139: A New Occupant-Centric Metric for Building Energy Performance

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Abstract
Energy use in most building types essentially stems from the demand to provide a suitable environment and "creature comforts" for their occupants. It therefore follows that the energy consumption (or carbon emissions) per occupant should be the natural metric for building energy performance. Supported by computational energy simulations based on a series of occupancy models in office buildings, this paper investigates the practicability of occupant-normalised metrics (ONMs) vis-à-vis conventional floor area-normalised metrics (ANMs).

Keywords: energy performance occupant centric normalised metric kwh co2

1. Introduction

It is common to start papers by quoting statistics. The most fashionable statistic in this industry right now, it seems, is the assertion that buildings consume 40-50% of the world's energy. Yet, in essence, buildings don't in fact use energy at all. People use energy. In reality, the energy used by "buildings" accounts for the energy people consume in providing themselves with comfort, with means to productivity, with entertainment and with sustenance. However, the author would argue that the growing institutionalisation of the current metrics for reporting predicted and measured energy use in buildings is in danger of erasing this reality from our collective mindset.

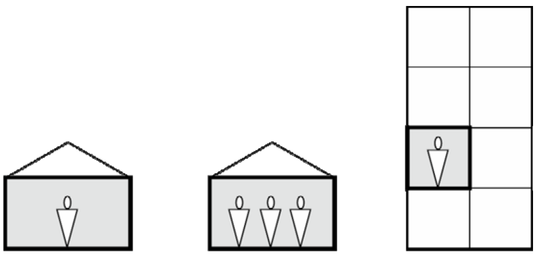


Fig 1. A three bedroom house will clearly not meet the needs of a single occupant as economically as it will meet those of three occupants. However, non-equivalent accommodation types require more complex quantitative mechanisms for comparison

In contemporary discourse, the "energy efficiency" of a building is measured as a product of its intrinsic physical properties – of its fabric and building services – and is generally normalised by floor area in a metric such as kWh/m² or, increasingly, translated into carbon emissions as kgCO2/m² or equivalent. Yet, intrinsically, the energy efficiency of most building types should in fact be a measure of a building's ability to economically meet the essential energy needs of its individual occupants (see Fig 1.) – a form of measure particularly relevant in an time of personal "carbon footprinting", and with growing calls for individual carbon trading mechanisms, such as a Personal Carbon Allowance (PCA) [1]. Taking the example of the EU, and more specifically the UK[1], existing and proposed legislation act to cement the use of ANM-based methodologies for calculating and reporting both predicted and measured energy consumption. The 2003 EU Energy Performance of Buildings Directive (EPBD) has led to national legislation requiring a unified methodology for calculating building energy use, referred to in the UK as the National Calculation Method (NCM)[2]. For building regulations compliance, this methodology requires design teams to prove a performance improvement over a "notional" baseline energy model. Essentially, this involves proposing a building massing and starting from standard specifications of building fabric, services, lighting etc. and then putting in place incremental measures to reduce energy consumption until compliance criteria are met. From 2008, the same methodology is used, against a subtly different "benchmark" baseline model to provide an energy rating on an A to G scale.

With such obstacles to negotiate, design teams[3] are increasingly becoming preoccupied with putting in place measures to satisfy the demands of these generic models, rather than approaching the unique energy management demands of the specific project in question[4]. For example, since the models rely on standardised occupancy and

[1] Here, the UK is assumed to offer an illustration of a general trend of current thinking common across the developed world.
[2] In the UK there are separate energy models for dwellings and non-dwellings. These are developments of the pre-existing SAP (Standard Assessment Procedure) and SBEM (Simplified Building Energy Model) respectively. Although the models are different, the underlying compliance methodology is the same.
[3] The "design team" here refers primarily to architects and building services/environmental engineers.
[4] Likely client demand for energy A-ratings under EPBD-related legislation is likely to augment this trend.

operational profiles, little can be done to reward intelligent space management and zoning in buildings with complex and varied patterns of occupancy[5]. In addition, a fundamental failure of all methodologies relying on ANMs is that they are unable to demonstrate the reduction in energy demand from efficient space planning, or from reducing the serviced proportion of a building. For example, in an academic learning resource centre (LRC) with a traditional library open from 8am-8pm, but an ICT area open 24/7, the single design gesture that would slash potential energy consumption would be to ensure that these two zones were serviced independently from one another.

