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# The Cambridge Non-Domestic Energy Model

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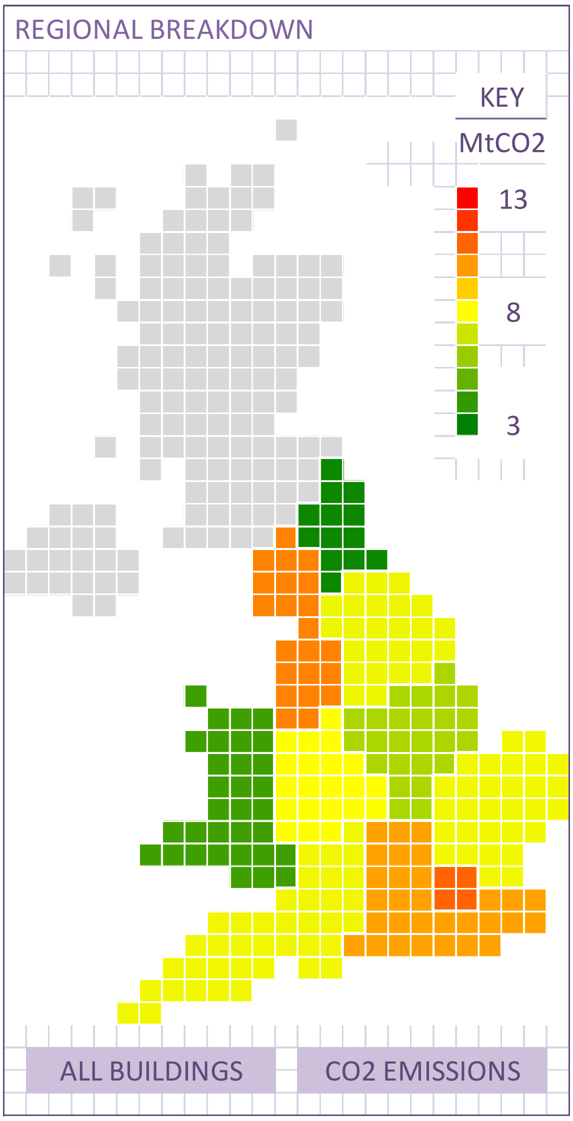


