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UK office buildings archetypal model as methodological approach in development of regression models for predicting building energy consumption from heating and cooling demands

Ivan Korolija [a,*], Ljiljana Marjanovic-Halburd [b], Yi Zhang [a], Victor I. Hanby [a]

[a] Institute of Energy and Sustainable Development, De Montfort University, Queens Building, The Gateway, Leicester, LE1 9BH, UK
[b] Bartlett School of Graduate Studies, University College London, Central House, 14 Upper Woburn Place, London, WC1H 0NN, UK

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ABSTRACT

An archetypal simulation model of office building representing variability in UK office building stock by parameterising built form, construction elements, occupancy/usage and operational/control strategy has been developed thus enabling detailed energy performance simulation to be used for stock modelling and parametric studies. The paper discusses the building characteristics needed to be considered for energy performance simulation, their values, and how they can be used in parametric studies. These parameters include built forms, fabrics (including thermal mass and insulation positioning), glazing percentages and characteristics, daylight and solar control measures and activity and operational related parameters (heating and cooling set points, ventilation rate, occupancy density and metabolic rate, equipment and lighting gain). The default parameter values suggested for the archetypal simulation model reflect typical existing and currently proposed UK office building stock. An archetypal model, combined with parametric studies, can be used in assessing energy performance of building stock and evaluating adaptation/retrofitting strategies.

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1. Introduction

Energy efficiency of built environment in urban areas is an important factor in mitigating the challenges of climate change, resource depletion and wider environmental issues. In the UK, buildings account for about half of all energy consumption, compared to 41% in Europe and 36% in the USA [1]. Compared to dwellings, non-domestic buildings tend to have higher energy consumption per square meter of floor area. Offices and retail spaces are amongst the most energy intensive typologies in the non-domestic building sector. They alone account for over 50% of total energy consumption for non-domestic buildings [2]. According to Perez-Lombard et al. [2] it is advisable to start the analysis of energy demand of the non-domestic building stock with office buildings. The reason is not only the energy intensity of the office buildings but their constant increase in total floor area coupled with increase in lighting, IT and air conditioning. The other important reason is that office buildings are quite uniformly distributed across the buildings stocks in developed countries with three key energy end uses, HVAC, lighting and appliances, adding up together to around 85%.

In order to develop general understanding of energy issues, and to provide evidence for policy makers in regards to energy consumption reduction, it is often necessary to consider a specific non-domestic typology as whole. For the example of office buildings, a conventional approach is to select/develop a typical or exemplar office building whose energy performance can be analysed in detail and subsequently generalized to similar buildings. This approach has been used by Jenkins et al. [3,4] to investigate the refurbishment options aiming at 50% reduction in CO_2 emission inside the UK office building stock. The investigation was based on an example building which represents ~20% of the UK office building stock in terms of built from, and 9% of the UK office building stock in terms of construction age. Similarly, Dascalaki and Santamouris [5] classified European office buildings into five typical types, each located in a different, typical climatic zones in the OFFICE project which investigated passive and active CO_2 emission reduction measures.

Office buildings are much diverse in terms of built form, construction, occupancy and activities. It may not be possible to identify a small number of buildings that can represent the majority of existing office building stock. The alternative approach we propose is to develop a number of archetypal buildings that represent typical office building built forms. In addition, the design,

* Corresponding author. Tel.: +44 0 116 207 8836; fax: +44 0 116 257 7977.
E-mail addresses: ikorolija@dmu.ac.uk, ivan.korolija@gmail.com (I. Korolija), l.marjanovic-halburd@ucl.ac.uk (L. Marjanovic-Halburd), yizhang@dmu.ac.uk (Y. Zhang), vhanby@dmu.ac.uk (V.I. Hanby).

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construction and activity features that influence energy performance will be parameterized, therefore customizable, to represent individual buildings. With the archetypes and parameters, it is possible to create sample that represents the majority of the existing building stock.

The aim of this paper is to develop office building simulation archetypes, thus enabling detailed energy performance simulation to be used for stock modelling and parametric studies. An archetypal simulation model is an abstract model that generalizes the characteristics of a particular building type, and represents variability in building stock by parameterising construction elements, components, design features, and occupancy/usage. An archetypal model, combined with parametric studies, can be used in assessing energy performance of building stock and evaluating adaptation/retrofitting strategies. The described approach has been applied to the UK office building stock. Sections 2–6 of this paper discuss the "parameters" needed to be considered for energy performance simulation and their values. These parameters include the built forms, the construction components, and the operational strategies of the buildings because of their impact on energy performance. The suggested values reflect the typical UK office building design. Section 7 presents the parametric archetypal model implemented in jEPlus [6]/Energy Plus [7], and how it can be used in parametric studies.

