National Heat Study

Heating and cooling in Ireland today

Archetype Profiles, Spatial Analysis, and Energy Efficiency Potential

seai SUSTAINABLE ENERGY AUTHORITY OF IRELAND

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Report 1 of the National Heat Study

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February 2022
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The National Heat Study and associated reports were commissioned by a project team across the SEAI Research and Policy Insights Directorate and developed with the assistance of Element Energy and Ricardo Energy and Environment.

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Sustainable Energy Authority of Ireland

SEAI is Ireland's national energy authority investing in, and delivering, appropriate, effective and sustainable solutions to help Ireland's transition to a clean energy future. We work with the public, businesses, communities and the Government to achieve this, through expertise, funding, educational programmes, policy advice, research and the development of new technologies.

SEAI is funded by the Government of Ireland through the Department of the Environment, Climate and Communication.

Key insights

Greenhouse gas emissions from heating and cooling in Ireland

- The total CO_2 emissions from fossil fuel consumption for the heating of all buildings (residential and non-residential) and from industrial applications in Ireland is 14.1 $MtCO_2$. This represents 38% of total energy-related CO_2 emissions, or 24% of total national greenhouse gas emissions.
- The majority of these emissions are from natural gas (39%) and oil (36%), with the remainder from coal and peat.
- The residential and industrial sectors account for a combined 81% of total CO_2 emissions from fuels used for heating.
- The total CO_2 emissions from the cooling of all buildings and industrial applications in Ireland is approximately 1.3 $MtCO_2$.
- Retail buildings account for the bulk of CO_2 emissions from energy used for cooling (72%), due largely to refrigeration.

Residential

- The residential sector causes just under half (48%) of all CO_2 emissions from fossil fuel used for heating (6.8 $MtCO_2$) annually.
- Residential oil boilers account for 25% of the total CO_2 emissions from energy used for heating across all sectors.
- 61% of CO_2 emissions for heating in the sector come from detached houses, within which most emissions (52%) result from oil use.
- 21% (1.5 $MtCO_2$) of residential CO_2 emissions for heating come from solid fuels, i.e. coal and peat. This is more than comes from natural gas use in the sector. This is due to both the high CO_2 intensity of solid fuels and the low efficiency of open fires.

Industry

- Industry has the second largest share of CO_2 emissions from fuel used for heat, accounting for 33% (4.6 $MtCO_2$) per year. It is also responsible for 19% (0.26 $MtCO_2$) of CO_2 emissions from cooling.
- The large industrial sites within the EU Emission Trading Scheme (ETS) account for 87% of the energy-related CO_2 emissions from the sector. The top 15 sites account for 38% of CO_2 emissions.
- Heat demand is split relatively evenly between different grades/temperatures of heat. Heating demands at >500°C (high-grade heat), 150-500°C (medium-grade heat) and 100-150°C (medium-low-grade heat) are ~26%, ~35% and ~32% of total heating demand respectively, with a smaller demand for low temperature heat (<100°C) of ~8% of total industrial heating demand.

Commercial and public services

- Commercial and public services create 17% (2.5 $MtCO_2$) of heating-related CO_2 emissions and 72% (1.0 $MtCO_2$) of cooling-related CO_2 emissions per year.
- Electricity accounts for 70% of the CO_2 emissions and 62% of the energy used for heating in commercial offices and retail.
- Education is the only services activity where oil accounts for most CO_2 emissions (64%) and energy use (59%) for heating.

Fuel use for heating and cooling

- The total fuel use for the heating of all buildings and industrial applications in Ireland is approximately 60 TWh, or 42% of final energy used in Ireland in a typical year.
- The residential sector has an annual fuel use for heating of 26.3 TWh and negligible cooling demand, representing 18% of Ireland's total final energy use.
- Industry has an annual fuel use of 20.7 TWh for heating and 0.8 TWh for cooling, corresponding to 15% of total final energy use.
- The services sector has an annual fuel use of 10.0 TWh for heating and 3.1 TWh for cooling, corresponding to 9% of total final energy use.

- The highest heat demand densities (energy demand per unit area) are around the cities and existing industrial sites.
- 20-25% of domestic, commercial and public heat demand is within the five largest cities in Ireland (Dublin, Cork, Galway, Limerick and Waterford).
- 53% of industrial heat demand is in just four small geographical areas.

Energy efficiency

- The analysis finds a lower potential for energy efficiency measures to reduce energy demand and greenhouse gas emissions than in previous studies. The estimates include an updated assessment of the suitability of various efficiency upgrades for different building and industrial archetypes. This assessment also considers the energy efficiency upgrades delivered across all sectors to date.
- The energy efficiency savings presented in this report focus on the potential for reducing energy use via improved building fabric, improved industrial processes, lighting and appliances. They do not include the potential for switching to more efficient heating technologies, such as heat pumps.[1]
- For the residential sector, the potential savings are adjusted to account for comfort gains taken in lieu of energy savings, also known as the rebound effect. Rebound effects are not considered for the other sectors due to a lack of data.
- If the improved building fabric and industrial processes measures considered in this report are adopted in all buildings and industrial applications in which they are deemed suitable, they could reduce emissions from heating and cooling demand by 2.2 $MtCO_2$ (16%) per year.
- Sectorially, this potential breaks down as 9% in industry (0.4 $MtCO_2$), 16% in residential (including rebound) (1.2 $MtCO_2$), 19% in public services (0.2 $MtCO_2$) and 25% in the commercial services sector (0.4 $MtCO_2$).
- 41% of the potential heating demand savings in the residential, commercial and public sectors would result from installing high-efficiency glazing in suitable properties. A further 37% of the potential heating demand savings would result from improving the fabric wall insulation for both solid and cavity walls in suitable properties across these three sectors.
- Energy efficiency improvements could reduce non-heating electricity consumption (e.g. that used for lighting and appliances) by a total of 15% (0.9 Mt CO_2) across all sectors.

These findings, together with other insights in this report, inform the wider National Heat Study. A final report will analyse net-zero pathways to 2050. The full suite of reports will be available at www.seai.ie/data-and-insights/national-heat-study/.

[1] Heat supply technology switching is accounted for separately in the wider National Heat Study and net-zero pathways presented therein.

Acknowledgements

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- Auginish Alumina
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- Irving Oil Whitegate Refinery
- SEAI Large Industry Energy Network (LIEN) participants
- Technology Ireland

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Executive summary

Ireland's 2021 Climate Action and Low Carbon Development (Amendment) Act commits to reducing greenhouse gas emissions by 51% by 2030 and to achieving economy-wide carbon neutrality by 2050. This requires immediate emissions reductions in every sector. Energy used for heating and cooling accounts for 24% of Ireland's greenhouse gas emissions, but the current pace of decarbonisation falls short of the cuts required. Almost every sector of Ireland's economy uses heat energy, and decarbonisation efforts will need to be implemented by industry, businesses, and households. This requires a comprehensive, robust and actionable evidence base that policymakers and other stakeholders can use to make decisions.

The Sustainable Energy Authority of Ireland (SEAI) commissioned Element Energy and Ricardo Energy and Environment to work with SEAI on the National Heat Study to provide this evidence base. The study evaluates the costs and benefits of various pathways that reach net zero by 2050. We based the evaluation on a comprehensive understanding of heating and cooling demand in Ireland and the deployment costs, potential and suitability of technologies, infrastructure and fuels to reduce emissions.

We have separated the insights and analysis from the study into eight reports (outlined in Figure 1)[2]. These reports provide a rigorous and comprehensive analysis of options for decarbonising heating and cooling in Ireland up to 2050. The findings support Ireland's second submission to the EU of a national comprehensive assessment of the potential for efficient heating and cooling, as required by Article 14 of the Energy Efficiency Directive.[3] There are seven major technical reports, each focusing on topics that form the overall analysis. The concluding report is called *Net-Zero by 2050*[4]. It outlines the study's key insights across scenarios that achieve net-zero emissions from heating and cooling.

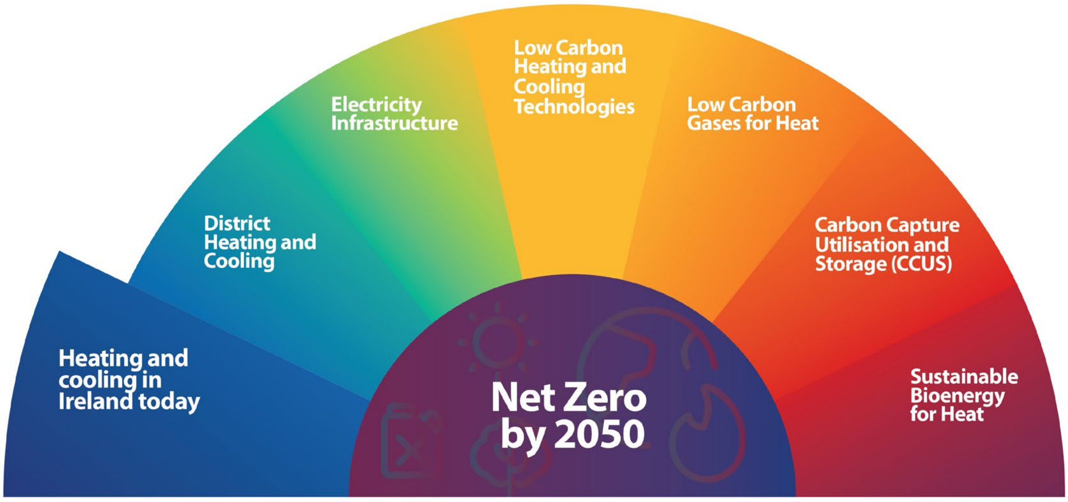
This report, *Heating and cooling in Ireland today*, describes the analysis carried out to profile Ireland's heating and cooling energy demand and CO_2 emissions. It includes a detailed description of the archetype model that has been developed, the spatial analysis of heat demand, and the analysis to quantify the maximum potential for reducing heating and cooling emissions through energy efficiency measures.

[2] All reports and supporting materials published as part of the National Heat Study are available from www.seai.ie/NationalHeatStudy/

[3] SEAI, 'Comprehensive Assessment of the Potential for Efficient Heating and Cooling in Ireland, report to the European Commission'. 2021 [Online]. Available: https://www.gov.ie/en/publication/e4332-introductory-text-for-publication-of-the-national-comprehensive-assessment-on-govie/#.

[4] SEAI, 'Net-Zero by 2050: Exploring Decarbonisation Pathways for Heating and Cooling in Ireland. 2022 [Online]. Available: www.seai.ie/publications/Net-Zero-by-2050.pdf.

Figure 1: Framework of reports



Improved data and insights

The data and analysis in this report builds a robust and detailed representation of Irish heating and cooling demand. It adds to previous SEAI work on profiling demand in Ireland [1] [2] and advances and improves on previous studies. The updated analysis includes:

- Incorporation of the latest data from the domestic (i.e. residential) and non-domestic (i.e. commercial and public services) Building Energy Rating (BER) databases.
- A new approach for the industrial sector, categorising industrial heating demand by industrial subsector, processes, equipment and temperature of heat is used to enable improved understanding of the decarbonisation options for Irish industry.
- Detailed agricultural archetyping, leveraging the best available agricultural data from the Central Statistics Office (CSO) and recent Teagasc studies.
- Updated geospatial mapping to depict the latest understanding of the distribution of existing heat demand across Ireland's 18,641 small areas, as defined by the National Institute of Regional and Spatial Analysis (NIRSA), on behalf of the Ordnance Survey Ireland (OSi) and used by the CSO.

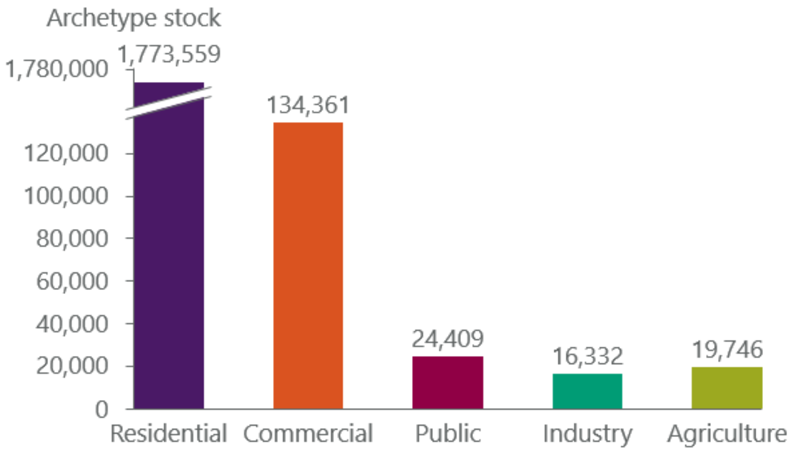
Approach

The profiling of the heating and cooling demand in Ireland is split into five primary sectors: residential, commercial services, public services, industry and agriculture. The sectors were chosen to match the classification in the *National Energy Balance* data [3]. This link enables the modelled energy use of each sector to be calibrated to the official national energy statistics, as produced by SEAI.

To characterise the energy demand and associated emissions for heating and cooling, a set of archetypes represents each sector.

For each of the five sectors, data were gathered to represent the (i) heating demand, (ii) cooling demand and (iii) non-thermal electrical demand of each archetype (i.e. building type or industrial application), using the latest available data sources. The archetyping approach allowed the representation of the entire Irish building stock and industrial applications at a higher level of detail than any previous SEAI work. *Figure 2* shows the high-level archetype stock breakdown by sector.

Figure 2: Total number of archetype stock in each sector



Note:

- *Industry stock represents pieces of industrial equipment.*

Total emissions and demand from heating and cooling in Ireland

The total annual CO_2 emissions from fossil fuel consumption for the heating of all buildings and industrial applications in Ireland, across all sectors, is approximately 14.1 $MtCO_2$. This represents 38% of total energy-related CO_2 emissions, or 24% of total national greenhouse gas emissions. CO_2 emissions from gas (39%) and oil (36%) make up the majority (75%) of these emissions. The residential and industrial sectors account for a combined 82% of total heating fuel use.

Figure 3 and *Figure 4* show total emissions ($MtCO_2$) from energy used for heating by sector. *Figure 5* and *Figure 6* show heating demand (GWh) by fuel type.