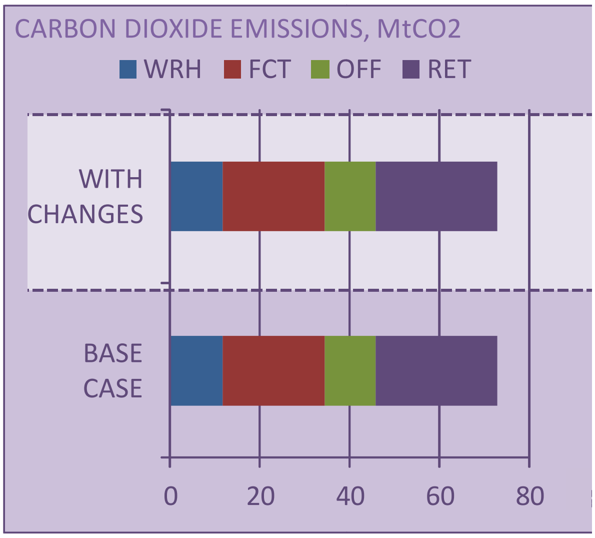


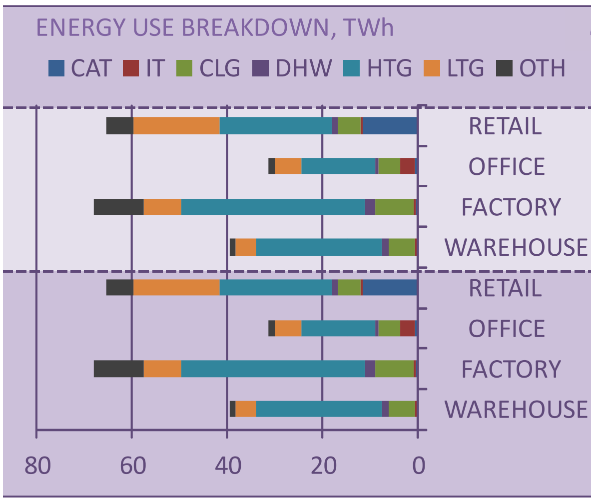

## THE CAMBRIDGE NON-DOMESTIC ENERGY MODEL

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### 1 INTRODUCTION

This briefing note summarises the work carried out on the Cambridge Non-Domestic Model (CNDM). This was the first stage in modelling the energy performance of the non-domestic building stock in England and Wales, and exploring the possible impact of different changes over the coming decade.

In the UK, there are approximately 2 million non-domestic buildings, producing almost one-fifth of the nation's annual carbon dioxide emissions. The current turnover rate of these buildings is low, meaning that over two-thirds of the non-domestic buildings in 2050 are likely to already exist. Improvements to the current stock will therefore need to form part of the efforts to meet the UK's 2050 emissions reduction targets. This means it is important to be able to understand the energy use of the current building stock, as well as having a means of quantifying the impact of possible future changes.

Although they only make up around 7% of the total building stock, the non-domestic sector is considerably more difficult to analyse than the domestic sector. This is due to the greater complexity and diversity of the building designs, systems and uses.

The approach taken here is similar to that used for the Cambridge Housing Model (see blue box). The total non-domestic stock has been disaggregated into almost 35,000 generic building archetypes, designed to be representative of the diversity of buildings in England and Wales. Approximate numbers of each of the generic buildings were gathered from the Government's Valuations Office, and Display Energy Certificates. Next, a simplified, steady-state building energy model was created. The typical energy use of each generic non-domestic building was calculated using the energy model, and the results combined to provide an estimate of the performance of the overall stock.

**The Cambridge Housing Model**

The Cambridge Housing Model (CHM) is a domestic energy model, used to generate estimates of energy use for the Department of Energy and Climate Change (DECC) Housing Energy Fact File (HEFF) and Energy Consumption in the UK (ECUK). The input data is taken from the English Housing Survey (EHS), which in 2011 provided data on 14,591 representative typical dwellings in England. Building physics calculations, based on the UK SAP (Standard Assessment Procedure) energy model, are carried out on each dwelling, producing energy and CO2 emissions rates for each dwelling. This is then scaled up to the entire UK stock using weighting factors for each dwelling. For further information about the CHM, please refer to reference.

After introducing the current status of the work, this report outlines the two key components of the CNDM (the *Stock Model* and the *Building Energy Model*) and explains how they have been combined (into the *Results Spreadsheet*). The results from the CNDM are then compared with equivalent data from the Government's 'Energy Consumption in the UK' statistics, to give an indication of its accuracy. Next, the CNDM has been used to examine the impact of a several scenarios, with different possible changes to the non-domestic building stock. Finally, the report summarises the possible next steps in developing this work further.

A usable version of the Model  is freely available to download from **tiny.cc/CNDM**.

## 1.1 SOME CAVEATS

The CNDM is currently at a prototype stage, demonstrating the methods used. It contains a number of assumptions and simplifications, primarily due to limitations in data availability at the time of writing. We intend to develop and improve the model, and opportunities to improve are explained in the report where applicable. The results, where given, should be considered as an illustration of the type of results that could be achieved with the CNDM.

## 2 THE MODEL

The CNDM combines a *Stock Model* of the non-domestic buildings in England and Wales, with a *Building Energy Model* based on SBEM (Simplified Building Energy Model), the Government's standard energy use model for non-domestic buildings. This methodology is similar in principle to the Cambridge Housing Model (CHM), which combines a large dataset with a standardised energy model. The outputs of these components are combined in the *Results Spreadsheet*, which allows users to examine the impact of different changes to the stock. The flow chart below summarises the way that the different sections interact:

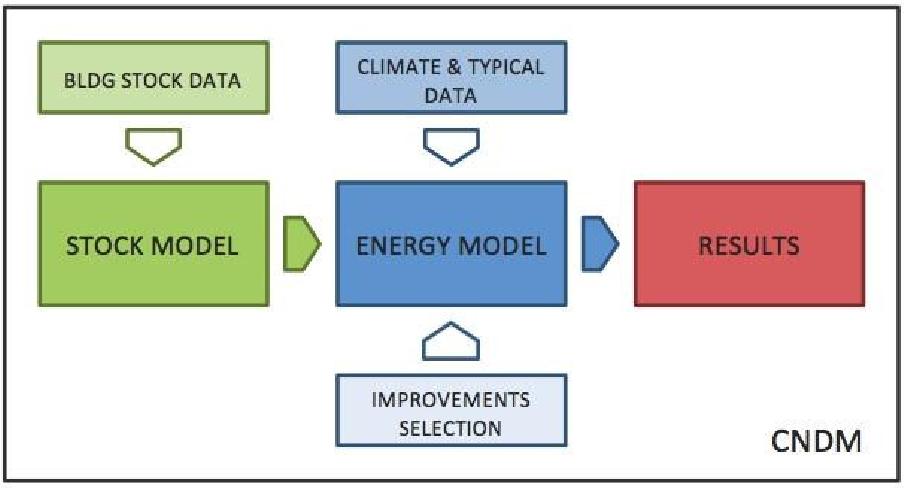


*Figure 1: Flow chart showing the movement of data through the model*

Essentially, the CNDM treats the non-domestic building stock as 35,000 building archetypes. For example, one could be "30-100 $m^2$ air conditioned 1980s office block, in the Midlands". The *Stock Model* estimates the current number of each archetype in England & Wales. The *Building Energy Model* then estimates the typical energy consumption breakdown of each archetype. Finally, the *Results Spreadsheet* combines the two, to provide a breakdown of the energy performance of the overall stock, and calculate related factors such as $CO_2$ emissions.

The impact of different future scenarios can then be assessed within the *Results Spreadsheet* by changing the make-up of the stock, or key factors such as the carbon intensity of different fuels. For example, an increased demolition rate is treated as a reduction in the number of older buildings. Alternatively, a policy to refurbish existing gas-heated offices to become electrically-heated, is estimated by changing the proportions of these building archetypes accordingly. More complex changes -such as alterations in occupancy density in offices or retail display lighting- are represented in the CNDM by the addition of completely new archetypes.

In the following sections, each of the components of the CNDM is explained in detail.

## 2.1 THE MODEL: THE STOCK MODEL

Within the UK, data on the residential building stock is collected regularly via the English Housing Survey: an annually updated, fully disaggregated dataset containing detailed information for a sample of 15,000 homes. Currently, there is no equivalent unified source of information for non-domestic buildings. Consequently, the stock model for this study combines publicly available aggregated data from a number of different sources. The key sources of data used are summarised below.

| **Source** | **Year** | **Data** |
|---|---|---|
| VOA Commercial and Industrial Property Statistics | 1998 - 2012 | Aggregated building **floorspace** and **number** data, split by **building type** and **location**. |
| VOA Building Age Statistics | 2012 | Aggregated floorspace and number data, for **building age**. The data is split by building type and location. |
| Display Energy Certificates | 2008-2011 | Disaggregated **HVAC** data for a sample of public non-domestic buildings. Data includes floor-space, location, building type, etc. |
| Steadman, et al. Env. And Planning | 2000 | Aggregated **building form** data, for a survey of non-domestic buildings. The data is split by building type and size. |
| BRE, Non-Domestic Factfile | 1998 | Aggregated **building form** data, for a survey of non-domestic buildings. The data is split by building type and size. |

*Table 1: Summary of data sources*

The disparate sources listed above have been combined to form a single *Stock Model* dataset, using the VOA commercial and industrial property statistics for 2012 as the base, with 4 building types; offices, retail, warehouses and factories.

Each of the sources has been added by scaling the floor-space and number figures to 2012 where necessary. In lieu of more accurate data, where the correlation between variables is unknown these have been treated as independent. For example, data showing how HVAC (heating, ventilation and air conditioning) varies with building age was not found, so these have been assumed to be independent.