There is a clear need to investigate alternative approaches to reporting energy consumption – both predicted and measured – to account for the shortfalls of those currently at the fore. The following pages offer an investigation into the formulation and application of Occupant-Normalised Metrics (ONMs) towards this end.

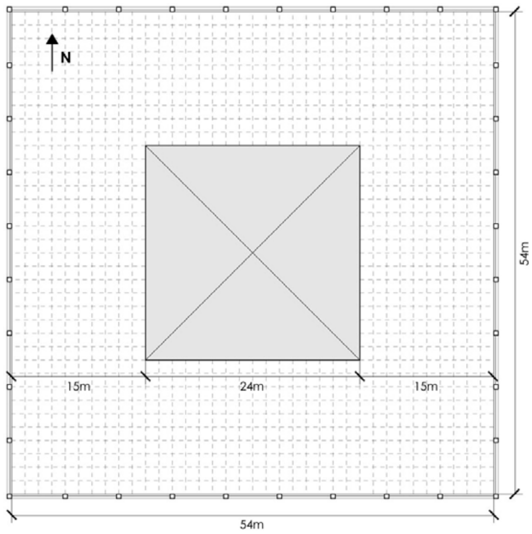


Fig 2. Floor plan of air-conditioned office type

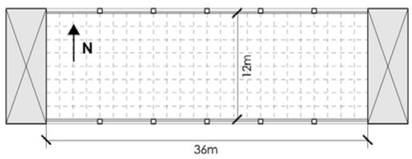


Fig 3. Floor plan of naturally ventilated office type

2. Modelling ONMs

In 2007, the author undertook a theoretical study into the impacts of varied patterns of occupancy and operation on energy use in naturally ventilated and air conditioned office types [2][6] (see Figs 2. and 3.). During the study, the opportunity arose to investigate the application of ONMs vis-à-vis ANMs in the context of energy predictions. The study focused on annual energy consumption figures and diurnal energy consumption profiles, calculated for four distinct occupancy/operational profiles (outlined in Figs 4. to 6.), reported in terms of carbon emissions[7].

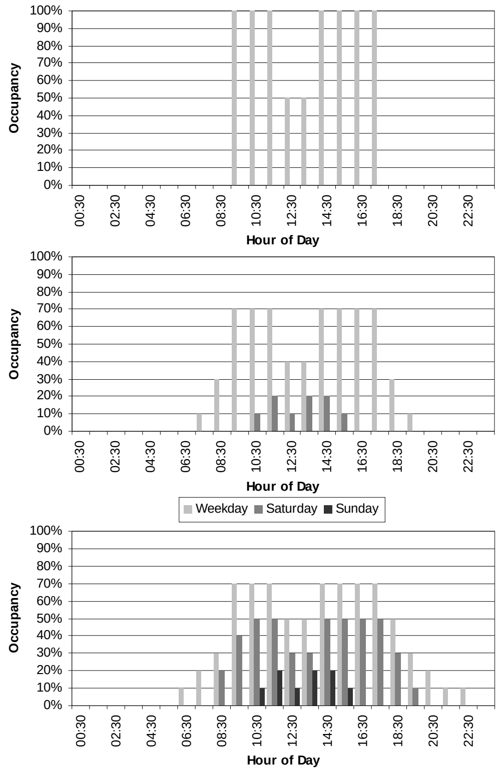
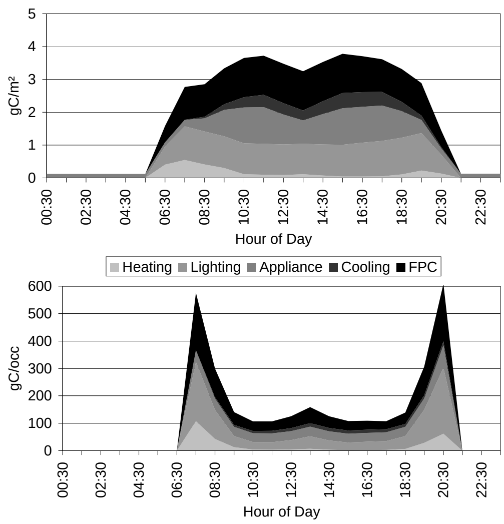


