Paper No 135: The impact of carbon modelling on domestic building design

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Abstract

This paper studies the impact of this shift in metrics for professionals who are active in the field of the design and performance assessment of domestic buildings. It presents a Performance Indicator (PI) - based review of tools available to analyze the carbon emissions of buildings. This is combined with a study of the potential impact of increasingly stringent CO_2 targets on the way of working in the (architectural) design office. This latter part has been structured along the lines of interviews with professionals working in the field.
The findings of the work lead to the conclusion that the use of carbon emissions as metrics adds another 'shell of complexity' around what remains primarily an energy balance for buildings. While this relates building design to an important human ambition (reduction of CO_2 emissions) it also introduces additional uncertainties and assumptions. For the design office, the use of carbon metrics combined with increasingly stringent targets will require a different approach to design. This will either result in further collaboration between architects and consultants, or the need for architectural companies to appoint in-house experts.

Keywords: carbon emissions, modelling, domestic buildings, design practice

1. Introduction

The energy efficiency of buildings has been a factor of importance ever since the energy crisis of the 1970s. Since then, different drivers have been pushing the construction industry to make buildings more energy efficient: first of all the oil crisis of the 1970s, then the aim for sustainable development [1], and more recently concerns about peak oil [2] climate change [3]. In the western world, buildings are now responsible for about a third of the overall energy consumption. As a consequence there is substantial work being undertaken to understand, and subsequently reduce, the energy use of buildings.

The heating and cooling of buildings is mostly achieved by the combustion of fossil fuels, which in turn results in the release of carbon dioxide. Although less potent than other chemicals as an agent of global warming, carbon dioxide has received the most attention not only politically but also in the popular press. Cutting carbon has become the cause célèbre of the campaign to halt global warming with high profile public information drives encouraging the populace to be aware of their personal impact on the environment.

As a consequence, there currently occurs a shift of metrics for measuring energy efficiency away from basic energy consumption (kWh, J/year) to carbon emissions (kg/year). In the United Kingdom, government targets for the thermal behaviour of buildings are now being expressed as reduction in carbon emissions [4]. Carbon emissions are believed to offer a more universally applicable method of comparison. However, they also add an extra layer of complexity when the carbon intensity of energy conversion and transport is taken into account in the carbon emission calculation. They require a new range of building performance assessment methods to analyze the impact of existing and planned buildings.

The use of carbon emissions as key metrics for energy efficiency can be expected to have a large impact on the practice of building designers. This paper aims to analyze the tools available to the trade, and provide an insight into the potential effects on design practice. For scope, the focus of this paper is on the design of domestic construction (housing) only.

1.1 Factors in carbon emission analysis

Carbon emissions in the built environment are intrinsically linked with the main heat flows in buildings (ventilation, solar gain, internal gain, transmission and storage) and with the combustion that takes place in the heating, air-conditioning and cooling (HVAC) system that heats and/or cools the building, as depicted in figure 1. Note that the system where combustion takes place can be contained within the building (e.g. a boiler) or can be remote (e.g. an urban power plant). Also note that there are alternatives to combustion, like PV panels, wind energy and hydro-energy; however, combustion is by far the prevalent driver of HVAC system.

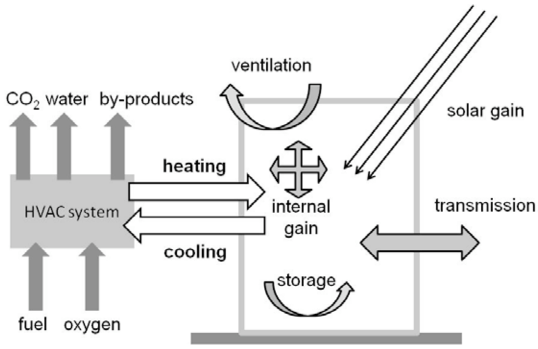

Fig 1. Relation of CO_2 emission to the thermal behaviour of buildings and HVAC system