The final *Stock Model* categorises the England & Wales' non-domestic buildings using the 8 variables listed in the table below. Each variable is known to have a significant impact on building energy use and emissions, either directly (e.g. heating fuel impacts directly on building emissions, as the carbon intensity of electricity is roughly three times higher than natural gas), or indirectly (e.g. building age, which was used to approximate envelope thermal and system performance).

| **Variable** | **Number** | **Options** |
|---|---|---|
| Building Type | 4 | Office, Retail, Factory, Warehouse |
| Building Age | 7 | Pre 1940, 1940-70, 1971-80, 1981-90, 1991-2000, 2001-03, 2004-2012 |
| Region | 10 | East Midlands, Eastern, London, North East, North West, South East, South West, Wales, West Midlands, Yorkshire & Humber |
| Floor Area ($m^2$) | 7 | Up to 30 $m^2$, 30-100 $m^2$, 100-300 $m^2$,300-1000 $m^2$, 1000-3000 $m^2$, 3000-10,000 $m^2$, over 10,000 $m^2$ *[The exact floor area in each category depends on the building type]* |
| HVAC | 4 | Air Conditioned, Mechanical Ventilation, Mixed Mode, Naturally Ventilated |
| Heating Fuel | 2 | Electricity, Fossil Fuel |
| Building Form | 2 | Type 1 (Side Lit), Type 2 (Deep Plan for retail/offices, or Shed for factories/warehouses) |

*Table 2: Summary of building variables*

Not every combination results in a real building type, therefore the total 2012 stock is represented by 29,960 unique building archetypes. A further 4,280 archetypes are used in the CNDM to represent 'new' buildings built post-2012, in future scenario testing. It should be noted that the distribution of these types is not uniform, so many of these types represent very small numbers of buildings.

## 2.2 THE MODEL: THE BUILDING ENERGY MODEL

Building energy models may be top down (statistical) or bottom up (physical models), and can include various levels of detail. For the purposes of the CNDM, a simple bottom up model was considered ideal, as this allows improvements to buildings to be assessed, as well as requiring a low level of input detail and computation compared to e.g. a Dynamic Simulation Model.

For each building, the CNDM *Building Energy Model* calculates annual energy use and $CO_2$ emissions. These figures are categorised by end-use (catering, IT, cooling, domestic hot water, heating, lighting and other), as well as fuel type (electricity or fossil-fuel). These uses can be considered as either 'regulated' or 'unregulated' energy consumption, which are estimated using slightly different approaches in the CNDM.

### 2.2.1 THE MODEL: THE BUILDING ENERGY MODEL: REGULATED ENERGY USE

Regulated energy use is defined as energy that is covered by the Building Regulations and covers heating, cooling, lighting, ventilation and pumps & fans. The CNDM uses an adapted version of the SBEM

(Simplified Building Energy Model) algorithms to estimate regulated energy use. SBEM is an accepted energy model used in the UK, based on the BS EN ISO 13790 standard. It uses a simple quasi-steady state heat balance approach to heating, by estimating internal and external gains (e.g. from occupants and equipment, or from solar gains), and heat loss through the building fabric. This approach has historically been used as a compliance tool for estimating energy use for Building Regulations and EPCs, but is also the basis for the Non Domestic Green Deal.

The adapted SBEM algorithms were implemented in Microsoft Excel, with details of the calculations being taken from the SBEM Technical Manual, the SBEM User Guide, and the SBEM C++ code, and the NCM (National Calculation Method) Modelling Guide. All of these documents are available to download from http://www.ncm.bre.co.uk/. The NCM templates describing typical building operational details may be accessed through the latest version of the SBEM model, using Microsoft Access to view the tables. This was used to provide the following details on the building operation and local environment:

| **Operation** | **Local External Environment** |
|---|---|
| Light levels | External Illuminance (by time of day) |
| Internal gains (occupants and equipment) | Average External Temperature |
| Heating and Cooling Setpoints | Solar Radiation (by orientation) |
| Ventilation requirements | Average Wind Speed (by orientation) |
| Domestic Hot Water requirements | |
| Operational hours | |