Figure 3: Total annual emissions ($MtCO_2$/annum) from fuel use for heating, by sector

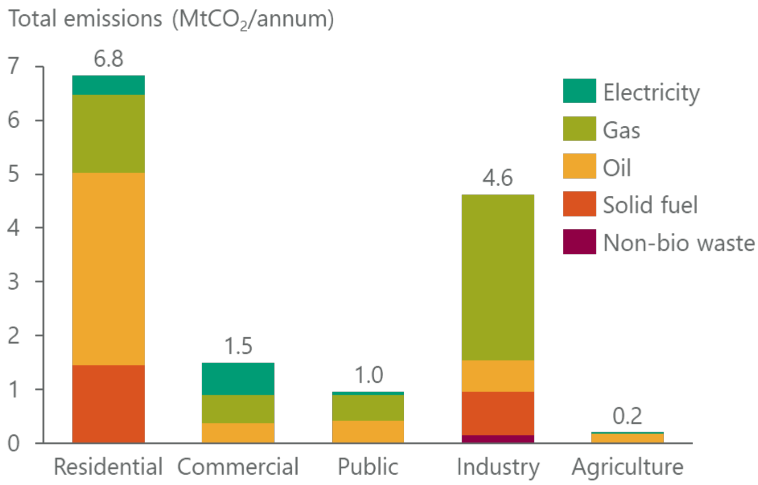


Figure 4: Percentage breakdown of emissions from fuel use for heating, by sector

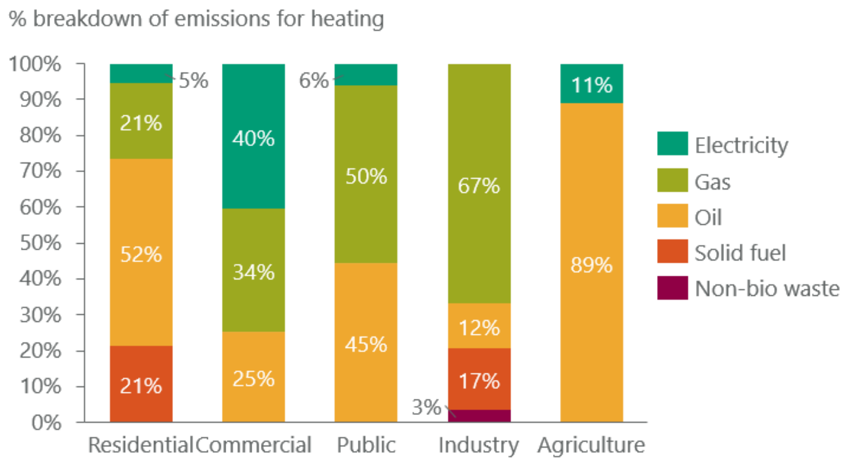


Figure 5: Total annual heating demand (GWh/annum), by sector

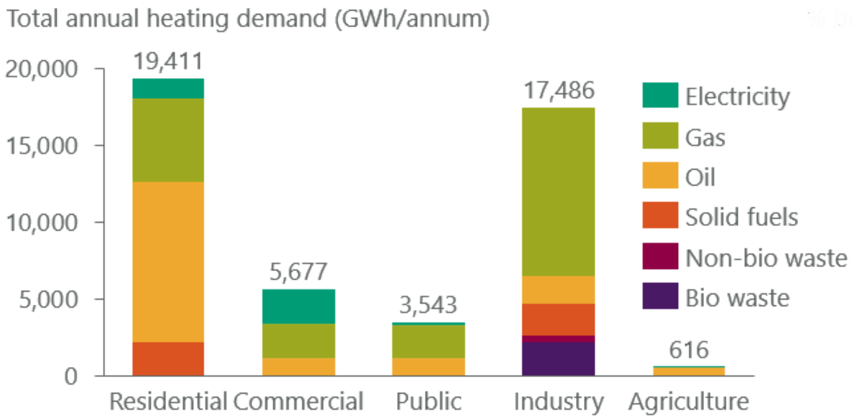


Figure 6: Percentage breakdown of total annual fuel use for each sector, by fuel type

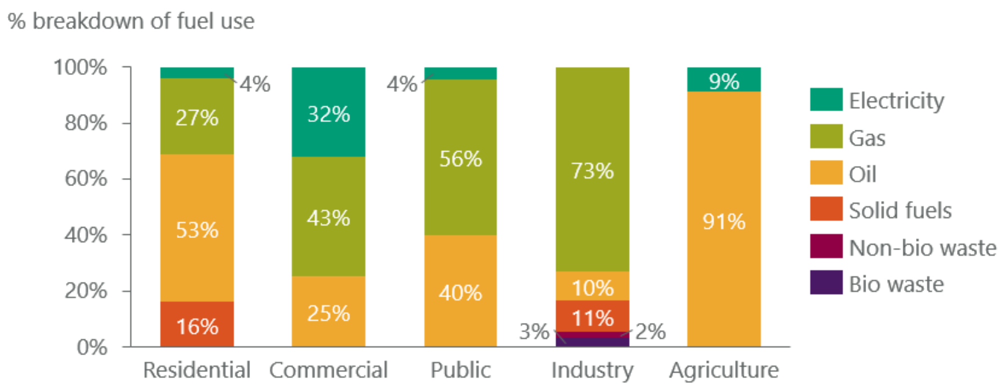
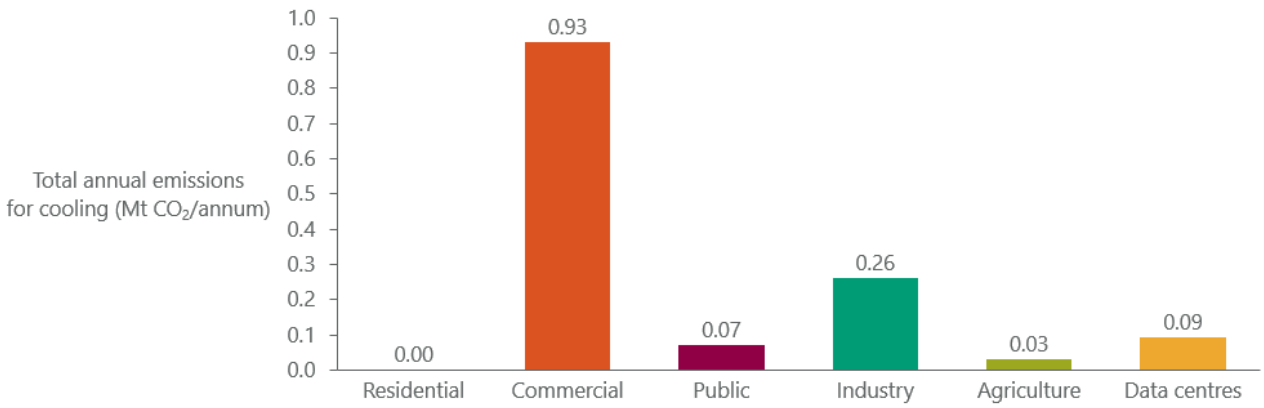


Figure 7 and *Figure 8* below show the annual emissions from cooling by sector. All cooling demand is assumed to be met by electricity.

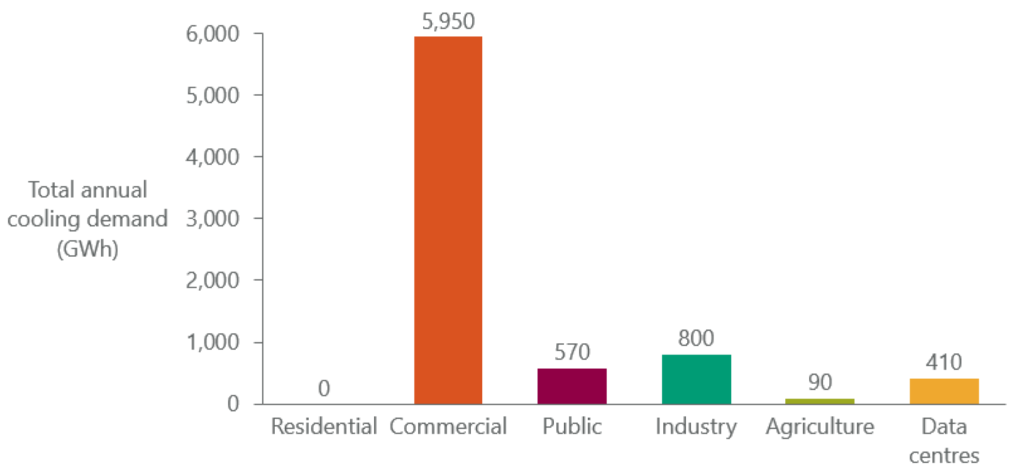
Figure 7: Total annual emissions from cooling ($MtCO_2$/annum), by sector



Note:

- *All cooling demand is assumed to be met by electricity.*

Figure 8: Total annual cooling demand (GWh/annum) by sector



Note:

- *All cooling demand is assumed to be met by electricity.*

Residential sector heating and cooling profiles

Profiling of the residential sector is based on the residential BER database. This includes detailed data on more than 700,000 residential properties, including:

- Property type
- Size
- BER rating
- Main heating system
- And an estimate of the annual energy used for space heating, water heating and lighting, based on standardised operating conditions.

Estimates of energy use are derived by adjusting the BER data to account for real heating behaviour, through a calibration process to Ireland's *National Energy Balances* [3], as produced by SEAI.

The residential sector is the largest source of CO_2 emissions from heating, responsible for approximately 6.8 $MtCO_2$. Of that total, 52% is due to oil use (mainly in detached homes) with a further 21% due to gas and 21% due to solid fuels, as shown in *Figure 9*. Space heating demand constitutes 75% of the total heat demand across all dwelling types, with the rest due to hot water heating demand. Cooling demand in the sector is negligible today, and this is not anticipated to change between now and 2050.

Figure 9: Total annual heating demand (GWh/annum) in the residential sector, by fuel type and building type

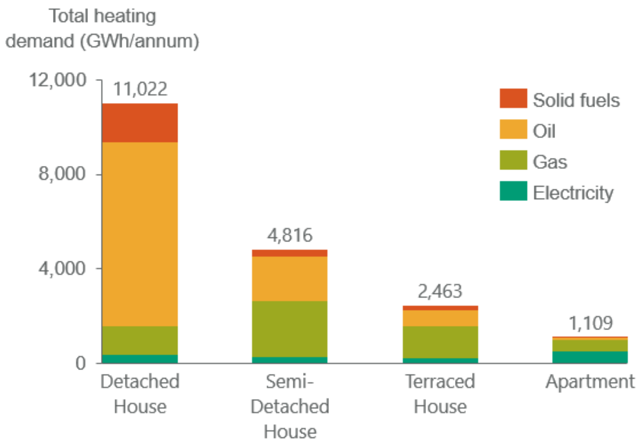
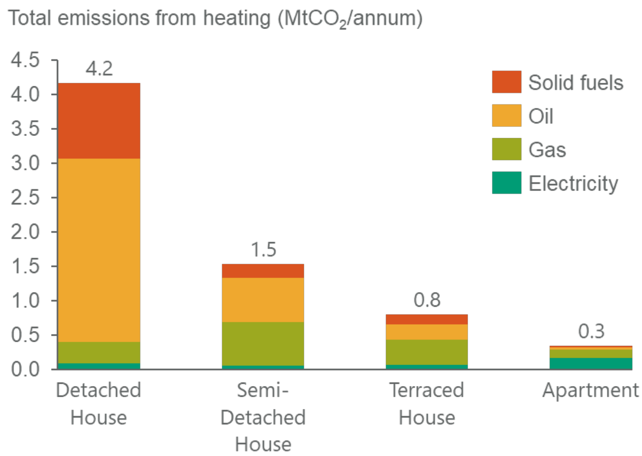


Figure 10: Total annual emissions from heating ($MtCO_2$/annum) in the residential sector, by fuel type and building type



Commercial and public services sector heating and cooling profiles

Profiling of the commercial and public services sectors is based on the non-domestic BER database. This includes data on more than 70,000 commercial and public buildings for parameters, including:

- building type
- size
- main heating system
- estimated energy use, categorised by end use (heating, hot water, cooling, auxiliary, lighting and equipment).

This work builds on the *Extensive Survey of the Commercial Buildings Stock in the Republic of Ireland* [1] which provided a detailed picture of the commercial building stock in Ireland. The latest data on the total number of dwellings and detailed energy use data from the non-domestic BER database are incorporated. The education, healthcare and public office subsectors form the public services sector, with the remaining five subsectors forming the commercial sector.

Total annual emissions from heating across the commercial and public services sectors are estimated to be 2.5 $MtCO_2$. Thirty-two percent of emissions are from oil across both sectors, with the majority in the education and healthcare subsectors. A further 40% are from gas. The commercial sector is responsible for the vast majority of the cooling demand in Ireland (6 TWh of a 7.5 TWh total), of which a majority is attributable to the retail sector. Emissions from electricity use for cooling in these sectors contribute a further

1.0 $MtCO_2$. Current emissions from non-cooling electricity use across the sectors are responsible for 0.67 $MtCO_2$.

