumption. In Germany, for example, new builds have to achieve an average maximum heating energy consumption of 70 kilowatt-hours per square metre of useable floor area (kWh/m^{2}a). For ease of communication in this paper we call this the 'energy performance rating' (EPR). The type of thermal technology of most new homes in frigid and temperate European climates today has altered little over the past 15 years: thick wall insulation of the building envelope; double- or triple-glazed windows with inert gas between panes; air-tightness; and an energy efficient boiler (or connection to a district heating system) with room-by-room radiators, controlled both centrally and at each heating element.

There are a number of alternative thermal technologies in housing, such as under-floor heating, and heat-pumps as an energy source, though results with these are somewhat mixed. Another and now well-established alternative is the passive house (PH). Developed jointly by German Wolfgang Feist and Swede Bo Andersen, this concept differs from a conventional house (CH) in that it does not employ a conventional heating system. Instead, through

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its ventilation system it recycles indoor heat captured from the sun and generated by human indoor activities, and supplements this with a small heat pump. Heating energy consumption (EPR) is thereby kept to a maximum of 15 kWh/m^{2}a.

As this is powered by electrical energy, which is normally generated elsewhere through inherently inefficient processes and transmitted over loss-prone lines, the primary energy demand of a PH can be close to three times its final energy demand, i.e. around 45 kWh/m^{2}a (cf. [6]). But this still betters a basic, gas powered CH by 25 kWh/m^{2}a. As long as this edge is maintained there can be no doubt that the daily running of a PH causes less climate damaging pollution than a standard CH. Whatever else is said about PHs in this paper, it does not question that fundamental assumption.

The first prototype PHs were built in the early 1990s in Darmstadt Kranichstein [7] and Gross-Umstadt [8], both in Germany. As experimental designs these were significantly more expensive than low-energy CHs even with a comparable EPR. However, PHs became commercially successful with the building of a block of PH terraced houses in Wiesbaden in 1997 by the building firm Rasch and Partner, and another in Naumburg by architects Karl-Heinz Fingerling [9].

The economic downside of a PH is that it generally costs more to build than a CH, while the upside is that it saves money in the medium to long term by consuming less fuel. A homeowner-investor will want to know how this balances out. Is a PH an economic winner or loser? Of course, the saving of 25 kWh/m^{2}a can be seen as a long term monetary gain for society regardless of building costs, as it reduces climate damage [10]. But because there is not (yet) an effective emissions trading scheme to reward energy-frugal households, all financial benefits, from the investors' point of view, result from the reduced cost of heating energy. In short, a cost-benefit analysis needs to be performed, to see if a PH pays from the point of view of the investor.

Studies to date have made important contributions to the question of PH economic viability. Audenaert et al. [11] compare break-even times (i.e. years to amortisation) of PHs and low-energy CHs (i.e. those with a lower EPR than the legal maximum) as alternatives to standard CHs. Their modelling, based on EPRs, indicates that the low-energy CH breaks even earlier than the PH. An open question, however, is whether these houses would consume, in real life, the quantities of energy assumed in the modelling.

Mahdavi and Doppelbauer [12] offer a similar analysis as part of a wider comparison of PH and low-energy CH performance features such as indoor temperature, relative humidity and CO_2 concentration. Although their fuel consumption comparison is based on actual measured values rather than EPRs, it includes only 5 months of running. Further, their methodology at this point is not transparent, and the cost-benefit results, which are offered without explanation as to how they were derived, do not seem to square with the data in the study.

Georges et al. [6] investigate the modelled performance of PHs and low-energy CHs using Belgian building and fuel cost figures. Having established that the low-energy CH represents an 'economic optimum', where the best possible return is achieved for the excess investment in thermal features, they explore whether the PH also represents an economic optimum. They conclude that a PH would need either financial incentives, or a low discount rate and high increase in future fuel prices, to represent an optimal return on investment.

Amstalden et al. [13] include the Swiss 'minergie' standard house – Switzerland's version of the PH – along with other standards in a study of economic viability of energy-efficient retrofitting. In most cases they find that such retrofitting requires state subsidies to be economically viable for the homeowners, and there is no particular consideration of the effects of minergie-standard costs and benefits.

Other studies, in which actual heating consumption of PHs is systematically measured, do not offer cost-benefit analyses [14–17].

To date there has not yet been a transparent cost-benefit study of PHs compared to CHs based on the *actual* consumption of these dwellings. The common practice is to base such studies on the dwellings' EPRs. But as these are theoretical, modelled consumption figures, the results do not necessarily fit with the benefits homeowners are most likely to recoup for their investment. Further, existing studies tend to assume there is such a thing as economic viability (or otherwise) of a PH, rather than allowing that whether a project is economically viable depends very much on the perspective of the investor. This paper attempts to address both these problems. It takes the 'benefit' part of the cost-benefit analysis beyond figures based on each type of home's EPR and works towards a method of basing the benefits on the likely actual consumption of each type of house, which is often very different from the EPR [18]. In that sense it is 'reality-based' rather than 'model-based'. It also constructs a cost-benefit model with the flexibility that allows different investors' perspectives to influence the values of key variables, in particular the discount rate. Despite many commentators' attempts to tell investors what the discount rate should be in energy-efficiency investments, it is ultimately a subjective thing: the investor has to decide on a rate and live with the consequences. In that sense, the approach in this paper is 'subjectivist'.

The paper thereby offers a method that a prospective homebuyer-investor can use, to decide whether a PH is a more economical option for him or her, than a CH of equivalent size and layout.

For its consumption data this paper draws on datasets within the papers cited above, and also a number of other studies available at the time of writing. It does not consider state subsidies as elements in the cost benefit analyses, as these are not assured in the long term and vary for different types of CH, as well as from country to country.

Because of this paper's emphasis on actual consumption of PHs compared to CHs, the two principal variables on all the graphical displays are years to amortisation of a PH, and consumption advantage of the PH over an equivalent CH, while other parameters are varied in each scenario.

The remainder of this paper proceeds as follows. Section 2 outlines the methodology for deriving results in terms of the two principle parameters, namely years to amortisation and PH consumption advantage. Section 3 estimates the knowable parameters: the building cost, the likely building cost difference between a PH and a CH, and the cost of heating fuel, and offers sample calculations. Section 4 introduces the novel element of estimating actual consumption for PHs and CHs, explaining how this affects cost-benefit comparisons. Section 5 shows how variations in the knowable factors affect the amortisation time as a function of the PH consumption advantage. Section 6 shows what happens when the two unknowable parameters – future fuel price rises and discount rate – are varied. Discussion follows in Section 7, and Section 8 concludes.

2. Methodology

2.1. The basic comparison

The basic cost-benefit problem of a passive house (PH) compared to a conventional low energy house (CH) can be outlined as follows.

A PH costs more than a CH to build. The PH would then have to save the difference, through reduced heating costs, within a reasonable amortisation period in order to be economically viable