*Table 3: NCM template details used in the CNDM*

### 2.2.2 THE MODEL: THE BUILDING ENERGY MODEL: UNREGULATED ENERGY USE

The CNDM assesses unregulated energy using data from a recent analysis of building surveys (originally led by Sheffield Hallam University) carried out by Liddiard (2013). The data describes typical unregulated electrical energy use intensities across the non-domestic stock, split by end use, room type and building sector, for the following end uses using area weighted averages from each room type:

- Computers
- Catering
- Small Power
- Lifts
- Telecoms
- Process Loads
- Other and Unknown

The typical energy use intensities are available as kWh/m$^2$/yr, and these are multiplied by the floor area for each building in the CNDM to estimate the annual consumption.

## 2.3 THE MODEL: RESULTS SPREADSHEET

The CNDM *Results Spreadsheet* combines the results of the *Stock Model*, with the *Building Energy Model* to provide estimates of the performance of the overall non-domestic building stock in the UK, and examine the potential impact of changes.

Future energy use for 2012 to 2022 is assessed using user-selected new build and demolition rates to estimate the number of each building archetype in each year. Similarly, energy use is converted into $CO_2$ emissions using user-selected carbon intensity, to allow for changes to electricity generation technology to be examined. The spreadsheet presents the overall energy & emissions results, future projections and regional distribution (see figure below). It has been designed to be interactive, so users can adjust the future projection criteria, as well as the variables presented in the results.


*Figure 2: Screenshot of the Results Spreadsheet*

Although the framework of the CNDM allows for significant flexibility in considering changes to the stock, a number of simplifying assumptions have been made at this stage in order to streamline this preliminary model. For instance, demolition and new build rates are treated as being uniform across building types.

## 2.4 THE MODEL: COMPARISON WITH ECUK

In order to validate the CNDM, the outputs were compared against the latest available publication of Energy Consumption in the UK (ECUK). This is published each year by the Department of Energy and Climate Change (DECC), and gives energy consumption figures aggregated over the whole UK, split by end use in the Domestic, Services, Industrial and Transport sectors. The services sector broadly covers the non-domestic sector, as well as a few miscellaneous sectors such as agriculture, though it does not include consumption from factories or industry. Therefore, this comparison has been carried out just for the Retail, Offices and Warehouse CNDM categories, with the Retail, Government and Commercial Offices, and Warehouse sub-sectors respectively.

Due to the different levels of geographical aggregation (the CNDM covers England and Wales, while ECUK covers the UK) the results are presented for the proportion of energy use for different end uses across the stock, rather than the absolute figures (see below).