Figure 11: Total annual emissions ($ktCO_2$/annum) from fuel use for heating by subsector

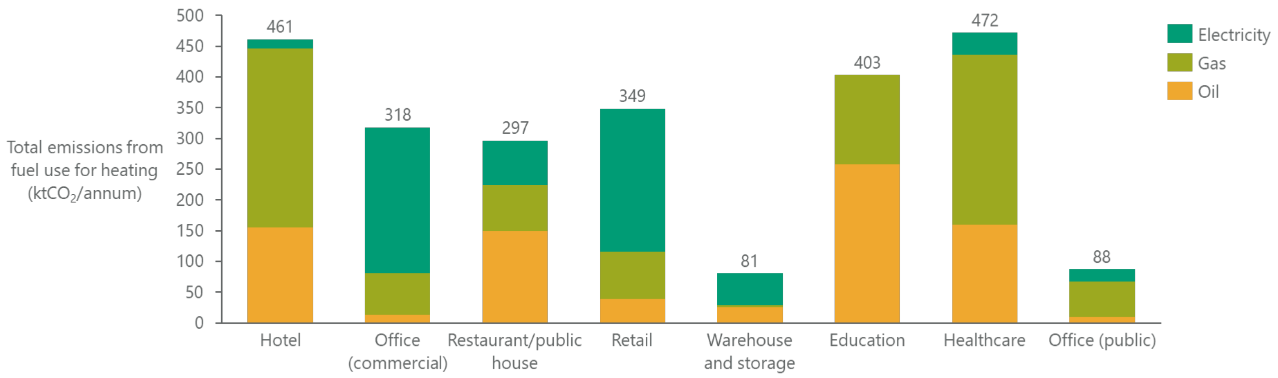


Figure 12: Total annual heating demand (GWh/annum) for buildings in the commercial and public sectors, by building activity and main fuel used for heating

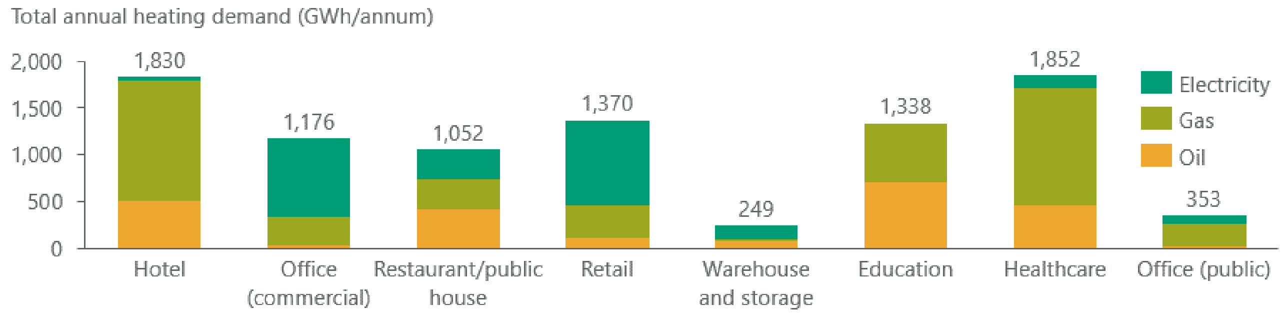
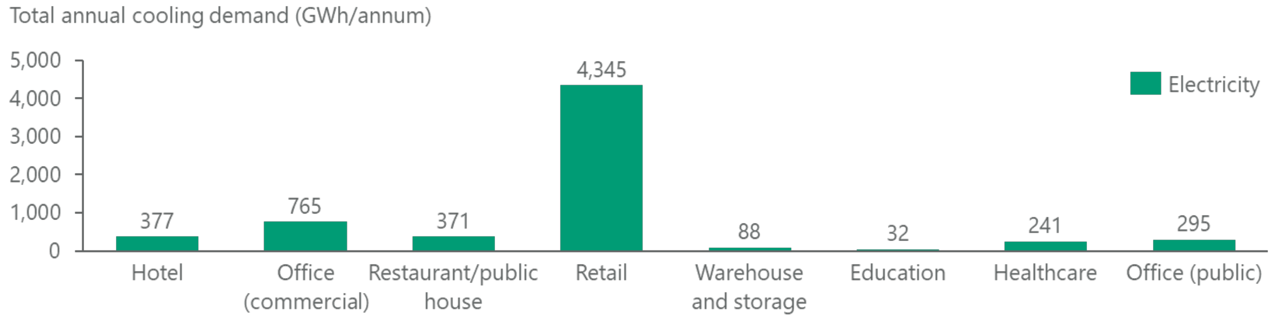


Figure 13: Total annual cooling demand (GWh/annum) for buildings in the commercial and public sectors, by building activity



Industry sector heating and cooling profiles

Profiling of energy use in the industrial sector has been significantly improved since previous reports. Additional data has been sourced from mandatory reporting by emitters within the EU Emissions Trading System, environmental permits published by the European Environment Agency (EPA) and detailed external industrial stakeholder engagement. This additional data allows more detailed insights into the wide variety of heating processes and technologies present in Irish industry, and a categorisation of heating demands by industrial subsector, industrial process, equipment type and temperature/grade of heat. Less data are available on energy use for cooling in industry in Ireland. For this modelling exercise, the proportion of electricity demand in each industrial subsector used for cooling processes was estimated based on international data.

Almost 400 archetypes for heating demand in industry have been developed and total fuel use in the sector (and subsectors) has been calibrated to the latest *National Energy Balance* totals [3].

The Industry sector creates 4.6 $MtCO_2$ from its heating processes every year, see *Figure 14*. These heating processes use 22 TWh of energy per annum, (81% of total industrial energy demand). Heat demand is split relatively evenly between different grades/temperatures of heat. Heating demands at >500°C (high grade heat), 150‑500°C (medium grade heat) and 100-150°C (medium-low grade heat) are ~26%, ~35%, and ~32% of total heating demand respectively, with a smaller demand for low temperature heat (<100°C) of ~8% of total heating demand.

Approximately 80% of the industrial emissions are from the 60-70 larger industrial sites within the EU ETS, with the remaining approx. 20% from smaller industrial sites. The top 15 sites account for 38% of total emissions.

Figure 14: Annual heating emissions (thousand tonnes of CO_2) in industry, split by subsector and fuel

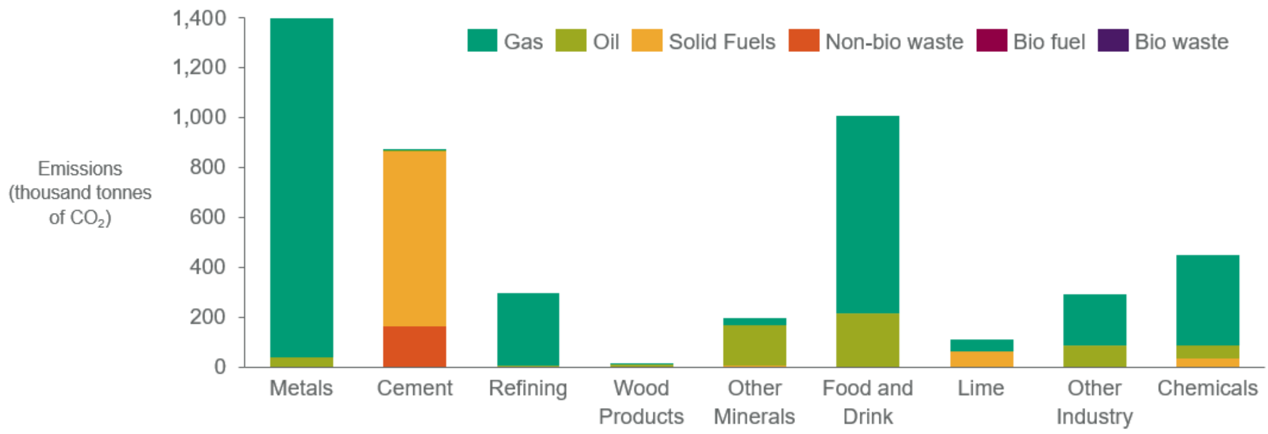


Figure 15: Annual heating emissions (thousand tonnes of CO_2) in industry (GWh) split by equipment type and ETS status

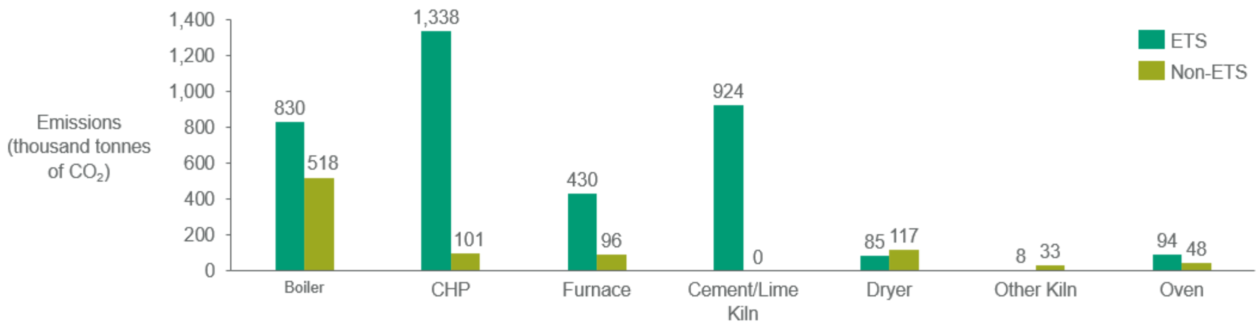


Figure 16: Annual heating demand (GWh) in industry, split by subsector and heating grade

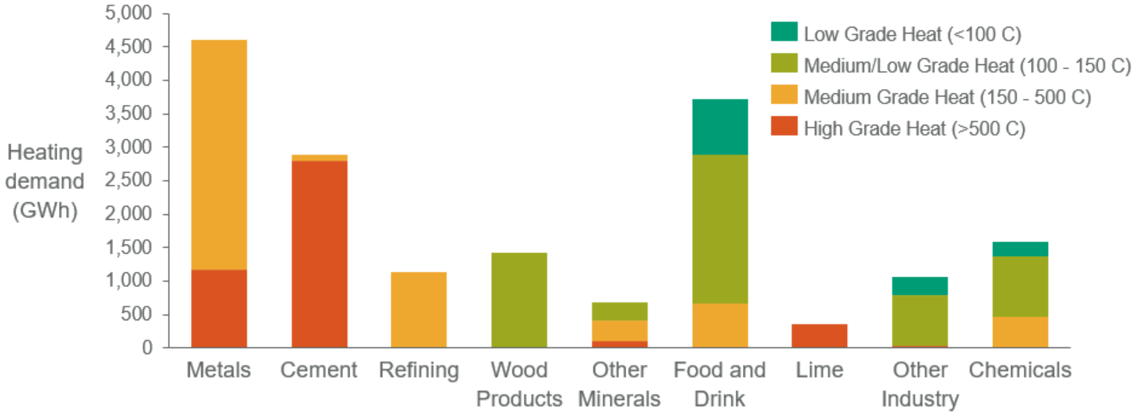
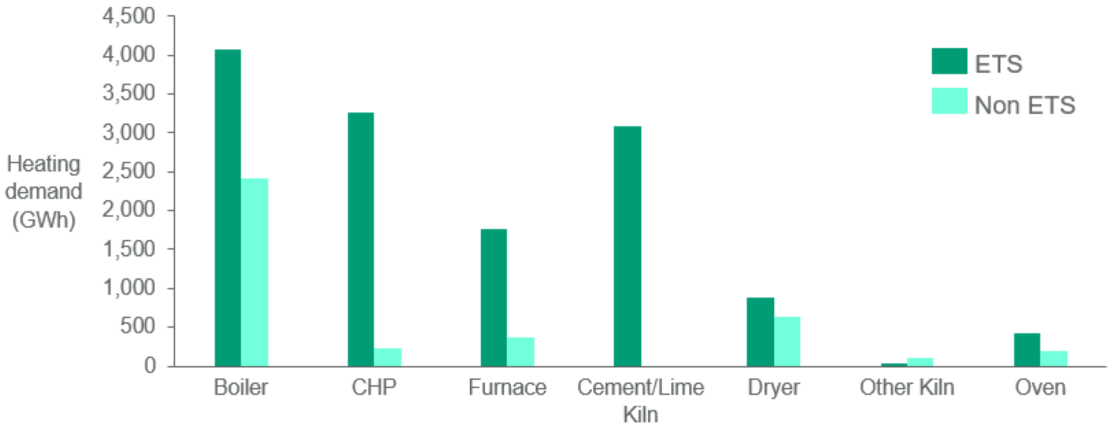


Figure 17: Annual heating demand in industry (GWh), split by equipment type and ETS status



Agriculture sector heating and cooling profiles

CO_2 emissions resulting from energy use for heating and cooling in the agriculture sector (excluding energy use for non-heating uses, such as machinery and all non-energy greenhouse gas emissions, such as biogenic emissions), have been estimated based on the best available data from Teagasc and the CSO. The three farm types considered were Dairy, Poultry and Pigs, and 11 archetypes were modelled. *Figure 18* and *Figure 19* show the estimated agriculture energy-related emissions for heating. Emissions from cooling in the Dairy sector are 0.03 $MtCO_2$/annum.

Figure 18: Total annual heating demand (GWh/annum) for the agriculture sector

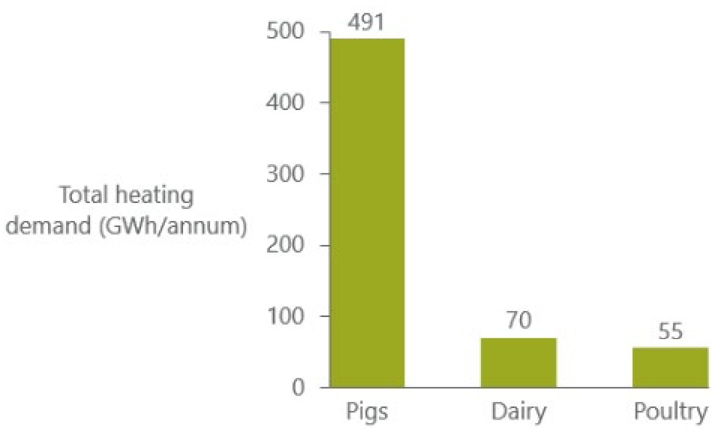
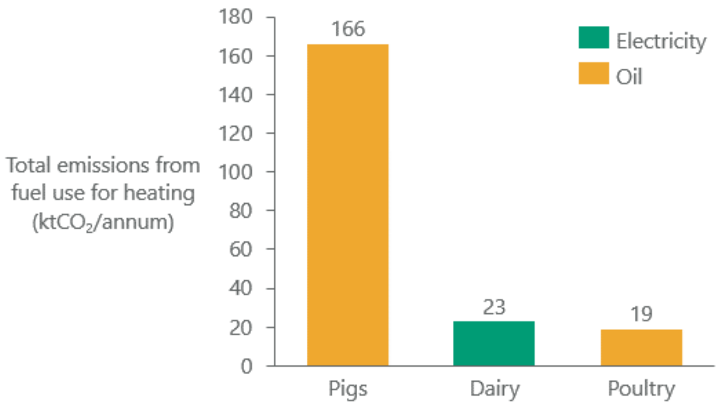


Figure 19: Total annual emissions from fuel use for heating ($ktCO_2$/annum) in the agriculture sector, by fuel type



Data centres

Growth in data centre deployment in Ireland is an area where significant increases in total electricity demand are projected. As such, data centres were modelled explicitly (i.e. separately from the commercial and public sectors) using the latest available data from EirGrid, external stakeholder feedback and the available literature. Data centres have been divided into four archetypes (Hyperscale, Co-location wholesale, Co-location and Private), based on data centre size and ownership type.

Cooling is responsible for only a small proportion of total electricity use by data centres, at approximately 14%. Data centres currently have annual electricity use for cooling of 0.4 TWh, corresponding to 0.3% of total final energy use or 1.4% of electricity use.