2. Built forms of UK office buildings

Building geometry can have a significant impact on building energy demand and, therefore, special attention has to be paid to a classification of built forms when analysing energy consumption in building sector. A detailed study of UK non-domestic building geometries resulted in the identification of six basic built forms: Daylit cellular, Artificially lit cellular, Daylit hall, Artificially lit hall, Daylit open-plan, and Artificially lit open-plan [8,9].

This classification of built forms was made according to two basic criteria: whether or not a space is predominantly daylit or artificially lit and a space layout [8]. Authors observed that rooms take typical ranges of size depending on their functions and created three subcategories: cellular spaces, open-plan spaces, and halls. Cellular space arrangement is typical for strings of individual offices in commercial buildings, bedrooms in hotels, classrooms in schools, etc. Such rooms are more or less comparable sizes, equipped and furnished in similar ways, serve quite standardised purposes, and accommodate roughly equal number of occupants. Open-plan spaces and halls are similar in both size and shapes, and both are unobstructed by walls. The difference between them is in the occupants' activity. Halls are large single specialised spaces occupied by single coordinated activity such as lecture theatres, conference and meeting rooms, assembly halls, churches and chapels, cinemas, etc. On the other side, the occupants of the open-plan spaces are engaged in many different activities. In most cases, this type of space accommodates office activities, but the same description can be applied to many large shops or warehouses.

Table 1 shows that the sidelit cellular up to four storeys tall (CS4) is the UK non-domestic building stock most common built type with nearly 34% of the floor area with additional 5% for the sidelit cellular more than four storeys tall (CS5). The sidelit cellular built form category thus dominates the non-domestic building stock with roughly 40% of the total gross floor area. Second largest individual built form category is the composite sidelit cellular around artificially lit open-plan (CDO) which occupies approximately 20% of the total floor area. The majority of the corresponding activities in these two categories are offices, shops and hotels. Open plan artificially lit multi-storey space (OA), which accounts for 5.5% of the total, is used for warehouses, factories, offices and shops. The sidelit open plan up to four storeys (OD4) and the sidelit open-plan with five storeys or more (OD5) use together nearly 3% of the floor area and accommodate mainly offices.

Table 1
Principal forms floor area representation across UK building non-domestic stock [8].

Type	Percentage [%]
CS4	33.9
CS5	5.2
CS4 + CS5	39.1
OD4	0.9
OD5	2.0
OD4 + OD5	2.9
CDO	19.5
OA	5.5
Total	67%

The built forms for the UK office building simulation archetypes were developed to represent the most typical office building built forms (see Fig. 1). The first office building type represents open-plan sidelit buildings (OD). The second building type is the cellular sidelit building (CS). The third type is artificially lit open-plan building (OA) and the last type symbolised the composite sidelit cellular around artificially lit open-plan (CDO) built form category. These selected built forms correspond to 67% of the total floor area in the UK non-domestic building stock.

Thermal zoning is important simulation parameter, since it impacts energy demand calculations as well as the performance of multi-zone HVAC systems and required HVAC equipment capacity [10] which is why each floor in the developed office building models was divided into office zones and a common area zone. Also, where several rooms or areas of a building behave in a similar manner, the common practice is to group them together as one "zone", which was the approach adopted in creating simulation archetypes for cellular office zones. Each storey in office building simulation archetype model is composed of office areas (zone 1) and common spaces (zone 2). Common spaces represent areas such as reception areas, toilets, tea kitchens, circulation space, etc. Diagrams of the four building types can be seen in Fig. 1. Floor area of the each storey is roughly the same in all models and amounts around 510 m^2. Building types 1 and 2 are narrow plan buildings with a 32 m by 16 m footprint. Types 1 and 2 are sidelit and differ only in the office space arrangement. The office space in building type 1 consists of one large open space (zone 1), while the office space in the building type two is divided by corridor into two zones of cellular offices (zone 1a and zone 1b). Building types 3 and 4 have square footprint with a 22.5 m by 22.5 m. The floor plane of building type 3 is dominated by a single large open-plan office area (zone 1). Office building type 4 has both open-plan (zone 1a) and cellular (zone 1b and zone 1c) office areas, while zone 2, as in the previous building types, is reserved for common areas.

In order to reliably extend the simulation results using archetypes to a stock level, the buildings should be at least three storeys tall with recommended floor to ceiling height of 3.5 m. The main reason for always taking at least three storeys into account for simulation purposes is the possible unequal energy demand each storey can have due to its interactions with the environment. The ground storey's energy demand is affected by the heat exchange with the ground through the floor. On the other hand, the top storey is exposed to additional solar heat gains through a roof element. Moreover, a transmission heat transfer area is increased by the area of the roof. The intermediate storey usually does not interact with the external environment through floor and ceiling elements which means that, if a floor layout is unique for a whole building and if conditions above and below are identical, these two elements can be assumed to be adiabatic surfaces. Energy consumption of intermediate storeys in buildings with more than three storeys can be

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