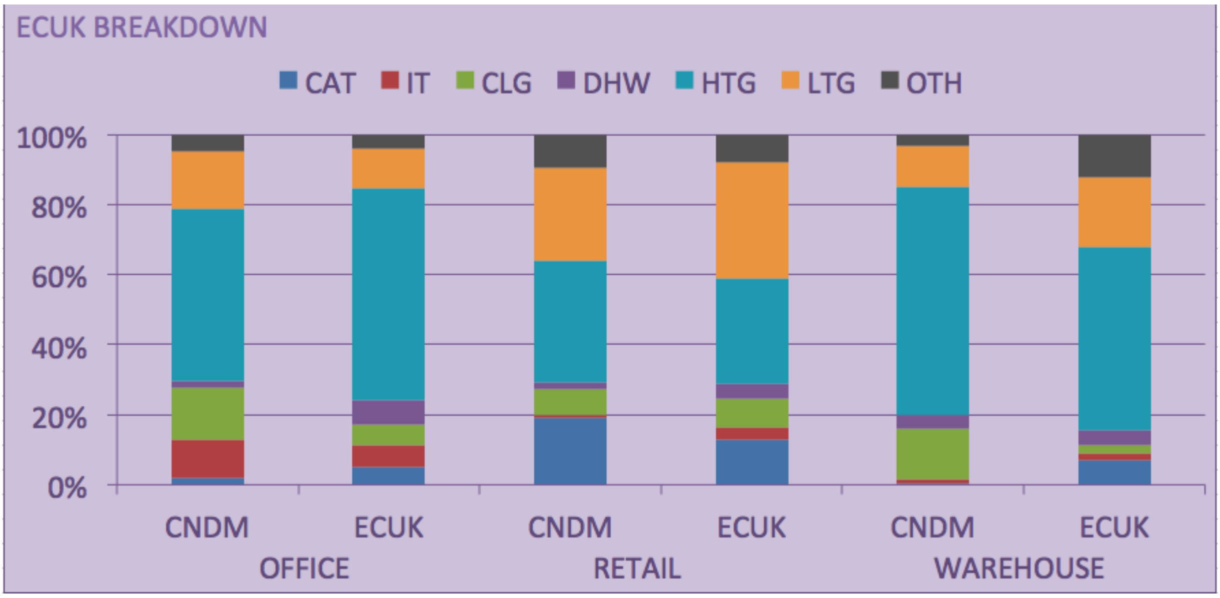


*Figure 3: Comparison between the CNDM and ECUK for the Retail, Office and Warehouse sectors*

The comparison shows a good level of correlation between the CNDM and ECUK figures. This indicates that while the CNDM is still a work in progress, it is still capable of estimating the energy consumption in the non-domestic sector effectively.

## 3 ANALYSIS & RESULTS

As an illustration of the capabilities of the CNDM, this section describes the outputs of the model for the base model between 2012 and 2022, and the results from a range of improvement scenarios.

### 3.1 ANALYSIS & RESULTS: FUTURE SCENARIOS

The primary function of the CNDM is to estimate the energy consumption in the non-domestic stock by region, type and end use. It is also able to project future energy consumption figures, given estimates of the net build rate for the non-domestic stock, and the energy characteristics of the new buildings.

The figure below shows the trajectory of non-domestic energy consumption between 2012 and 2022, assuming a constant build rate of 2% per year and demolition rate of 0.5% per year. This assumes that new builds have a 25% reduction in regulated emissions over recent buildings (2004+), but a 25% increase in unregulated emissions.

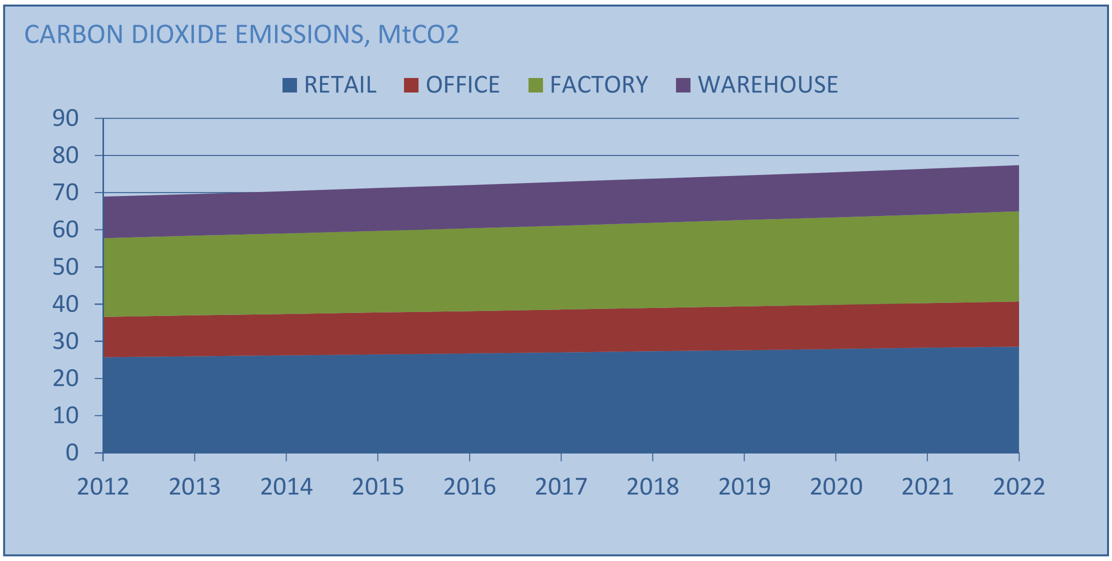


*Figure 4: Emissions trajectory between 2012 and 2022*

Further development of the model could allow for greater fine tuning of the demolition and build rates for the non-domestic stock, spatially and in time, as well as a more nuanced representation of future Building Regulations. Also, the impact of different climates could be included, drawing on research from UKCIP on the trends in temperature due to climate change.