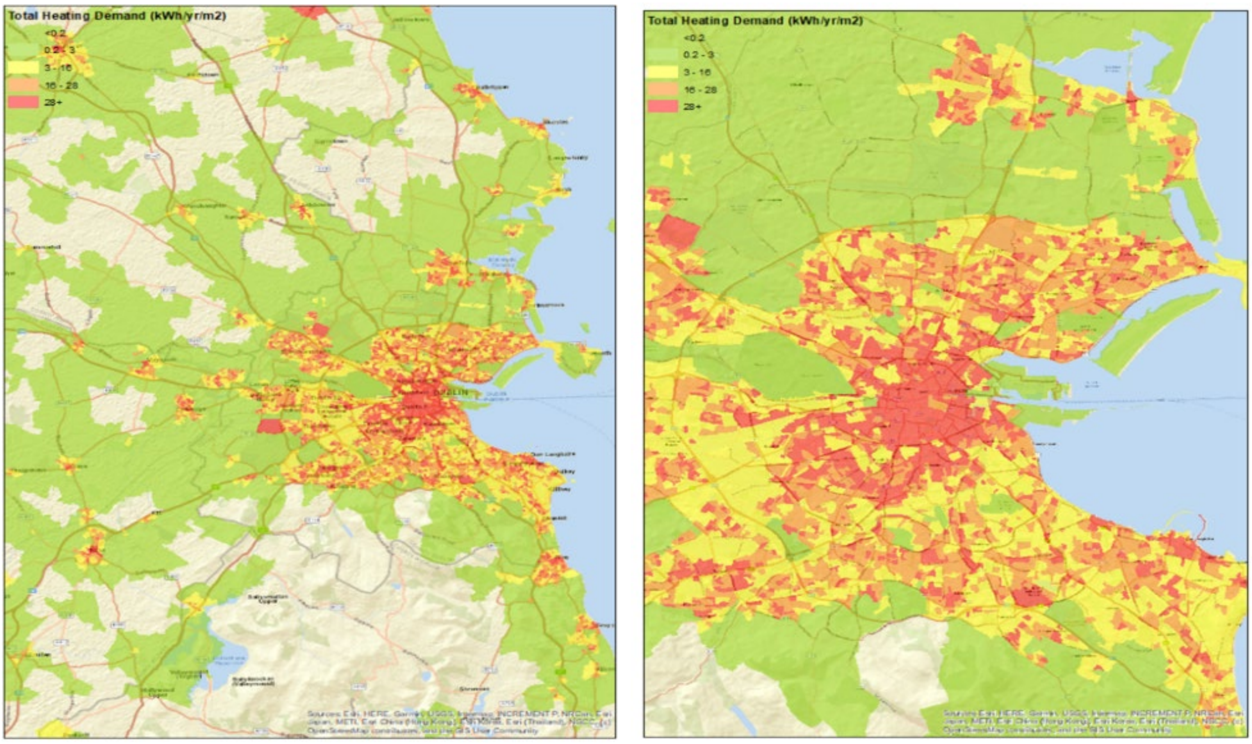
Spatial mapping of existing thermal demand

The heating and cooling demand of each sector has been analysed spatially to produce a national map of heat demand. This map includes data on potential waste heat sources and the potential geothermal energy resource at different depths. The data were linked to Ireland's 18,641 small geographical areas. The report describes the methodology for developing the national map of heat demand. The map is available on the SEAI website[5].

This detailed spatial analysis of heat demand and potential heat sources forms the foundation of the analysis of the potential for district heating in Ireland that has been carried out as part of the broader National Heat Study. This new assessment of the potential for district heating is one of the significant contributions made by the overall study.

[5] Available from www.seai.ie/NationalHeatStudy/

Figure 20: Sample of results of the spatial analysis of total heat demand



Energy efficiency potential

The National Heat Study considers a range of energy efficiency measures for each sector. In the overall study, the level of energy efficiency savings achieved in each scenario depends on the level of uptake of the various efficiency measures, which is modelled using a consumer uptake model. Consumer uptake decisions are modelled using payback periods and a consumer's willingness-to-pay; factors affecting this uptake include upfront costs, the expected fuel cost savings, and the type and level of government support.

The consumer uptake model is a core element of the detailed modelling exercise at the centre of the National Heat Study, but is not covered by this report. The work described in this report is an input to the detailed modelling exercise.

The energy efficiency savings presented in this report focus on the potential for reduced energy use via improved building fabric, industrial processes, lighting and appliances. They do not include the potential for switching to more efficient heating technologies, such as heat pumps, but the wider National Heat Study includes this.

This report describes the work done to estimate the maximum technical energy efficiency potential for the energy efficiency measures considered in each sector. For each sector, it outlines the considered measures and methodology used to estimate the savings potential. To estimate the maximum potential savings, all measures were assumed to be adopted in all archetypes in which they were technically suitable. For the residential sector, the potential saving is adjusted to account for comfort taking, also known as the rebound effect. Rebound effects are not considered for the other sectors.

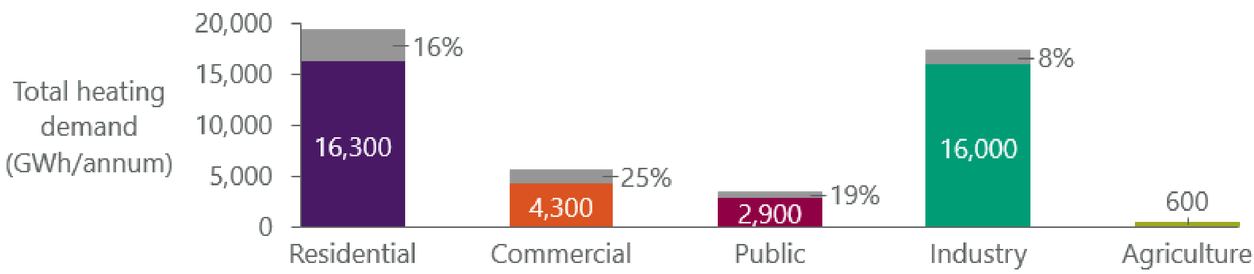
If the energy efficiency measures considered in this report were to be adopted in all buildings and industrial applications in which they have been deemed suitable, they could reduce emissions from heating demand across all sectors in Ireland by 2.2 $MtCO_2$ (15.8%) per year (see *Figure 21*).

The maximum technical potential for reducing heat demand through the energy efficiency measures considered in this report (relative to 2019 base-year) ranges from 9% in industry (0.4 $MtCO_2$), 16% in residential (including rebound) (1.2 $MtCO_2$), 19% in public services (0.2 $MtCO_2$) to 25% in the commercial services sector (0.4 $MtCO_2$).

In the residential, commercial and public sectors, 41% of the potential heating demand savings would result from installing high-efficiency glazing in suitable properties; a further 37% would result from improving the fabric wall insulation for both solid and cavity walls in suitable properties across these three sectors.

Energy efficiency improvements could reduce non-heating electricity consumption (e.g. that used for lighting and appliances) by a total of 15% (0.9 Mt CO2) across all sectors.

Figure 21: The remaining heating demand in each sector after energy efficiency measures have been applied to all suitable stock



Note:

- *The grey area of each chart represents the heating demand saved by the implemented energy efficiency measures.*

1 Introduction

Ireland's 2021 Climate Action and Low Carbon Development Bill sets the goal to achieve economy-wide carbon neutrality by 2050. This requires deep emissions reductions in every sector. Energy used for heating and cooling accounts for 24% of Ireland's greenhouse gas emissions, equivalent to approximately 14 million tonnes of carbon dioxide equivalent ($MtCO_2e$), but decarbonisation progress in heating and cooling has lagged the electricity sector. Heat energy is used in almost every sector of Ireland's economy and decarbonisation efforts will affect households, businesses, and industry, as well as the supporting supply chain activities. This emphasises the need for a detailed, comprehensive and actionable evidence base that policy makers and other stakeholders can base their decisions upon.

SEAI, in its role as the National Energy Authority, is conducting the National Heat Study to support these needs. The study aims to provide a consistent, detailed, and robust evidence base for policy decisions. The study evaluates the costs and benefits of various pathways that reach net zero by 2050. This evaluation is based on a comprehensive understanding of the profile of heating and cooling demand in Ireland, as well as the costs, potential and suitability of the technologies, infrastructure and fuels that can be deployed to reduce emissions.

This report serves as a standalone document detailing the analysis carried out to profile heating and cooling energy demand in Ireland, including a detailed spatial analysis, and also the analysis to quantify the potential for reducing heating and cooling demand through energy efficiency measures. It is the first in a series of eight reports that will be produced as outputs from the National Heat Study.

This report describes the approach taken to profile the existing heating and cooling demand in Ireland for the Irish building stock, agriculture sector and industrial sector. The work uses the latest available data to create an archetype model of the Irish building stock, agriculture and industrial use cases. Both heating and cooling demand and heating and cooling energy consumption are modelled. Heating and cooling demand is defined as the amount of energy required to fulfil heating and cooling needs (i.e. energy service demand). Heating and cooling energy consumption is defined as the actual amount of energy used to meet heating and cooling needs (i.e. actual fuel used). The latter data are reported in aggregated form in the *National Energy Balance* [3].

Accurate profiling of heating and cooling demand is a necessary first step to establish a 'baseline' energy demand. This is then used as the basis for modelling demand reductions that can be achieved by switching to renewable heating technologies and installing energy efficiency measures. Modelling several scenarios that would achieve net zero by 2050 can inform policy decisions and highlight areas where further support is required to achieve targets.

Work has been done previously to profile the Irish building stock and the energy used for heat in buildings; see, for example, the *Extensive Survey of the Commercial Buildings Stock in the Republic of Ireland* [1] and *Unlocking the Energy Efficiency Opportunity* [2]. This work builds upon and improves on previous attempts, with notable advancements including:

- Incorporation of the latest data from the domestic (i.e. residential) and non-domestic (i.e. commercial and public services) Building Energy Rating (BER) databases.
- A new approach for the industrial sector, categorising industrial heating demand by industrial subsector, processes, equipment, and temperature of heat to enable improved understanding of the decarbonisation options for Irish industry.
- Detailed agricultural archetyping using the best available data from the CSO as well as recent Teagasc studies.
- Updated granular geospatial mapping to depict the latest understanding of the distribution of existing thermal demand across Irelands 18,641 small areas.

The report has ten main sections. The introductory chapter highlights the overall objectives of this work and the larger project. It then presents the approach taken to profile heating and cooling demand, and gives a high-level description of the method and the key assumptions. The following sections describe in more detail the approach taken for each sector, and present the main results. *Section 7* brings the main results for all sectors together and summarises the overall picture of the existing state of the Irish heating and cooling demand. *Section 8* describes the geospatial mapping of the existing heating and cooling demand. *Section 9* describes the energy efficiency measures considered for each sector and presents the technical potential for reducing energy demand through energy efficiency. *Section 10* concludes by providing suggestions for further work.

1.1 Objectives

The objectives of the work done on profiling heating and cooling energy demand in Ireland described in this report are:

1. Quantify the useful energy and final energy consumption in Ireland's heating and cooling sectors.
2. Develop an archetype model (i.e. a set of building and consumer archetypes) which represents the latest available data.
3. Create a spatial mapping of existing thermal demand at small area level across Ireland.
4. Quantify the potential for energy efficiency savings in all sectors.

The results of this work are also important inputs to the overall National Heat Study. The goals of the overall study are to:

1. Develop a detailed understanding of heating and cooling demand in the residential, services and industrial sectors and the opportunities to reduce this.
2. Assess the potential and costs of the low-carbon technologies and fuels that can decarbonise heat generation.
3. Explore pathways for technology and fuel deployment to reach net zero by 2050.
4. Understand the perspectives of various stakeholders and seek to include data and information from a wide range of sources in the analysis.
5. Provide detailed analysis and useful insights to policymakers, stakeholders, and the public.
6. Build modelling capacity to support further work on policy development.

1.2 Purpose of archetype modelling

Archetype modelling was chosen as the method for profiling heating and cooling demand in Ireland. Using this approach, a complex real-world environment is represented by a simplified set of archetypes. In this case, nearly two million buildings and industrial facilities are represented by 680 archetypes. It is important that the archetypes are detailed enough to provide a good characterisation of the real-world system, but simplified enough to allow for practical model run-times, and for it to be feasible to populate the model with good quality data. The sections that follow outline how we have balanced these considerations and where additional data can further enhance the representation.

The attributes of the archetypes are chosen with the aim of the modelling in mind. For instance, the existing heating system of a building has a strong influence on the suitability and cost of installing a renewable heating technology. Therefore, 'existing heating system' was selected as one of the archetype attributes, given that one of the aims of the overall project modelling is determining the most cost-effective renewable heating technology for all buildings in Ireland. A further advantage of archetyping is that it significantly reduces the time and effort required to set up and run a model; this is due to the reduced time required for data entry, quality assurance, and processing required for model runs.

The number of archetypes used in this work was chosen to achieve a balance between level of detail and tractability, in terms of data volumes, data gathering effort, processing power, and processing time. The archetyping process was carried out separately for five distinct sectors, as shown in *Figure 22*.

Figure 22: The five distinct sectors included in the archetyping process in this study

The five sectors were selected to match the sectors used for reporting total energy use in *Ireland in the Energy Balances* [3]. One of the advantages of this choice is that it allows the modelled energy demand for each sector to be calibrated separately to the Energy Balances. The purpose of calibration is explained in *Section 2.1*.

The methodology for developing archetypes was tailored to each sector, considering the most relevant parameters and the availability of data. The archetyping methodology for each sector is detailed in the later sections of this report.

Data centres are considered separately from the sectors above because of the large impact they can have on cooling demand. The total share of electricity demand from data centres was separated into four data centre archetypes and, for each archetype, the electricity demand for cooling was estimated. This method is detailed in *Section 6*.

1.3 Archetyping methodology

The aim of the archetyping process is to represent the whole Irish heating and cooling demand at a level of detail sufficient to demonstrate the distinctions between different properties, both within a sector and in different sectors. An outline of the high-level methodology is shown in *Figure 23*. The exact methodology varies depending on the sector and is explained in more detail in later sections.

Archetype modelling has several advantages but some features of the approach are important to bear in mind when considering the results. A key assumption is that each archetype is representative of all the building or use-case stock attributed to it. In reality, the actual underlying stock will vary around the defined archetype.

In arriving at a final, tractable number of archetypes, several simplifications were made. In all cases, maintaining sufficient resolution and detail in the model was a key consideration. The key simplifying assumptions relate to combining buildings with slightly different characteristics into single archetypes. This was primarily done for cases involving relatively few buildings with similar characteristics. In such instances, aggregating the records under a single, representative archetype was deemed an acceptable simplification, as it had the advantage of reducing the total number of archetypes modelled whilst having a limited overall impact on accuracy. An example of this is the residential archetype where the heating system is specified as a 'solid boiler'. This archetype includes buildings which use ten different heating fuels according to the BER database, ranging from coal to wood. However, eight of the ten fuels have a very small number of records – less than 1,000 – associated with them. As such, combining the different building types into a single archetype was deemed an appropriate simplification, given that it led to a significant simplification in terms of the model and had only a minor impact on precision.

A second key assumption relates to the datasets used to derive the archetypes. In both residential and services sectors, BER data were used as the primary data source. For both the domestic BER data and non-domestic BER data, the records have approximately 50% coverage of the relevant building stock (see later sections). To ensure that the data were well-representative of the total stock, BER data were combined with other data sources, as described in later sections. For the residential sector, CSO Census data [4] was used. For the commercial and public sectors, additional GeoDirectory data [5] was used; this was also combined with insights from previous work profiling the commercial and public sectors [1], which informed the choice of archetypes in these sectors.