Fig 4. Occupancy/operational type A: "design case"
Fig 5. Occupancy/operational type B: "standard office"
Fig 6. Occupancy/operational types C and D: "extended hours" (type D assumes "always-on" 24 hour servicing)



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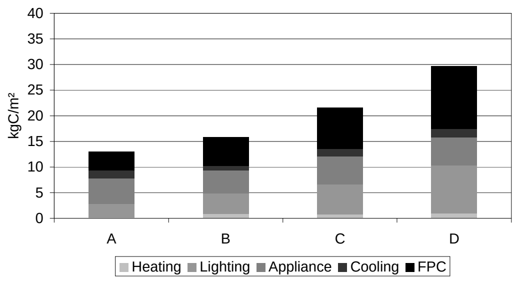
[5] In an academic learning resource centre (LRC) with a traditional library open from 8am-8pm, but an ICT area open 24/7, the single design gesture that would slash potential energy consumption would be to ensure that these two zones were serviced independently from one another.

[6] The investigation used the ESP-r software package to model 32 office variants, based on ventilation type (x2), thermal mass (x2), internal gains level (x2) and occupancy/operation pattern (x4). Figures illustrated here relate to occupancy/operational patterns applied to the air conditioned, high thermal mass, high internal gains case.

[7] Conversions were 0.052kgC/kWh for gas (heating) and 0.127kgC/kWh for electricity, based on Energy Consumption Guide 19 (XXX). Note, 1kgC is equivalent to 3.67kgCO2.

Fig 7. Diurnal emissions profile for type B occupancy/operation in gC/m² (mean annual day)
Fig 8. Diurnal emissions profile for type B occupancy/operation in gC/occupant (mean annual day)

In the diurnal profiles (Figs 7. and 8.), the difference between the two metrics is stark. The ANM of gC/m² showed slight peaks in the hours of highest occupancy[8], whilst the ONM of gC/occupant showed pronounced peaks in periods of low occupancy[9]. The use of this metric here clearly illustrates the need for appropriate energy management outside of a building's core operating hours. Whilst an alternative model incorporating suitable zoning and controls to manage out-of-hours space provision would show emission reductions using both metrics, only the ONM would quantitatively demonstrate the effectiveness a design measure of this nature[10].



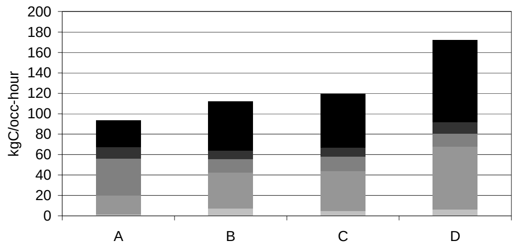


Fig 9. Total annual emissions comparison in kgC/m²
Fig 10. Total annual emissions comparison in kgC/occupant-hour

In the annual profiles (Figs 9. and 10.), contrasting the metrics illustrates something quite different. The ANM of kgC/m² increases significantly between occupancy/operation types B and C (the two broadly realistic cases), whereas the ONM of kgC/occupant-hour remains approximately constant. Although the absolute energy consumption of the building does increase, the ONM demonstrates that this is in proportion to the increase in occupancy. This is a finding particularly relevant in defining benchmarks that can be interchangeable between buildings of a similar typology, but with different patterns of occupancy. In the UK, benchmark guides such as Energy Consumption Guide 19 [3] for offices require users to make their own adjustments to account for occupancy, whilst assessment tools such as CIBSE TM22 [4], LES-TER [5] and the OR (Operational Rating) method[11] have inbuilt functionality to modify benchmarks. However, in theory at least, benchmarks defined in kgC/occupant-hour wouldn't require any such adjustments in order to provide an applicable yardstick.