### 3.2 ANALYSIS & RESULTS: IMPROVEMENT SCENARIOS

In addition to using the CNDM to project future energy consumption, it is also possible to use it to test the impact of changes to the stock. This could be policy changes, such as retrofitted improvements, or cultural changes such as an increased use of air conditioning. The prototype model includes the following example scenarios for the non-domestic stock, applied to the year chosen by the user:

- Fabric improvements (to the whole stock)
- Lighting improvements (to the whole stock)
- 75% uptake of air conditioning
- 75% uptake of electric heating in office and retails units

To demonstrate the impact of fabric improvements, the model was tested, assuming that infiltration rates dropped to 4 $m^3/m^2/hr$@50Pa, external wall U-values improved to 0.35 $W/m^2/K$ (i.e. cavity, internal or external insulation), and glazing U-values improved to 1.8 $W/m^2/K$ (i.e. double glazing). The lighting improvement assumed that all lighting was replaced with high efficiency fluorescent lighting, with improved controls.

Note that these improvements are used as an example only; further development of the model will allow a greater refinement of the improvement model, including uptake rates and rebound effects. The impact of the fabric and lighting improvement scenario is illustrated in the table below, both separately and combined:

| Energy Consumption (TWh) | Heating | Cooling & Ventilation | Hot Water | Lighting | Other | Total |
|---|---|---|---|---|---|---|
| Base Case | 102.4 | 21.6 | 4.8 | 35.0 | 31.6 | 195.6 |
| Fabric Improvement | 56.1 | 22.1 | 4.8 | 35.0 | 31.6 | 149.7 |
| Lighting Improvement | 97.8 | 20.9 | 4.8 | 13.5 | 31.6 | 168.7 |
| Fabric + Lighting | 52.5 | 21.0 | 4.8 | 13.5 | 31.6 | 123.6 |

*Table 4: Energy reductions due to fabric improvements across the stock*

## 4 CONCLUSIONS & FURTHER WORK

The analysis presented here shows the potential for the CNDM methodology to model the non-domestic sector in England and Wales.

Further work would include developing a robust method for scaling the results up to the UK. This could potentially be done by using the figures for total UK energy use from DUKES for some of the key sectors, and then applying these scaling factors to the rest of the stock.

This analysis only used high level statistics from the VOA, meaning that the analysis could only be carried out at the regional level. Obtaining more detailed data from the VOA could allow the model to be run at a lower geographical scale, with more detail on the distribution of non-domestic buildings types and their internal uses.

## 5 REFERENCES

Useful links:

- CHM download and report: https://www.gov.uk/government/statistics/cambridge-housing-model-and-user-guide
- ECUK data: https://www.gov.uk/government/collections/energy-consumption-in-the-uk
- National Calculation Method: http://www.ncm.bre.co.uk/

Data sources:


- BRE, 1998. Non-Domestic Building Energy Fact File. BRE Press, Watford.
- Display Energy Certificates database https://www.ndepcregister.com/
- Liddiard, R., 2013. Room-scale profiles of space use and electricity consumption in non-domestic buildings. Build. Res. Inf. 42, 72–94. doi:10.1080/09613218.2013.817112
- Steadman, P., Bruhns, H.R., Gakovic, B., 2000. Inferences about built form, construction, and fabric in the nondomestic building stock of England and Wales. Environ. Plan. B Plan. Des. 27, 733-758. doi:10.1068/bst13

- VOA, 2012. Business Floorspace (Experimental Statistics), http://www.voa.gov.uk/corporate/statisticalReleases/120517_CRLFloorspaceReleaseNotes.html