Understanding the heating and cooling demands of each archetype is the primary goal of this work. However, reported data on energy use – including Energy Balances and BER databases – includes electricity use not associated with heating or cooling. This was separated out into a standalone category in the modelling. This allows heating demand to be handled separately and facilitates further analysis, outside of this project, on non-thermal electricity use. This is particularly relevant for buildings which use electricity for heating or cooling, and ensures, for instance, that savings obtained via energy efficiency upgrades are only applied to actual heating demand.

Figure 23: Overview of archetyping methodology

The calibrated stock model of heating and cooling demand is a key input to other analysis. SEAI's National Energy Modelling Framework (NEMF) tool relies on the stock model as a basis for assessing the uptake, impacts and cost of various decarbonisation options that exist for each archetype. The NEMF tool is used in the National Heat Study to examine aspects such as the variation in technology readiness, technical suitability, cost data, and performance data, to assess various decarbonisation paths. The final National Heat Study report, *Net Zero by 2050: Exploration of Decarbonisation Pathways for Heating and Cooling in Ireland* has further detail on the modelling approach and how the data developed here is used[6].

1.4 Archetype breakdown

There are 680 archetypes across the five sectors. For the residential archetypes, the BER database and CSO Census data were used to obtain data. For commercial and public archetypes, the non-domestic BER database and GeoDirectory data were used. The BER data were not used to define the archetypes, but was used to estimate the relevant data for each archetype, such as floor area, heating demand and cooling demand. The total archetype stock across all sectors is given as 1,968,407 in 2020. This figure combines building numbers in the residential, commercial, public and agriculture sectors, drawn from CSO, GeoDirectory and Teagasc data, with in-use equipment numbers in the Industry sector drawn from Irish Business and ETS data.

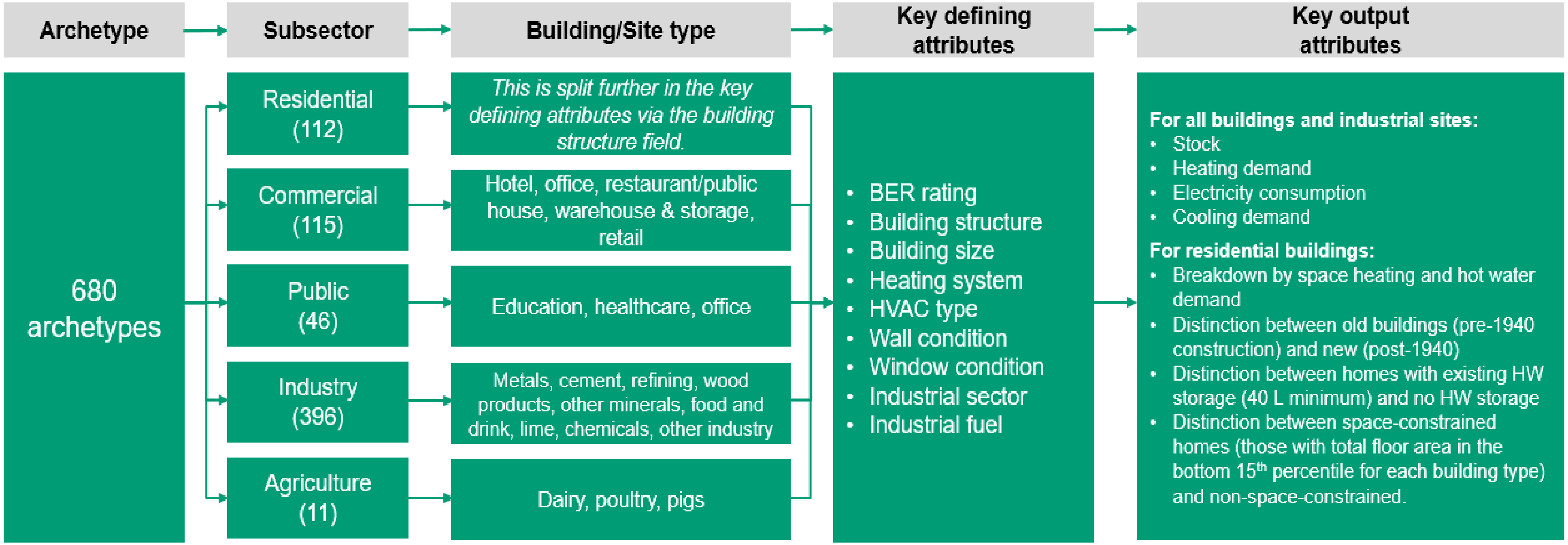
Figure 24 shows the high-level breakdown of all archetypes across the five sectors, within which they are further segmented by building type and other key defining attributes. Some of these key defining attributes are common across all archetypes (e.g. heating system), whereas some are only relevant for archetypes in one sector (e.g. wall condition in residential). An accompanying dataset providing full details of archetypes was developed to support this report and will be provided alongside this work, for reference and further detail[7].

All archetypes also have key output attributes, describing average values for all buildings or properties within that archetype. These average values are used to represent all buildings or properties in that given archetype in the modelling process. These include the total stock of each archetype, as well as attributes such as the average heating demand, average electricity consumption and average cooling demand for each archetype.

[6] Available from www.seai.ie/NationalHeatStudy/

[7] Ibid

Figure 24: Flowchart showing the breakdown of archetypes by defining characteristics (sector, building type and further key defining attributes), as well as some of the key output attributes used to describe all archetypes



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2 Residential sector heating and cooling profiles

Ninety percent of the buildings in Ireland are in the residential sector. Their energy use is responsible for nearly 11% of all greenhouse gas emissions in Ireland [6] and 24% of energy-related emissions (i.e. excluding emissions from agriculture and industrial processes) [3]. This sector has high quality data available for analysis, available from the domestic BER database. This is supplemented with data from the CSO to ensure the total residential building stock is represented, rather than only those homes that have undergone a BER assessment. CSO data are also used to ensure the modelled stock distribution (by house type and main heating fuel) matches the real-world distribution. This section describes the archetyping methodology used for the residential sector and highlights the main results.

2.1 Archetyping methodology and assumptions

The attributes selected to differentiate between archetypes in the residential sector were building type, main heating fuel and BER. The first two attributes were selected, as they matched the format in which CSO data on the total number of residential homes was reported [4], and had a strong influence on the type of renewable heating system to which a home could upgrade. BER rating was used as an attribute, as it informs the potential savings that can be obtained from energy efficiency upgrades. Secondary heating fuel was not used as an archetype attribute, as in most cases, the secondary fuel is the same as the primary fuel. The exception is solid fuels, which are commonly used in secondary heating systems in homes where the primary heating fuel is non-solid. To account for this, the calibration methodology was adjusted slightly for solid fuel archetypes.

When selecting archetype attributes, a key consideration was the availability of data in the BER database, which was the main data source for the residential sector. There were several possible options for each archetype attribute, as shown in *Table 1*. The number of options for each attribute was chosen to achieve a high level of detail, whilst maintaining a tractable overall number of archetypes (i.e. a number that would not pose significant challenges in terms of data gathering, data entry and model processing time). Out of a maximum number of 2,250 possible combinations, 112 residential archetypes were modelled.

Table 1: Attributes and attribute options used for residential archetyping

Attribute	Attribute options
BER rating	A1 – B2, B3 – C1, C2 – C3, D1 – D2, E1 – E2, F, G
Main heating fuel	Solid fuels, oil, gas, electricity
Building structure	Apartment, Terraced House, Semi-D House, Detached House

It is important to note that the distinction between archetypes by heating fuel refers to the main heating fuel, used for the primary heating system. Secondary heating systems and heating fuels are not explicitly modelled in this work. This is particularly pertinent for solid fuels, given that solid fuels are often used for secondary heating systems in homes. It is also worth noting that the solid fuels category used to represent existing heating systems primarily refers to unsustainable, high-carbon fuels, mainly coal and peat, as opposed to biomass.

Given that fuel for such systems can easily be purchased (at petrol stations, for example), there is concern that regulations on oil and gas heating systems may lead to increased use of high-emissions solid fuels in secondary heating systems. This possible leakage effect is not modelled in this work.

The domestic BER database was used as the primary data source, specifically a recent extract (October 2020) containing 725,870 complete records. This was used to profile the main characteristics of each archetype, namely space heating demand, hot water demand and non-heating electricity demand. Implied space heating demand and hot water demand are derived from the BER data, by combining estimates of final energy use with the technology efficiency of the main heating system. This is then calibrated to arrive at estimates of real heating demand, as explained below. Implied non-heating electricity demand is derived by summing the electricity demands from lighting and pumps and fans, as reported in the BER data. Appliance demand, which is not reported in BER data, is also added separately to non-heating electricity demand. Cooling demand for the residential sector was assumed to be zero (see *Section 2.2.3*). Non-heating electricity demand is reported separately from heating demand, in line with the approach used in the BER database. This is necessary so that any reductions in heating demand – due to energy efficiency upgrades for instance – are not applied to energy use from non-heating sources of electricity demand.

BER records contain data on delivered energy by end use and heating system efficiency. These were used to derive implied demand, via the simple relationship:

$$Demand\ (useful\ energy) = Delivered\ Energy\ (final\ energy) \times Technology\ Efficiency$$

In the above equation, useful energy refers to the theoretical amount of energy that would be used if there were no losses, for example, due to the conversion efficiency of heating technologies. Final energy, by contrast, corresponds to the energy consumption that normally appears on energy bills.

Since BER records do not exist for every residential home in Ireland, CSO Census data [7] – specifically number of homes by building type and main heating system – was used to determine the number of buildings assigned to each building type-heating system combination (e.g. the total number of apartments using gas boilers for heating). BER data were subsequently used to determine the number of buildings in each archetype, based on the distribution of BER ratings in each building type-heating system combination.

Since the latest CSO Census data are from 2016, data for new builds from 2017 to 2020 from the BER database, was also added. The total number of new builds for each year from 2017 to 2020 was assigned to archetypes based on data in the BER database for buildings constructed in the corresponding year; for example, if the BER database showed that most BER certificates for buildings constructed in 2017 were for apartments using gas boilers, the equivalent proportion of new builds in that year was assigned to building archetypes representing apartments using gas boilers.

Vacant homes – which numbered nearly 300,000 in 2016 according to CSO data - out of 2 million total homes [8] – were not considered when calculating total occupied building stock.

The final step involved calibrating heating demand so that total final energy consumption by fuel type matched 2019 Energy Balances data, a summary of which is shown in *Table 2*.

The Energy Balances data includes estimates of energy use from renewables, such as wind and solar energy. Renewable systems are mainly used to power secondary heating systems in homes where the main heating system is non-renewable. Since the archetypes did not include secondary heating fuel as an attribute – to reduce complexity – and because total fuel use from renewables is a small fraction of total fuel use in the residential sector (as shown in *Table 2*), the total energy use from renewables was distributed among the four other fuels. This was to ensure that the calibration took into account all energy use in the residential sector. Whilst this approach does lead to an over-estimation of energy savings when switching from a fossil to a renewable fuel, the effect is quantitatively negligible, due to the small contribution of renewables to total fuel use in the residential sector (2% of the total in 2019). It should be noted that the energy consumption of homes using heat pumps falls under the 'electricity' category in the Energy Balances.

Coal and peat are also used mostly as secondary heating fuels in Ireland, in homes that use oil or gas in the primary heating system, but a significant share of solid fuel is also used in homes where it is the primary heating fuel. According to the BER database, approximately 60% of solid fuel used for space heating is estimated to be for secondary heating, and 40% for primary heating. Secondary solid fuel use in homes is handled separately in the model, so the energy use of solid fuel homes was calibrated to match the 40% of total solid fuel use that is used for primary heating.

Table 2: 2019 Energy Balances data on total final energy consumption in the domestic sector, by fuel type

Fuel type	Total final energy use in 2019 (TWh)	Total redistributed final energy use in 2019 (TWh)
Solid (coal + peat)	4.2	2.2
Oil	13.5	13.9
Natural gas	6.9	7.1
Electricity	8.1	8.3
Renewables	0.8	0

Notes:
- *Final energy consumption from renewables (2.5% of the total) was subsumed amongst the other fuels, pro rata.*
- *Totals for columns may not match exactly, due to rounding.*

The calibration is a necessary step to ensure the model captured all the energy consumption from the residential sector in Ireland. Calibrating heating demand is particularly important when using data from the BER database, as it has been shown that BER estimates of fuel consumption, which are based on standard patterns of occupancy and are meant to provide only an indication of the energy performance of a property, can over-estimate the energy demand from less efficient buildings, due to under-heating in such homes [9].[8]

The calibration methodology used is outlined in *Figure 25*.

[8] A more recent study by Coyne and Denny [10] gained access to data on metered electricity and gas use of a sample of dwellings combined with the BERs for those dwellings. It found significant under heating of dwellings with poorer BER grades, as expected, but also found significant over heating of dwellings with A or B BERs, with these dwellings using 39 to 54% more energy than the BER would estimate. The study found such little variation in the average energy use of dwellings across BER grades that the authors conclude that the "results suggests that actual energy use is unresponsive to the [BER grade]". This study was published in July 2021, after the modelling work for the National Heat Project was already complete.

Figure 25: Outline of calibration methodology for the residential sector

Process	Key aspects	Key data sources
Derive total fuel consumption for heating	• Take delivered heating energy (i.e. final consumption) data from BER records and convert to useful energy (i.e. heating demand) via technology efficiency by fuel type. • Determine total heating fuel use over all archetypes for each fuel type by summing original delivered energy.	• Census of Population 2016 – Profile 1 – Housing in Ireland. • Domestic BER database.
Derive total electricity consumption	• Add non-heating electricity consumption from lighting and pumps & fans (using BER data) to electricity consumption from heating. • Add appliance energy consumption (derived separately) to obtain total residential electricity consumption.	• Census of Population 2016 – Profile 1 – Housing in Ireland. • Domestic BER database. • Electrical Appliance Ownership and Usage in Ireland (ESRI), 2012.
Calibrate with Energy Balance data	• Calibrate total final energy consumption independently for each fuel to match fuel consumption in Energy Balances data. • Calibrate heating demand from electricity & appliance electricity consumption separately.	• 2019 National Energy Balance, SEAI.

The first step in the process gives an initial estimate of final energy consumption for each of the four fuel types due to heating, based on the BER data. This is converted into estimates of useful energy (i.e. heating demand) by incorporating the technology efficiency (see the equation above), since the calibration calculation is applied to useful energy (i.e. heating demand).