3. Application and Practicability

It should be noted that the methodology for generating ONMs is likely to be quite different between design stage energy predictions and the reporting of measured performance data from actual buildings. This corresponds to the nature of the complementary, but fundamentally different, contexts of computational modelling and of undertaking energy field surveys [6].

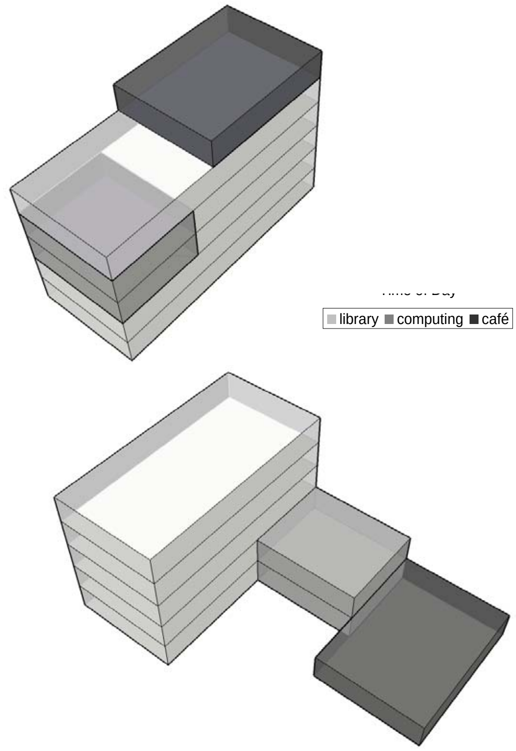


Fig 11. Schematic diagrams representing an academic LCR model with intermingled functions (above), and an alternative model with separated functions (below)

Primarily, design stage energy predictions are a tool for testing the performance of design iterations in a relative sense, where the accurate modelling of absolute energy consumption is a secondary concern. Here, an overall pattern of occupancy might be proposed for the building – this could be based on standard NCM data, and would remain constant for all design options[12]. For each design option, the building would then be broken down into a series of zones (both passive and controlled), where each zone would be given a more specific pattern of occupancy

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[8] A result of related equipment energy usage levels, and cooling loads in the air-conditioned models.
[9] Whilst the equipment loads remain constant per occupant, the energy to provide space heating, cooling and light becomes disproportionate.
[10] For example, halving the out-of-hours energy use per occupant.
[11] OR is the UK methodology used to produce Display Energy Certificates (DECs) of actual energy use in larger public buildings as required under EPBD legislation.
[12] Although the occupancy pattern would remain the same in terms of absolute numbers, the occupant density might vary.

relating to the proposed spatial planning and means of spatial management. The sum of these elements would always be equal to the assumed overall pattern of occupancy for the building. Returning to the example of an academic LCR building, Fig 11. depicts two possible zoning models. That of intermingled functions and that of separated functions. Fig 12. depicts the overall occupancy profile common to both LRC models, and then breaks this down by building zone. The implication is that, where the building is zoned as a homogenous, open-plan space, 24-hour operation is required throughout; whereas, if the building is broken down into three independently serviced zones, only the computing (ICT) area must be in operation continuously.