The heating (and cooling) within the HVAC system is mostly based on combustion, which converts fossil fuel and oxygen into heat, water, carbon dioxide and by-products. The universal chemical formula underlying this process is:

$$C_xH_y + (x + y/4)\ O_2 \rightarrow x\ CO_2 + (y/2)\ H_2O$$

The main fuels used in combustion are different states of hydrocarbons, coming in the form of solid (coal), liquid (oil) or gas (natural gas, LPG). The process of combustion is complex and influenced by a number of factors such as fuel/oxygen mix, temperature, mode (continuous or pulse), (im)purity of the fuel, and others. For a more in-depth discussion, see chapter 18 of the ASHRAE handbook of fundamentals [5].

1.2 Building performance

In order to design, operate and improve human-made systems most industries make use of well-defined performance criteria. For instance the automobile industry uses very clearly defined data on engine capacity, fuel consumption and power ratings that all can be measured (in independent laboratories / test benches) for each individual car. Efforts to introduce performance thinking into building have been ongoing since the early 1980-ies; some milestones along the way have been set by the report 'Working with the performance approach in building' by the International Council for Research and Innovation in Building and Construction [6], and the CIB Program on Performance-Based Building (PeBBu, 2001-2005). Performance thinking has entered building regulations [7], education [8] and industry [9]. However, the application to buildings remains problematic due to a number of factors like:

- the one-off characteristics of buildings, making it hard to predict the specific technologies (structure, infill, services) that will be used and the best way to measure their performance;
- the large changes that can be made to buildings during their lifetime in relation to other systems (renovation, large extension and installation of a complete new set of services is common in construction), introducing aspects of uncertainty and scenario change ;
- the structure of the industry, with a complex combination of actors like clients, architects, specialist consultants, contractors, tenants, financial institutions, facility managers working together on mostly one-off projects over a limited timeframe only, with different objectives, goals and values.

Current approaches to measure building performance have different backgrounds. On one side of the field there is a practical hands-on approach by means of Post Occupancy Evaluation (POE); a good background on this topic is Presser and Visscher [10]. POE efforts typically include straightforward measurements (meter readings) and the investigation of the user perception about buildings in operation. On the other side, building physics experts employ detailed measurement (monitoring) and computer simulation to capture and predict the behaviour of buildings in detail. For good overviews of the related field of building physics see the ASHRAE Handbook of fundamentals [5]; for building performance simulation see Malkawi and Augenbroe [11] or Clarke [12]. In general, it seems that building science largely focuses on today's construction and operation practice. The discipline only pays limited attention to uncertainty analysis, probabilities and risks; most analysis work on buildings is deterministic rather than probabilistic, and provides single value results rather than probable ranges.

The authors of this paper hold that in order to quantify the performance of system as depicted in figure 1, a Performance Indicator (whether that is acquired through a real experiment, a computer simulation, or any other type of assessment) needs to be defined which is based on:

1. the experimental set-up under consideration;
2. the experimental conditions under which the experiment takes place;
3. and the observation protocol employed to gather data from the experiment.

In more practical terms, that means that for the experimental set-up performance needs to be linked to a building or part thereof, with clear system boundaries, and where any simplifications and assumptions are explicitly stated. For the experimental conditions, it means that performance is related to things like the climate, occupant behaviour and control regime. These all need to be taken into account into the performance, as this performance might be different under modified conditions. Finally, it must be clear how data is gained from the experiment, and any aggregation that takes place.

2. Methodology

To study the impact of the shift in metrics from basic energy consumption (kWh, J/year) to carbon emissions (kg/year) on professionals who are active in the field of the design and performance assessment of domestic buildings, this paper starts out with a Performance Indicator (PI) based review of tools available to analyze the carbon emissions of buildings. This contrasts the system view from figure 1, and the three elements for defining a Performance Indicator (experimental set-up, experimental conditions, and observation protocol) with output from available tools, employing both a desk-based review and hands-on investigation.

This is combined with a study of the potential impact of increasingly stringent carbon emission targets on the way of working in the (architectural) design office. This latter part has been structured along the lines of interviews with professionals working in the field.