The second step adds non-heating electricity consumption, due to lighting, pumps, fans and appliances, to give the total electricity consumption. As explained above, non-heating electricity is separated out from heating related electricity demand to ensure that any heating demand savings from energy efficiency measures are only applied to electricity demand for heating, rather than total electricity demand.

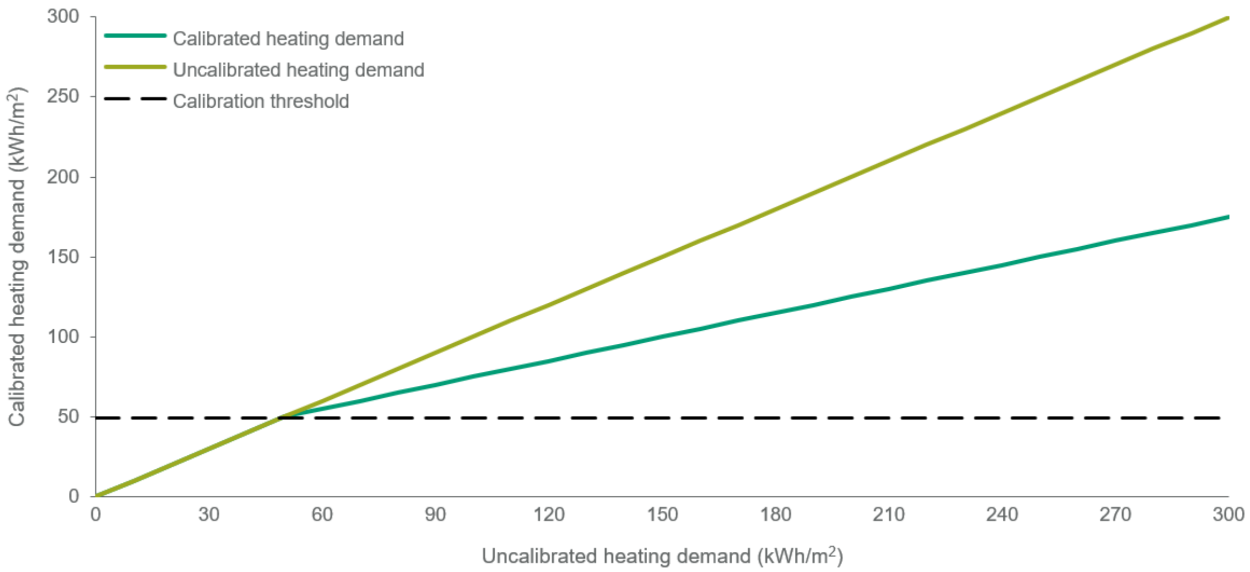
The first two steps account for all sources of energy consumption, giving an initial estimate of final energy consumption, which can then be directly compared with Energy Balances data. This leads into the third and final step, which is the calibration. This is required because initial estimates of consumption from the BER data do not match real consumption data in the Energy Balances.

For solid fuel, oil and natural gas, energy used for space and water heating is the only contributor to total fuel consumption. For electricity, non-heating energy consumption is also incorporated.

It is necessary to account for energy consumption from appliances, to allow direct comparisons with Energy Balances data. However, because the BER database does not report energy consumption from appliances, there is a lack of data on household energy consumption from appliances at a level of detail comparable to that of the other end-use categories. Energy consumption from appliances is therefore modelled in a more simplified way. This is done by assuming a uniform consumption for all homes. The value used is based on ESRI research [11] and covers the electricity use in Irish homes from refrigeration, wet appliances such as washing machines, appliances such as DVDs, TVs, kettles and cooking.

The heating demand calibration calculation scales all heating demand above a certain threshold – in this case taken as 49 kWh/m^2, which corresponds to the maximum heating demand for an A2 BER rating – by a factor chosen to calibrate the total fuel consumption to the *National Energy Balances* [3]. This approach is consistent with observations that BER data can over-estimate heating demand from less efficient (i.e. poorly rated) buildings, due to under-heating in such homes [11]. The calibration captures this effect by assuming that actual and predicted consumption are aligned up to a threshold of 49 kWh/m^2 and that there is a fixed reduction (in percentage terms) for demands above this threshold. This is graphically illustrated in *Figure 26*.

Figure 26: Comparison of heating demand before and after calibration



For solid, oil and natural gas heating, the calibration factor above the threshold is set so that the total calculated fuel consumption matches *National Energy Balances* data [3]. For electric heating, the calibration factor is set as the average of the calibration factors for solid, oil and natural gas heating. Appliance demand is also calibrated to ensure that total modelled electricity consumption matches Energy Balances data.

The calibration approach for electricity is different than that for the other fuels. This is because electricity consumption covers both demand from heating (for homes that use electricity as the main heating fuel) and demand from non-heating (for all homes, due to lighting, pumps and fans, and appliances). The approach used for electricity assumes that less efficient homes, which use electricity as the main heating fuel, have a similar level of under-heating to homes using other fuels. Once the electricity used for heating is estimated, the electricity used for appliances is taken as the total residential electricity use less the electricity used for heating.

Table 3 shows the final calibration factors obtained for the residential sector. The final calibration factor for appliance demand was 1.7. All calibration factors for heating are smaller than 1, which is consistent with the hypothesis that BER data tends to over-estimate heating demand [11].

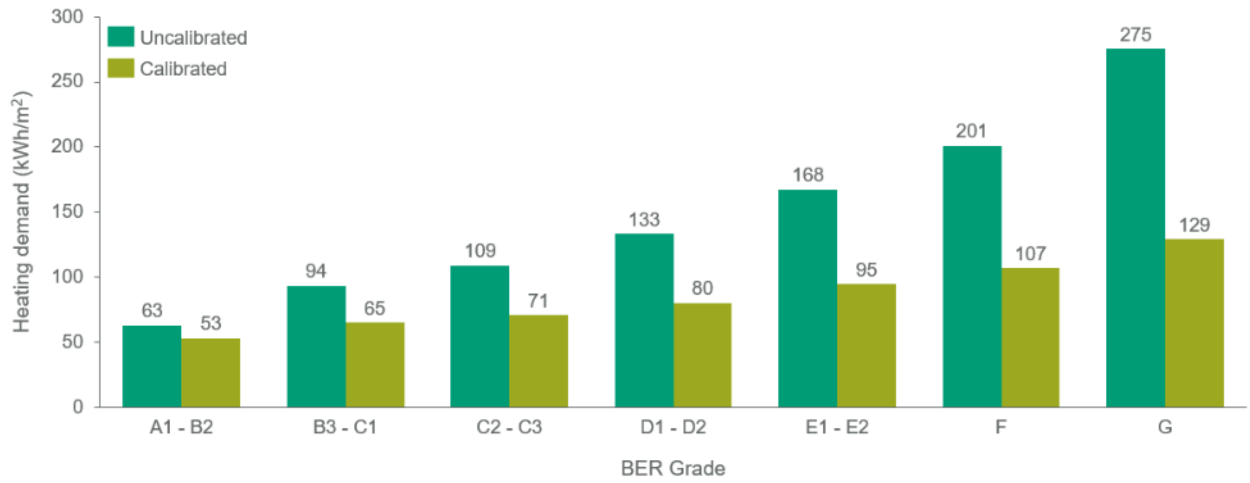
The calibration factor for appliances is larger than 1. This could reflect that the bottom up estimate of appliance energy use underestimates the electricity use of appliances, perhaps due to growth in appliance energy use. It is also possible that we are underestimating the electricity used for heating, which would result in more electricity being assumed to be used for appliances.

Table 3: Final calibration factors by heating fuel for domestic archetypes

Heating fuel	Calibration factor
Solid	0.32
Oil	0.61
Gas	0.44
Electricity	0.46

Figure 27 shows the result of the calibration on the average heating demand of archetypes, split by BER grade. As expected, the effect of the calibration is strongest in the least efficient homes, which have the lowest BER ratings.

Figure 27: Effect of calibration on average heating demand of residential archetypes, by BER grade



Compared to previous work in this area, the main advances of the approach described above are the use of the latest BER data and the added granularity provided by splitting heating demand into space heating and hot water demand. This increases the accuracy of the modelling by, for example, ensuring that savings due to energy efficiency measures are only applied to the relevant portion of total heating demand.

2.2 Stock, heating and cooling demand, and electricity consumption

This section contains breakdowns of the total stock, heating demand, cooling demand and electricity consumption for the residential sector. This shows the differences between building types within the residential sector and indicates the range in energy use across the various residential buildings in Ireland. Graphs showing the total consumption for each building type are provided, as well as an average consumption for each building type and BER rating within residential buildings. A heating demand breakdown by fuel use for each building type is also provided.

2.2.1 Residential stock

Figure 28 shows the breakdown of total residential stock by building type. 42% of the normally occupied residential properties in Ireland are detached houses, with 29% of properties semi-detached houses and 17% terraced houses. Only 12% of normally occupied residential properties in Ireland are apartments.

Figure 28: Residential stock breakdown, by building type

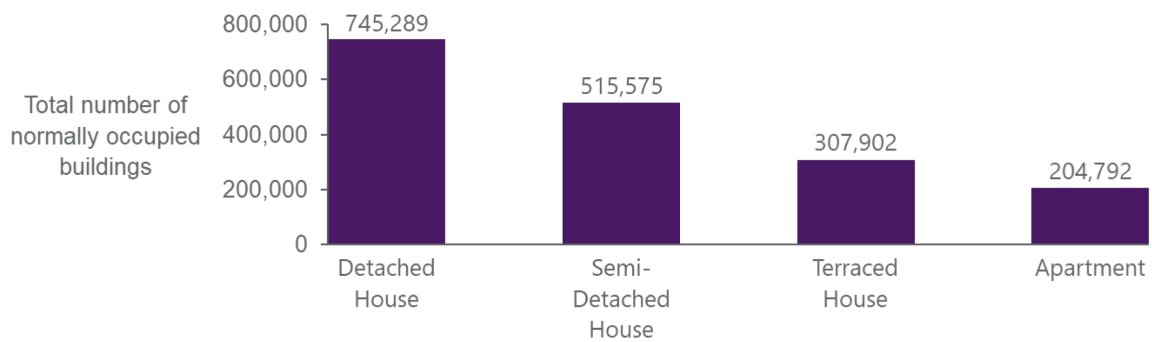
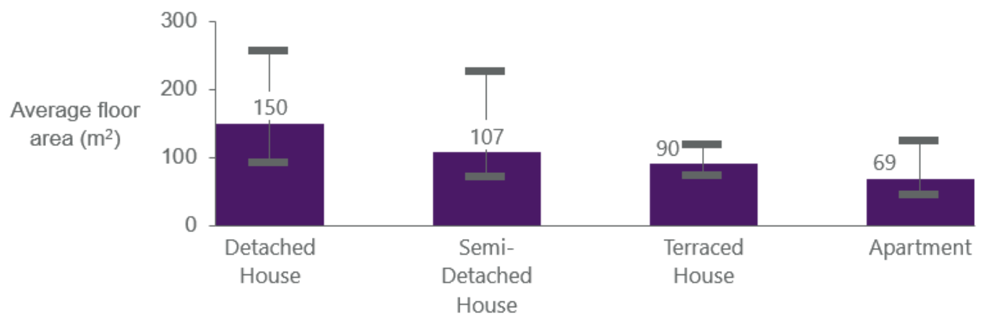


Figure 29 gives the average floor area for archetypes in the residential sector, by each building type. The coloured column shows the stock-weighted average floor area for each residential building type. The grey bars show the average floor areas for the archetypes with the highest and lowest floor area in each category.

As expected, detached houses have the largest average floor area in Ireland, followed by semi-detached houses. Detached houses also have the largest variation in floor area, with the largest houses 71% larger than the average; the smallest 40% smaller than the average detached house in Ireland. Apartments are, on average, the smallest properties. In terms of the 112 residential archetypes, (as opposed to the total occupied building stock), the data indicates that the variation in average floor area between homes of the same property type is often greater than the variation between average homes of different building types. This is illustrated further in *Figure 29*, which shows the distribution of floor areas for each building type.

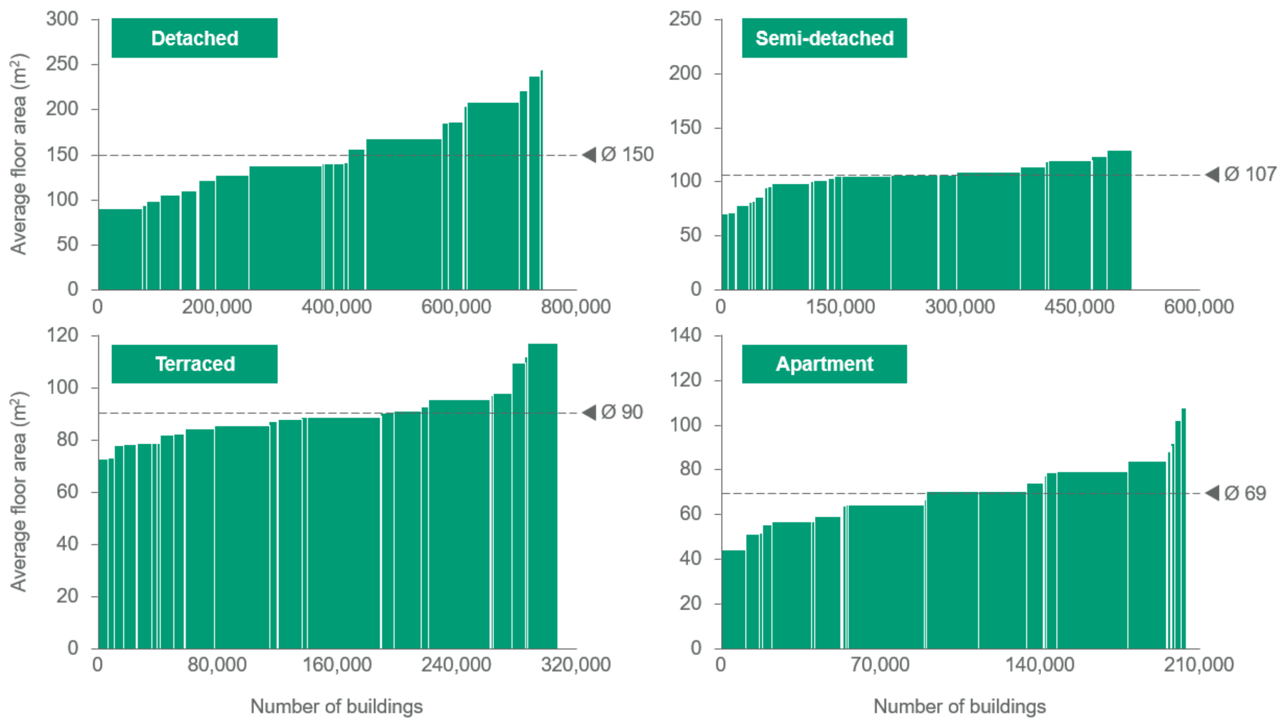
Figure 29: Stock-weighted average floor area (m²) for each building type in the residential sector



Note:

- *Bars indicate the maximum and minimum floor area of archetypes within each building type.*

Figure 30: Distribution of floor areas across building types



Notes:

- *Each bar corresponds to a building archetype; widths indicate the number of buildings represented by each archetype.*
- *Horizontal lines indicate stock-weighted average floor area, as shown in Figure 29.*

2.2.2 Residential heating demand

Figure 31 shows the total annual heating demand (GWh) for the residential sector by building type. Annual heating demand from detached homes exceeds the combined total for all other types of home. Comparing this with the stock distribution shows that detached houses tend to have heating demands higher than those for other house types. This is given that detached homes are 43% of all homes, but are responsible for 56% of all heating demand; for example, there are 45% more detached houses than semi-detached houses, but the total heating demand in detached houses is 129% higher than in semi-detached houses. A significant factor in this is the larger average floor area for detached homes compared to other properties, as shown by *Figure 29*.

