Building and Environment 46 (2011) 109–123

Contents lists available at ScienceDirect

Building and Environment

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

Applying a multi-objective optimization approach for Design of low-emission cost-effective dwellings

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ARTICLE INFO

Article history:
Received 7 May 2010
Received in revised form
5 July 2010
Accepted 8 July 2010

Keywords:
CO_2-eq emissions
Investment cost
Summer overheating
Building
Optimization
Pareto front

ABSTRACT

Modern buildings and their HVAC systems are required to be not only energy-efficient but also produce fewer economical and environmental impacts while adhering to an ever-increasing demand for better environment. Research shows that building regulations which depend mainly on building envelope requirements do not guarantee the best environmental and economical solutions. In the current study, a modified multi-objective optimization approach based on Genetic Algorithm is proposed and combined with IDA ICE (building performance simulation program). The combination is used to minimize the carbon dioxide equivalent (CO_2-eq) emissions and the investment cost for a two-storey house and its HVAC system. Heating/cooling energy source, heat recovery type, and six building envelope parameters are considered as design variables. The modified optimization approach performed efficiently with the three studied cases, which address different summer overheating levels, and a set of optimal combinations (Pareto front) was achieved for each case. It is concluded that: (1) compared with initial design, 32% less CO_2-eq emissions and 26% lower investment cost solution could be achieved, (2) the type of heating energy source has a marked influence on the optimal solutions, (3) the influence of the external wall, roof, and floor insulation thickness as well as the window *U*-value on the energy consumption and thermal comfort level can be reduced into an overall building *U*-value, (4) to avoid much of summer overheating, dwellings which have insufficient natural ventilation measures could require less insulation than the standard (inconsistent with energy saving requirements) and/or additional cost for shading option.

1. Introduction

The European Commission announced plans for a European Union energy policy that included a unilateral 20% reduction (compared with emission levels of 1990) in greenhouse gas emissions by 2020. Buildings contribute to about 35% of carbon dioxide emissions, which is closely related to climate change [1]. The main contributor to the total heating-related CO_2 emissions of 725 Mt/a from the EU building stock in 2002 was the residential sector (77%) while the remaining 23% originated from non-residential buildings. In the residential sector, single-family houses represent the largest group and are responsible for 60% of the total CO_2 emissions, equivalent to 435 million ton per year [2].

Aiming to environmental building solutions, the updated European regulations stipulate well-insulation (*U*-values) and heat recovery requirements. This has resulted in significant energy savings for heating, especially in northern Europe: for example, in Germany it has lead up to 30% energy savings compared to the previous standards, in France to 10% savings and in Ireland to 22–33% savings. Thermal insulation of buildings (external walls, roof and floor) and double-pane windows (even triple glazing with low-e and argon in northern countries like the Baltic States, Finland and Sweden) reduce annual energy consumption for space heating, by lowering heat losses through the building's envelope [3]. Energy consumption in insulated buildings may be 20–40% less than in non-insulated buildings [4].

Although most of the current European building regulations have well measures for energy saving, they cannot guarantee the best environmental solutions. Based on models representative for the range of the Norwegian district heating plants, calculations showed that heating-related CO_2 emissions in residential buildings connected to the district heating grid and with an energy standard in accordance with the new building regulations are lower than for similar buildings with a low-energy standard and with heating based on electricity [5]. The primary energy use and the CO_2 emissions depend strongly on the source of energy supply. A study by Gustavsson and Joelsson [6] shows that a single-family house

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doi:10.1016/j.buildenv.2010.07.006