Energy and Buildings 112 (2016) 21–27

Contents lists available at ScienceDirect

Energy and Buildings

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

Optimizing the distribution of Italian building energy retrofit incentives with Linear Programming

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ARTICLE INFO

Article history:
Received 12 January 2015
Received in revised form 6 October 2015
Accepted 19 November 2015
Available online 2 December 2015

Keywords:
Residential building stock
Energy retrofits
Incentive distribution
Linear Programming
Optimization

ABSTRACT

The goal of the research is to propose an optimization-based methodology for the evaluation of retrofit incentives, using as a benchmark the wide data collection reported by the ENEA Italian Agency since 2007. To determine the best mix of energy retrofit measures for different areas of Italy, two Linear Programming models are proposed. The first model maximizes energy savings and the second one minimizes retrofit costs. The results show a 17% reduction in the average cost for each MW h of saved energy. More importantly, the methodology can help decision-makers appreciate how energy efficiency incentives have been used so far and how effective they could be. Furthermore, the methodology can be used for setting future incentive distribution plans.

1. Introduction

“Buildings are at the centre of our social and economic activity. Not only do we spend most of our lives in buildings, we also spend most of our money on buildings. The built environment is not only the largest industrial sector in economic terms, it is also the largest in terms of resource flow” [1].

Nearly 76% of Italian dwellings were built before the first Italian law on building energy performance had been issued (Law N.373/1976). The old age of the existing residential building stock (in Italy, 49% of dwellings are more than 50 years old [2,3], whereas in Europe, this percentage is around 35%) typically goes with poor energy building performances.

Moreover, even though in Italy the first building legislation on energy performance was adopted in 1977 and several updates have been implemented, energy consumption levels in the residential sector have not successfully decreased. After the EPBD 2002/91 regulation was issued, a decrease ranging between 0.8% and 0.4% was registered in the growth trend for energy consumption. However, the low growth of new high-performance dwellings is not enough to invert the energy consumption trend. The implementation of effective retrofit solutions for the widely existent building stock is therefore necessary.

Since the European policy aims to significantly decarbonize the continent’s economy by targeting a cut of 80–95% below 1990 levels by 2050, the building sector undoubtedly plays a key role [4]. Moreover, any strategy to tackle the challenge in this field will clearly require both a significant amount of financial investments and long-term political commitments [5,6].

Nonetheless, it is very important to find out how to foster and encourage energy efficiency improvements and energy-saving measures in private dwellings, in order to achieve the advantages of reducing energy consumption in the private sector, as well as increasing investments and favouring the creation of additional cash flows. This combination of multiple benefits therefore makes the building sector a crucial field for policy-makers at the European and national levels.

The development of sustainable solutions for the refurbishment of existing buildings requires major innovations in retrofitting strategies and cost-effective and fruitful financing instruments [7–11]. In order to cope with the main European goals and energy-saving targets, the Italian government has recently established a system of financial incentives: they allow a tax deduction for a wide range of energy efficient retrofit investments, sustained both by private citizens and by companies. The deductions essentially consist of subsidies for energy-saving refurbishments in the household sector (a.k.a., “Energy Efficiency 55%”) financed by the Ministry of Economic Development. They concern opaque

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http://dx.doi.org/10.1016/j.enbuild.2015.11.050
0378-7788/

vertical and horizontal surfaces insulation, window replacement, solar panel installation, and thermal plants replacement carried out in existing buildings, as long as they are duly proved, certified, and respectful of specific technical requirements (such as transmittance limits, thermal plants efficiency, etc.).

However, these subsidies are granted without congruous and logical distribution criteria, overlooking their effective and final profitability, regardless of a fair evaluation in terms of their real cost-effectiveness. Hence, a far-sighted incentives distribution policy would be beneficial. Despite this shortcoming, a rather worthy initiative and investigation venture has been recently implemented by the ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development): it collected all the relevant data and information on the previous subsidies, and created a wide reports portfolio. In particular, these reports are able to inform the authorities about costs, energy savings, and the occurrences of retrofits in all Italian regions.