3. A PI-based review of tools for the quantification of CO_2 emissions

A first step in investigating the tools available for the quantification of CO_2 emissions by buildings is to gain an overview of the tools claiming to be able to fulfil this purpose. The Energy Tool Directory provided by the US Department of Energy on the internet at:
www.eere.energy.gov/buildings/tools_directory/
is arguably the most comprehensive overview of tools for building performance assessment that is currently available. This directory can be searched in different manners. A review of tools under 'other applications – atmospheric pollution' yields 10 programs: BEES, Building Greenhouse Rating, DOE-2, e-Bench, EnergyPlus, FEDS, HEED, LISA, REED and Solar-5.
An alternative is to search the directory with the keyword carbon. This results in different tools being highlighted, adding SBEM, IES VE (ApacheSim) and EMISS to the list. It also returns programs like IAQ tools that deal with carbon dioxide as a tracer gas for indoor air quality.

A related but deeper review of one category of tools is provided by Crawley *et al* [13] who have conducted an in-depth comparison of twenty mainstream whole building energy analysis tools. According to their findings as presented in table 9 of their report, 11 tools are fully able to quantify greenhouse gas emissions (CO_2, CO, CH_4, NO_x): BLAST, DOE-2.1E, Ener-Win, Energy-10, EnergyPlus, eQuest, ESP-r, HAP, HEED, IES/VE, and Tas. Two tools, BSim and DeST, can do this partially and have work in progress in this area.

It is interesting to note that these lists only partially overlap. It demonstrates that in the Energy Tool Directory the use of carbon emissions is not yet seen as a driving factor; at the same time the report by Crawley *et al* [13] shows that there is a range of tools that already can calculate carbon emissions, or that are in the process of being adapted to do so, which are not claiming this as one of their main characteristics. It is also interesting to note that tools with a background in the UK make up a significant part of the tools that do deal with carbon: SBEM, IES VE (ApacheSim), ESP-r and Tas all originate from this country.

In general, the carbon emissions returned by these tools are based on highly different principles.

Tools like Building Greenhouse Rating directly relate building size, building location, occupancy and in some cases existing billing data to a database containing information gathered from existing buildings in order to predict normalised greenhouse gas emissions and energy consumption. An input screen from this program is shown in figure 2. For the ensuing discussion these tools will be named 'relational tools'.

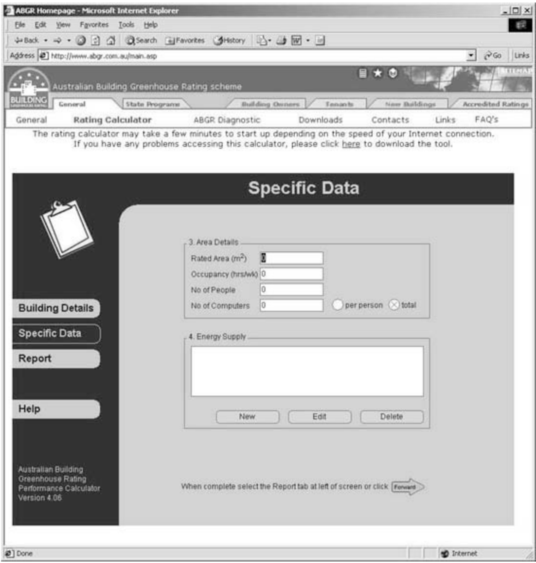

Fig 2. Overall input screen for Building Greenhouse Rating CO_2 emission calculation

SBEM is an interesting tool with close relation to the UK building regulations. The programme, named Simplified Building Energy Model, calculates monthly energy use and carbon dioxide emissions of a building based on input on the building geometry, construction, use and the HVAC and lighting equipment in the building. It is based on the Dutch semi-stationary methodology for calculating the energy performance of buildings NEN 2916:1998. It is the non-domestic counterpart to SAP, the Standard Assessment Procedure for dwellings, which is based on a similar calculation process. The semi-stationary element relates to the building in figure 1 of this paper; in SBEM and SAP the heat flows in this building are calculated based on monthly average values. Conversion to CO_2 emissions is based on emission rates using a simple multiplier, currently set at 0.914 for gas and 0.422 for electricity use. For the ensuing discussion these tools will be named 'intermediate tools'.