Figure 31: Total annual useful heating demand (GWh) in the residential sector, by building type

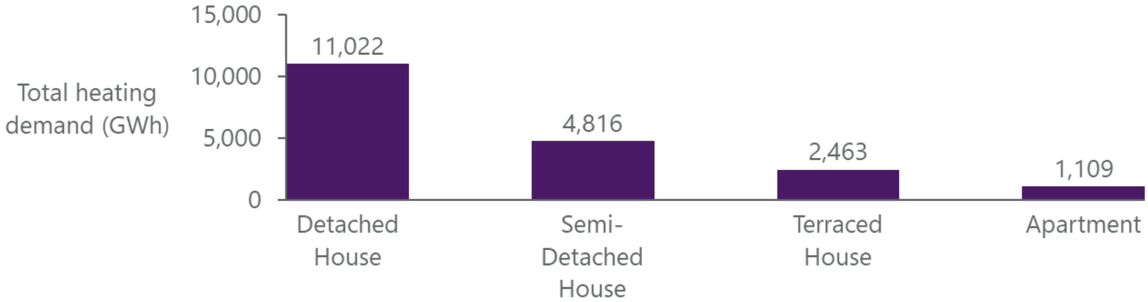
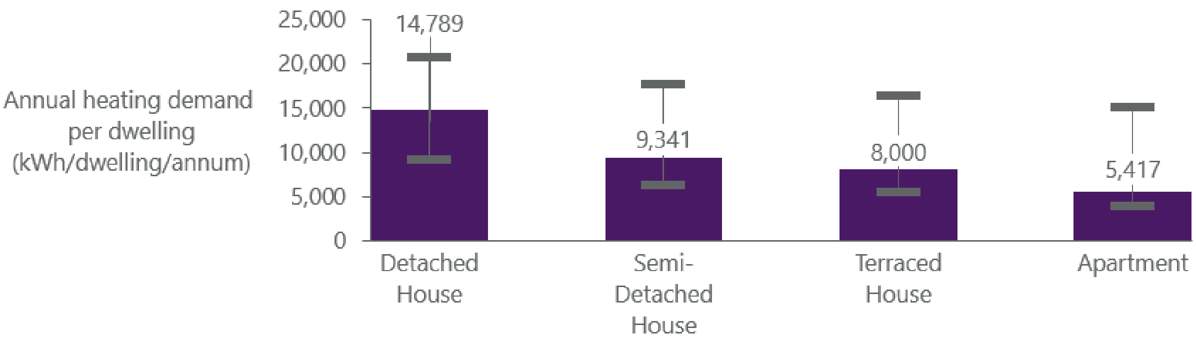


Figure 32 shows the average annual heating demand per dwelling (kWh/dwelling/annum) for each building type in the residential sector. This data follows the same trend as the floor area distribution shown in *Figure 29* above, with detached houses having both the highest average heating demand and highest variation. The heating demand in detached homes is on average nearly three times higher than the heating demand in apartments. *Figure 33* shows the distribution of heating demand across building archetypes for each building type.

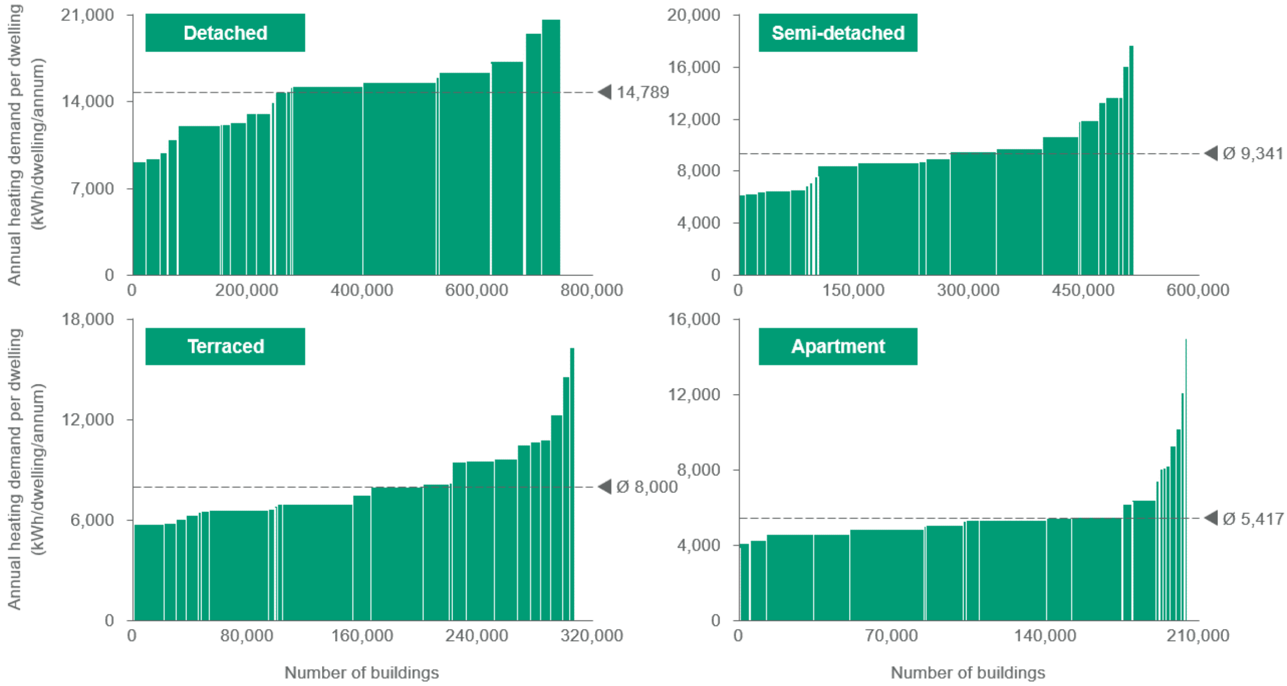
Figure 32: Stock-weighted average annual heating demand per dwelling (kWh/dwelling/annum) for each building type in the residential sector



Note:

- *Bars indicate the maximum and minimum heating demand for archetypes within each building type.*

Figure 33: Distribution of annual heating demand across building types



Notes:

- *Each bar corresponds to a building archetype; widths indicate the number of buildings represented by each archetype.*
- *Horizontal lines indicate stock-weighted average annual heating demand, as shown in Figure 32.*

Figure 34 shows the contribution of each fuel to total fuel consumption for heating, by building type. The predominant heating systems across building types are oil and gas boilers. Oil boilers dominate in detached homes; in all other building types, gas boilers are the dominant technology. Electric heating is present in a significant proportion only in apartments.

Figure 34: Percentage breakdown of fuel used for space heating and hot water in the residential sector, by building type

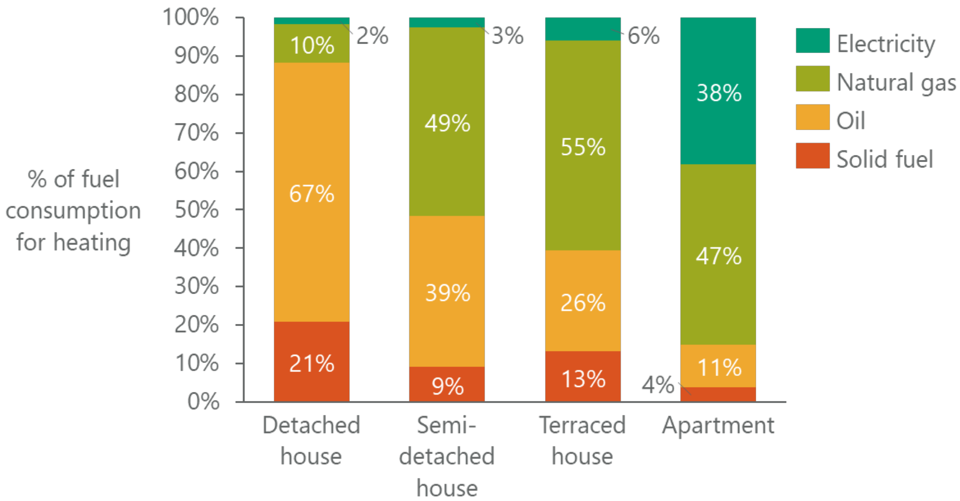


Figure 35 shows the total annual heating demand (GWh) in the residential sector for each BER rating. There is a significant contribution to the total residential sector heating demand from all BER ratings. Domestic properties with BER ratings in the range C2-D2 contribute 45% to the total residential heating demand. 20% of all heating demand in residential properties in Ireland is in buildings with BER ratings of F or G.

Figure 35: Total annual useful heating demand (GWh) in the residential sector, by BER rating

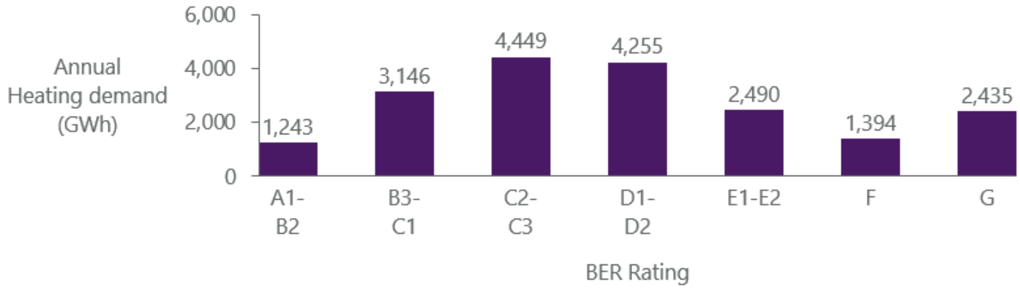


Figure 36 shows the stock-weighted average annual heating demand per dwelling (kWh/dwelling/annum) for the residential archetypes by BER rating. On average, the least efficient homes have heating demands more than 50% higher than the most efficient homes. However, there is a large variation between archetypes, as the bars in the graph show. For 'G' archetypes, the highest heating demand is more than 20,000 kWh per year; this compares to a demand of less than 5,000 kWh per year for the lowest demand 'A1-B2' archetype. It should be noted that real-world heating demand is ultimately determined by the thermal performance of a building and the personal choices of the occupants.

Figure 36: Stock-weighted average annual useful heating demand (kWh/dwelling/annum) in residential properties, by BER rating

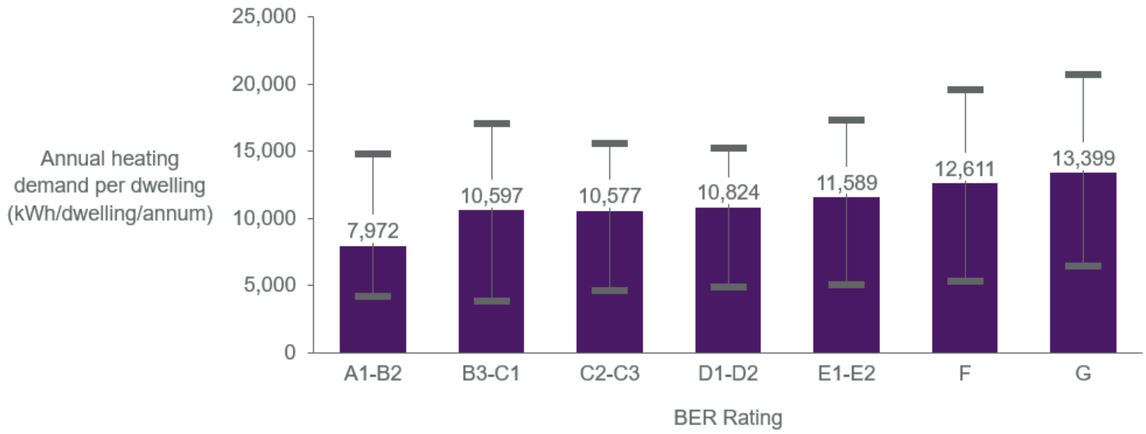


Figure 37 shows the total emissions from fuel use for heating purposes in the residential sector by heating fuel and by building type. Detached houses contribute to the majority of emissions from heating in the residential sector, making up 61% of these emissions. Oil is the fuel that contributes most to heating-related emissions in the residential sector, contributing 52% to the total. Emissions from solid fuels and natural gas each contribute 21% to total residential heating-related emissions, with emissions from electricity use for heating the smallest portion.

Figure 37: Total emissions from fuel use for heating per annum (ktCO2/annum) in the residential sector, by building type and fuel used

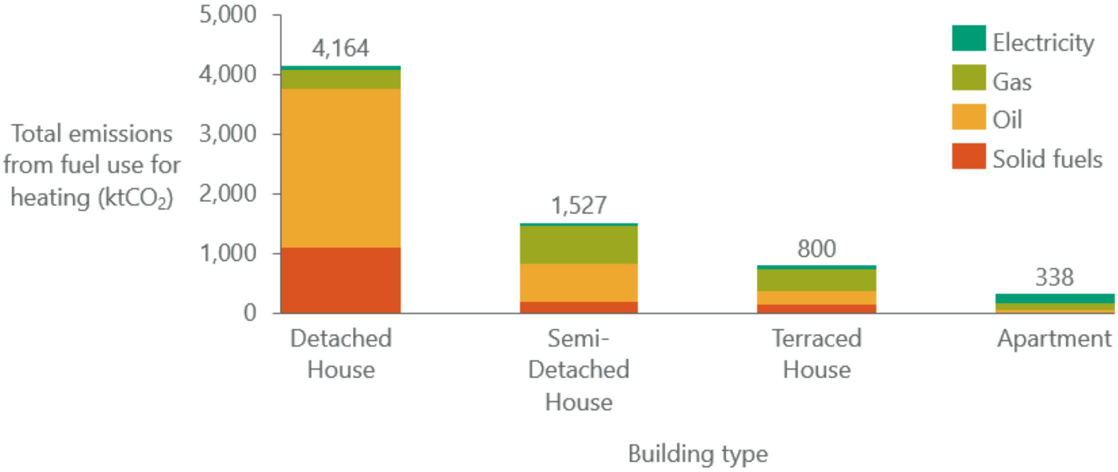


Figure 38 shows the contribution of each fuel to total fuel consumption for heating, by BER rating. Solid fuel heating is common in homes with the lowest ratings (which tend to be older), but becomes increasingly rare in more efficient homes. For all homes except those with 'G' ratings, gas or oil boilers form the majority of heating systems used. As previously noted, solid fuel use for secondary space heating is not represented in the figure, which partly explains the very low shares for solid fuels in homes with higher BER grades.