This study aims to analyse the ENEA reports to quantify the cost-effectiveness of several building retrofit actions in different geographic areas. Next, the analysis of ENEA data is used to propose two Linear Programming [LP] models in order to determine which retrofit measures maximize energy savings and minimize retrofit costs in these geographic areas. The national scale of these models enforces the idea that buildings should no longer be renovated individually, but as a part of a global energy system where their interaction with the environment should be predicted and properly evaluated, while also taking into account the relationship with inhabitants and relevant stakeholders [12–17]. Finally, this study compares the outcomes of the LP models to the data derived from the ENEA reports.

2. Literature review

There are many obstacles to the spreading of good practices concerning the use of retrofit incentives. One of the main problems is the cost-effectiveness of home energy retrofits [18], which is rarely taken into account in national policy programs. In particular, the literature review highlights some critical issues:

Public subsidies are necessary to reduce payback time and increase economic benefits for investors [7,18].

Uncertainties about future energy prices make the economic feasibility analysis of a given work really difficult [12,19].

The value chain of the building sector is quite complex and involves a wide range of stakeholders, such as investors, building planners, property traders, equipment manufacturers, entrepreneurs, and last but not least, end-users. Hence, despite the incentives for taking action towards energy efficiency, all stakeholders face several obstacles. Such barriers too often prevail, resulting in too little action and a limited impact so that only a small part of the latent potential can be effectively carried out [20].

A key requirement for the analysis of retrofit incentives is the availability of reference data. Many reports and surveys were published, at both the European and international levels, taking a closer look at how financial instruments are currently implemented in Europe and providing some evidence of their effectiveness [21–29]. In particular, they underline a great variety of financial instruments available throughout the EU to support the improvement of a building's energy performance [30–35]. However, despite their undoubted relevance, none of them have analysed in detail the respective implications at a "single-nation-level". As a matter of fact, this particular topic is not thoroughly discussed, neither in the scientific literature, nor in specific technical guidelines: the example offered by the ENEA Reports [36,37] could represent, at a national level, a very important instrument for addressing the challenge of renovating the existing building stock, while also keeping pace with the ambitious aims of both the Italian nation and the European Union.

Several studies have already been carried out in the Linear Programming and optimization field. Some mixed integer programming techniques have been developed for building retrofits and energy-saving refurbishments in the residential sector in addition to the implementation of renewable and sustainable energy. Single and multi-objective optimization techniques have been proposed for short-term energy planning that consider multiple uncertainties and unpredictable parameters [38–41]. Furthermore, specific algorithms and mathematical techniques have been implemented to optimize insulation measures on existing buildings, as well as evaluate economic optimal retrofit investment options and solutions for energy savings [42,43]. LP has already been adopted to assess and sustain household energy conservation and heating systems. It has also been used for the evaluation of building energy systems to obtain an efficient allocation of the required budget [44–46]. Nevertheless, none of the previous studies attempted to evaluate energy retrofit solutions within an integrated optimization process.

This paper aims to cover the gap of adopting LP to assess economic and energy building retrofit policy implications under a strategic perspective. In the following section, some details are added about LP, although ad hoc books are required for a complete overview [47].

2.1. On Linear Programming

LP is concerned with the minimization or maximization of a linear function while satisfying a set of linear equality and/or inequality constraints. An LP model can be formulated as:

$$\min \sum_{j=1}^{n} c_j x_j \tag{1}$$

s.t.

$$\sum_{j=1}^{n} a_{ij} x_j = b_i \quad i = 1, \ldots\ldots m, \tag{2}$$

$$x_j \geq 0 \quad j = 1, \ldots\ldots, n \tag{3}$$

where, Eq.(1) is the objective function to be minimized. The coefficients c_1,...., c_n are known coefficient costs and x_1,...., x_n are the decision variables to be determined. Equation (2) is the ith constraint, which is made up by the technological coefficients a_{ij}, and b_i is the ith requirement to be satisfied by decision variables.

Inequalities (3) are the non-negativity constraints. A set of values of the variables x_1,.., x_n satisfying all the constraints is called a feasible point or a feasible solution. The set of all such points constitutes the feasible region or the feasible space. According to this terminology, the LP problem can be stated as follows: among all feasible solutions, find one that minimizes (or maximizes) the objective function.

3. Methodology

In the methodology, the data provided in yearly ENEA reports are analysed and processed. In addition, two LP models using the parameters determined from the ENEA data are presented. All the LP problem instances are solved to the optimum by a freeware release of the solver Lindo [48].