The whole building energy simulation tools like ESP-r and EnergyPlus use first-principle calculations to quantify the heat flows in the building. Rather than a monthly average they apply hourly climate data from a location-specific weather data file. Based on the definition of specific HVAC system components and taking into account type of fuel used and efficiency of combustion assumed, they allow the calculation of the related emissions. In a case like EnergyPlus the resulting CO_2 emissions are by default based on a default carbon emission factor, which can be manually changed if required. The program can also take into account NO_x and CH_4, which can be translated into equivalent carbon emissions on the basis of their assumed global warming potential. The sub-screen used for inputting the related data into EnergyPlus is shown in figure 3. For the ensuing discussion these tools will be named 'full first-principle tools'.

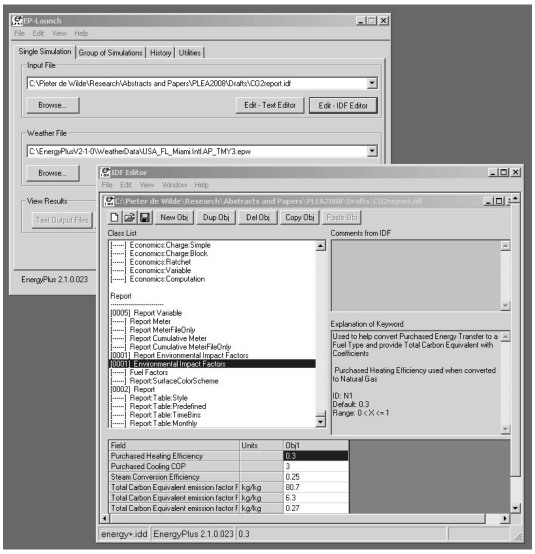

Fig 3. Input screen for setting (equivalent) carbon emissions in EnergyPlus

Relating these three main categories of tools for carbon emission quantification back to the criteria for clear-cut building Performance Indicators, it becomes clear that all types allow a valid assessment. However, the degree in which the user is in control over the information produced by the system is highly variable, as demonstrated by table 1.

Table 1: User control over Performance Quantification in different categories of carbon emission tools

	Exp. set-up	Exp. conditions	Observation protocol
Relational tools	limited	none	none
Intermediate tools	intermediate	limited	none
full first principle tools	full	full	full

A consequence of these different levels of user control is that the simple 'relational tools' provide a fixed performance indicator value that needs to come accompanied with a clear description of the experimental conditions and observation protocol assumed; these tools are inflexible when a slightly different tilt of Performance Indicator is required. A similar statement can be made for the intermediate tools. Note that SAP and SBEM, being legal instruments in the UK, need to have a fixed, prescribed way of predicting performance by their very nature. The full first-principle tools are flexible in all respects; while this has the advantage that Performance Indicators can be tweaked to specific preferences and demands, it also means that the output they generate is much more variable and needs to include information on selected settings in order to be comparable with other performance predictions.

4. Impact on the design office of increasingly stringent CO_2 targets

The method of examining case studies is a well respected method of investigating the impact of legislation upon working practices [14]. The case studies in this paper are based on the opinions of four architects who work for two practices. Both practices are fairly small, employing 18 (Practice A) and 15 (Practice B) people respectively. In both cases a senior architect who qualified over 20 years ago and a young architect who qualified recently were asked for their opinions.

Over the careers of the senior architects interviewed, the overall trend has been for an increase in regulation, both in its scope and the levels of performance to be achieved. An early edition of the complete Building Regulations, published in 1972 had 18 A5 pages. Introduced in 1995 Part L2 of the Building Regulations, which deals with the conservation of fuel and power alone, had 76 A4 pages and the complete regulations now constitute 19 such documents.