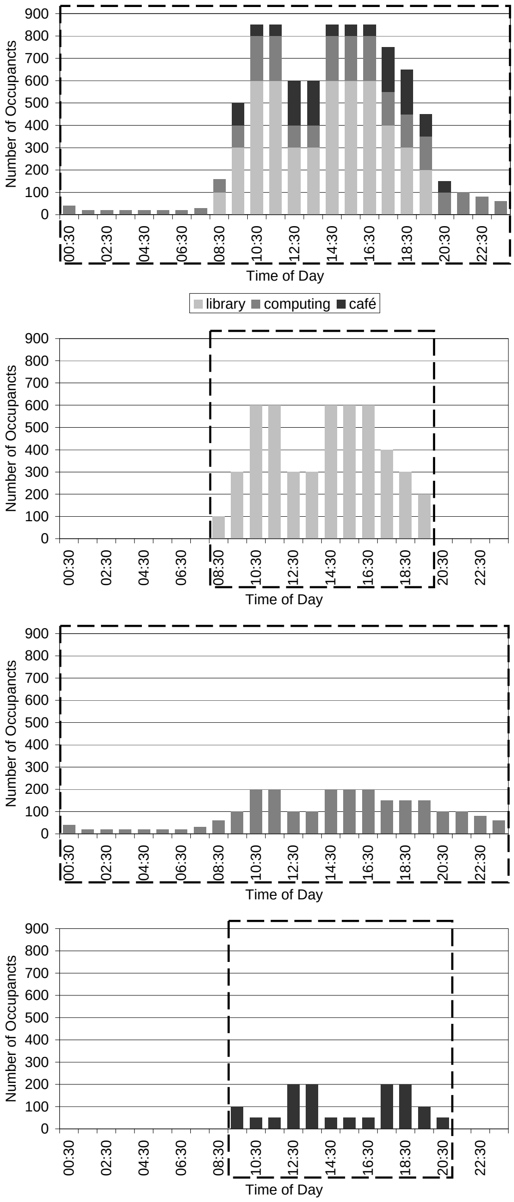

Fig 12. Illustrative weekday patterns of occupancy for an academic LRC building, combined and broken down by building zone. Highlighted areas indicate the necessary hours of operation for building services.

In the case of measured performance data, the primary concern is to ascertain precisely how energy is being used in order to identify means by which consumption may be reduced. Here, the key difference from design-stage situations is that patterns of occupancy are both real and measurable. Techniques such as Time Utilisation Studies (TUS) [7] can be used to produce detailed occupancy profiles and other space utilisation data broken down by building zone[13]. In association with suitable energy sub-metering, this would allow building facilities/energy managers to identify whether the energy consumption pattern of the building overall is in line with the occupancy pattern, and to hone in on areas of mismanagement or wasteful practice by building users. Even in the absence of actual occupancy data, relevant benchmark data could still be applied to facilitate rudimentary ONM energy analysis and target setting.

4. Conclusions

The purpose of this paper is not to tout ONMs as a bigger, better one-size-fits-all solution to energy analysis and reporting. Primarily, it is an exercise in illustrating some of the complexities and nuances of the relationship between people, buildings and energy that are masked by the predominant use of ANMs in contemporary building energy/CO2 reporting, and hence the need to establish alternative metrics. In reality, a multi-faceted approach to energy reporting may be required, with ANMs and ONMs used in parallel to one another (and perhaps "tangentially" to other metrics), to ensure that all of the dimensions of a particular situation are made visible.

In order to make ONMs a robust, integrated part of building regulations/codes compliance models, energy ratings and operational ratings, a unified methodology would be required for establishing occupancy data. Equally, a standardised mechanism would be required for adapting occupancy/operating profiles to demonstrate the impacts of design measures altering zoning/control and space planning efficiency. It should be noted that ONMs are very sensitive to inaccurate/inconsistent occupancy data, and are therefore potentially open to misuse, whereas "floor area" required for ANMs is a fact set in stone. Nonetheless, even pending solutions to these issues in "categorical" demonstration of performance, ONMs already offer a valuable tool to design teams and to building facilities/energy managers. For design-stage use, it would be relatively straightforward for vendors to add ONM reporting functionality to software incorporating occupancy profiles. In the absence of this, proprietary spreadsheets may be used to process data into this format. Likewise, the integration of ONMs into NCM tools would not require any fundamental reinvention of the energy models themselves.

[13] In places of work, an existing well-managed system of employee timesheets would also have the potential to provide an invaluable source for such information.

5. Acknowledgements
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