4.1 Results for Practice A

When the 2005 version of Approved Document Part L came in, the practice started to employ an external consultant to calculate SAP ratings for each job. This additional fee was passed on to the client. On the advent of the 2006 version of the regulations, the process of producing a rating became highly iterative and it became impractical for the number of ratings carried out by the practice to be calculated externally. At this point an internal SAP assessor was appointed to the practice. As the Code for Sustainable Homes is soon to be introduced, the SAP assessor now takes on the calculations and provision of advice internally to the company, and external companies are now interested in using the service that the practice has built up. Figure 4 shows the desk of this internal assessor with SAP running on the PC, approved documents at hand, and an architectural design being assessed.

In practice A the architects questioned are currently of the opinion that changes to the Code for Sustainable Homes and the inevitable increase in the levels of performance required can be absorbed by the practice. This is due to the availability of in-house expertise. Should the government introduce further measures, these would also be likely to be absorbed in-house, as the practice has embarked upon the route of having a dedicated member of staff and would continue to incrementally upskill that person to cope with the revised requirements.

Fig 4. Internal SAP expertise in Practice A

4.2 Results for Practice B

Practice B continues to employ external consultants to produce SAP rating and Code for Sustainable Homes information. They do not feel this to be a problem as their business has diversified away from new build housing and into interior design.

This move has meant that fewer assessments are required and they do not feel the need to bring this type of expertise in house. The also cite the cost of training for an employee to be able to achieve these roles and the scarcity of people already trained in the jobs market.

Practice B architects see their move toward interior design as a defence of their creativity against a rising tide of prescription and regulation in the new build housing field. Should further changes be introduced they are likely to move out of the field altogether and concentrate purely upon interiors.

4.3 Selection of tools in architectural practice

The selection of tools for carbon modelling is governed by the need to produce a building regulations compliant report for submission to the local authority. At present there are 14 proprietary tools quality assured by the BRE in the UK. As all these tools are quality checked, the accuracy of their output is not a factor in tool selection. This leaves costs, ease of use, and the desirability of other outputs as main factors on which a decision is to be made. In practice A, a tool in the mid-range of cost was selected due to ease of use considerations. As stated practice B uses an external assessor, and hence has not had to select a tool.

4.4 Discussion

Up to now architectural practice A has absorbed the changes in the regulations, with the overall trend being that proposals take longer to draw up and therefore cost the client more. Practice B has diversified away from the regulated area of business into a less regulated area. On the scale of the individual business this has positive results: the business has retained its profitability without having to invest in new staff or training. If this was repeated on an industry–wide scale, however, the consequences could be dramatic, with fewer practices willing to take on work in such a regulated field.

All the architects surveyed expressed dismay that the architectural creativity was being stifled by what they see as over regulation, although they recognise the ever increasing legislative burden to be inevitable. The senior architects stated that they would not be keen to join the profession today. The young architects recognised that the regulations represent a challenge, but could see the positive on the large scale with reduced environmental impacts.

5. Conclusions and remarks

This paper explores what performance assessment tools are currently available to predict the carbon emissions of buildings. It is found that a set of tools can deal with this assessment. Upon closer inspection, these tools can be broadly categorised as ‘relational tools’, ‘intermediate tools’, and ‘full first principle based tools’. All of these categories predict carbon emissions; however, they have different degrees of freedom where it comes to user control over the experimental set-up, experimental conditions, and observation protocol that is employed to calculate those carbon emissions. It seems fair to expect that the building industry would benefit from efforts that ensure that all relevant assumptions made in any carbon emission prediction are clearly presented, in order to prevent the extra complexity of the carbon emission calculation from losing track of the underlying assumptions, making it hard for users to assess what causes the difference between one prediction and another.

For the design office, the use of carbon metrics combined with increasingly stringent targets has already resulted in a need to develop different approaches to design. As demonstrated by the two cases discussed in this paper, it might either lead to different ways of working in the design office, with a new discipline joining the in-house team, or it might result in a change of focus away from carbon emission related design activities.

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