Figure 38: Percentage breakdown of fuel used for space heating and hot water in the residential sector, for each BER rating

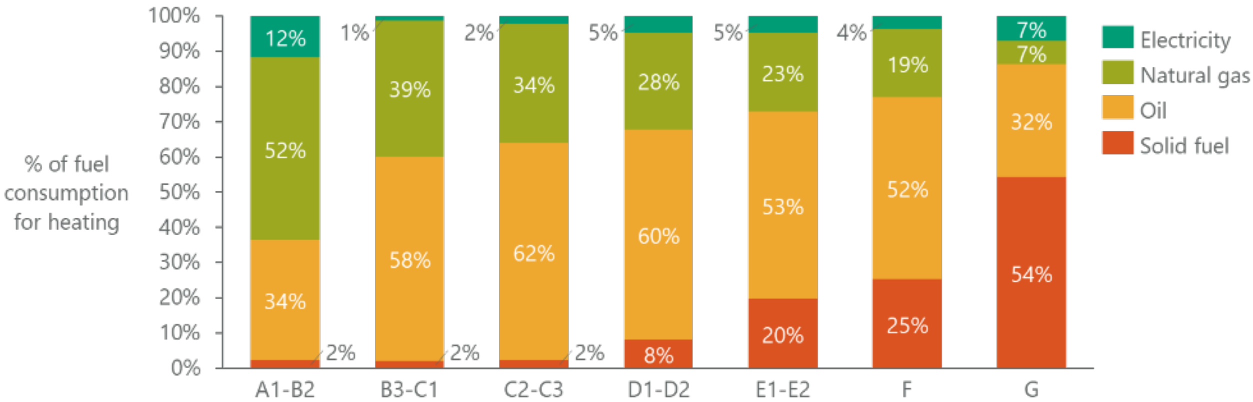
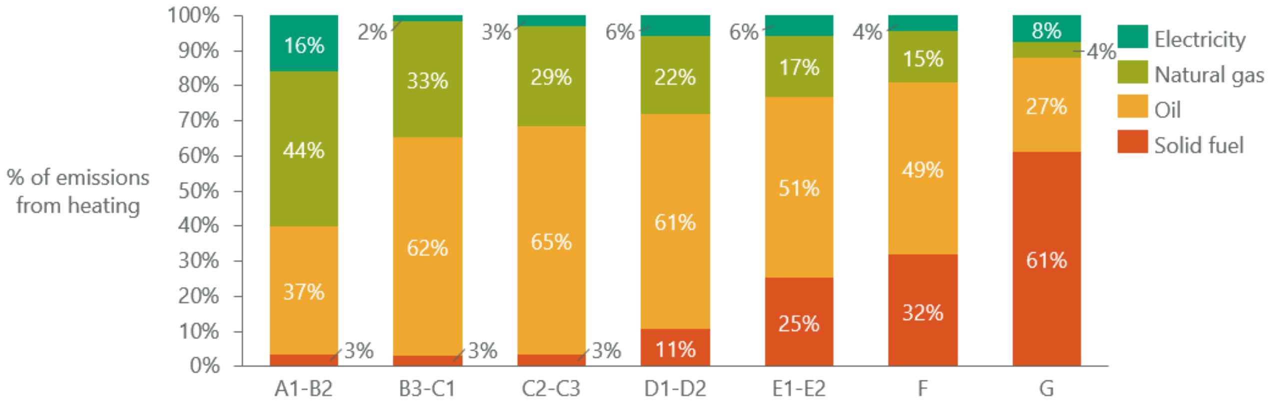


Figure 39 gives the same breakdown as the previous chart, but showing the percentage breakdown of emissions from fuel used for heating, rather than the percentage fuel use breakdown, for each BER rating in the residential sector. The key difference between these charts is the smaller proportion of emissions from gas use compared to fuel consumption. This is caused by natural gas releasing less CO_2 emissions per kWh of fuel burnt than oil and coal, which both have a higher proportion of emissions than fuel use in all BER ratings.

Figure 39: Percentage breakdown of emissions from fuel used for space heating and hot water in the residential sector, for each BER rating



2.2.3 Residential cooling demand

As a basis for analysis and to understand the underlying quantity of Irish cooling demand, a review of cooling degree days in Ireland was conducted. A cooling degree day occurs when the outside temperature is warm enough to require cooling inside (i.e. in a building/dwelling). According to Eurostat [12], there were zero cooling degree days between 2011 and 2019 in Ireland; in the nine-year period over which the data were collected, the outside temperature in Ireland was never high enough to require artificial cooling.

Cooling demand in the residential sector in Ireland is also not expected to increase. A study by the Joint Research Centre [13] (the European Commission's science and knowledge service) modelled the change in cooling degree days due to climate change across Europe. The results of this study show that even in the highest emissions scenario considered in the paper (RCP8.5, in line with a global 'business-as-usual' emissions trajectory, with projected global temperature increases of approximately 4.3°C by 2100), the number of cooling degree days per year in Ireland is expected to increase by only nine by 2050, and by 24 by 2100.

A European Commission study into the uptake of residential sector space cooling technologies [14] was considered when determining the proposed approach to the future demand of residential cooling in Ireland. This study describes how the uptake of residential cooling technologies (e.g. air conditioning) depends strongly on the number of cooling degree days in a location, based on the relationship between the uptake of residential cooling technologies and cooling degree days.

The study found that residential air-cooling technologies only start to be installed when the annual cooling degree day count surpasses approximately 20. This value is only expected to be reached in Ireland by 2090 in the high-emissions trajectory, never in the more moderate scenarios considered in the previous study. Whilst this analysis suggests there will be no cooling demand, there may be some future uptake of cooling technologies in residential properties for the purpose of maintaining comfort levels on warmer days in Ireland. In these cases, building design, passive cooling and potentially reversible heating/cooling technologies can be an important consideration for the general consumer. However, this is beyond the scope of the present study.

Due to low current requirements for residential cooling, and no significant projected demand increase (as explained earlier in this section), the uptake of domestic cooling technologies is not considered in this study. Furthermore, in the domestic BER database, (which formed the basis of the domestic archetype method used here), there is no domestic cooling demand data, so any attempt to quantify the domestic cooling demand in Ireland would be ineffective.

2.2.4 Residential non-heating electricity consumption

Figure 40 shows the total annual non-heating electricity consumption (GWh) in the residential sector by building type. Detached houses have the largest share of total electricity demand. This is partly because detached houses make up the largest share of total number of dwellings, as shown in *Figure 28*, and also tend to be larger, as shown in *Figure 29*. However, electricity use per dwelling varies less by dwelling type than heating demand does, because all dwellings tend to have the same electricity demand for appliances. Size does influence the portion of electricity demand attributed to heating and lighting and this does vary by BER and with floor area – larger detached dwellings therefore tend to have higher electricity demand than smaller apartments.

Figure 40: Total annual electricity consumption (GWh) in the residential sector, by building type

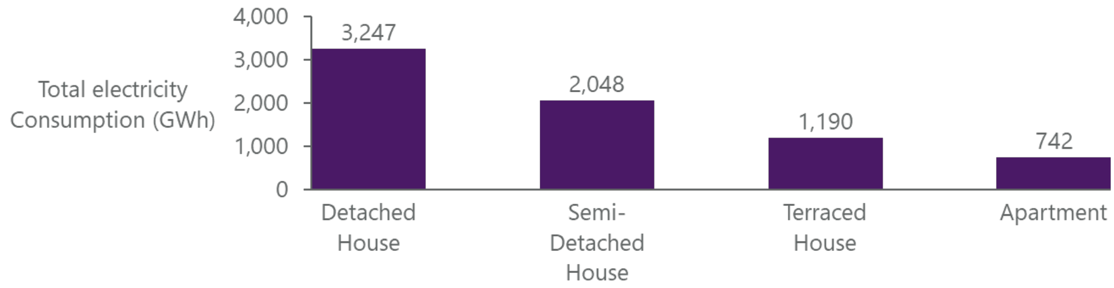
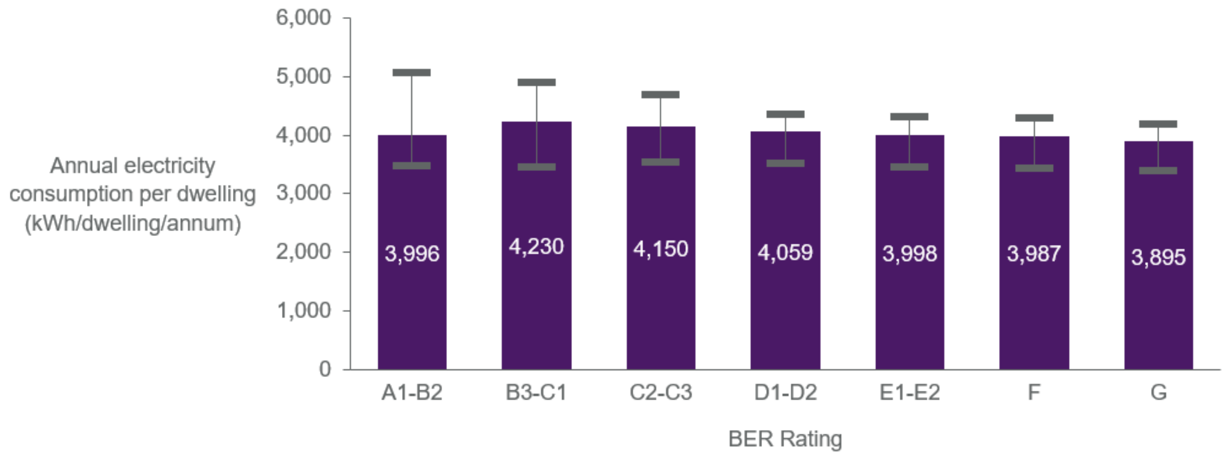


Figure 41 shows the average annual non-heating electricity consumption (kWh) for residential archetypes by BER rating. Unlike the trends for annual heating demand seen in *Figure 32*, electricity consumption does not vary noticeably with BER rating.

Figure 41: Stock-weighted average annual non-heating electricity consumption (kWh) in residential properties, by BER rating



Note:

- *Bars indicate the maximum and minimum heating demand for archetypes within each BER brand.*

3 Commercial and public services sector heating and cooling profiles

The representation of the commercial and public sectors has been challenging, as data are limited in many countries. SEAI carried out a project in 2015 to help address this for Ireland. The data collected was published in the *Extensive Survey of the Commercial Buildings Stock in the Republic of Ireland* report [1]. Since then, the non-domestic BER database has expanded significantly, and now covers approximately half the total number of commercial and public buildings in Ireland. Despite the expanded BER database, insights from the report were used to select the archetypes for the commercial and public sectors, given the effort taken at the time to ensure the sectors were surveyed comprehensively. The BER database is then used as the primary data source to estimate the heating and cooling demand of archetypes. This section describes the methodology for profiling heating and cooling demand in the commercial and public sectors and highlights the main results.

3.1 Archetyping methodology and assumptions

For commercial buildings, archetypes were selected based on previous work, which surveyed the commercial building stock in Ireland [1], as part of the wider *Unlocking the Energy Efficiency Opportunity* study carried out for SEAI [2]. The detailed survey work carried out 1,500 site visits to collect in-depth information for a variety of commercial building types. The sites surveyed were chosen carefully to ensure representative coverage of the commercial sector in Ireland. This was done by creating a target database using GeoBusiness – an electronic register of every business address in the State [5]. The address database was then combined with NACE codes[9] to allow classification into six high-level sector definitions, all of which were represented in the survey.

The commercial sector building stock is less homogenous than the residential building stock, and contains a wider variety of building forms, sizes and uses. To ensure a tractable modelling process and a resulting dataset with meaningful implications for policy design, a reduced set of representative building activity types was modelled. Five subsectors of building activity type were therefore modelled. These were chosen as they were found to be well-representative of the Non-Domestic Building Energy Ratings (ND-BER) database (i.e. 87% of the records in the non-domestic BER database are covered by the reduced set of building activity types). Further, the chosen set of building activity types closely corresponded with building activity types used in previous studies of the commercial building stock in Ireland, by Sheffield Hallam University [15], KEMA [16], and AECOM [17]. The five subsectors modelled are:

- Hotel
- Office
- Restaurant / public house
- Retail
- Warehouse and storage

For each subsector, the survey gathered data for each site including:

- Building activity
- Building size
- Building structure
- HVAC type
- Heating fuel

In addition to the above categories, data on wall and window condition were obtained from the non-domestic BER database.

Based on all the collected data, ~340 possible archetypes were identified, representing different combinations of building type, size, structure, HVAC type, heating fuel, wall condition and window condition.

For public buildings, archetype subsectors were restricted to 'Offices', 'Education' and 'Healthcare', as the Display Energy Certificate (DEC) database, which includes data for more than 2,000 public buildings in Ireland [18], suggests energy usage in public buildings is dominated by those three subsectors [2]. For each subsector, the same attributes used for commercial buildings were used to obtain a list of possible

[9] NACE (Nomenclature of Economic Activities) is the statistical classification of economic activities in the European Community.

archetypes. This included wall and window condition, data for which was obtained from the non-domestic BER database.

Table 4 lists the attributes used for commercial and public building archetyping and the options for each attribute. The thresholds U-values chosen to differentiate between ‘Good' and ‘Poor' walls and windows were kept consistent with values chosen for the Unlocking report [2].

Table 4: Attributes and attribute options used for commercial and public archetyping

Attribute	Attribute options
Building activity	Hotel; Office (Commercial); Office (Public); Restaurant/public house; Retail; Warehouse and storage; Education; Healthcare
Heating fuel	Oil boiler; Gas boiler; Electric heating
Building size	Small (defined as having a total floor area ≤1000 m^2); Large (defined as having a total floor area >1000 m^2)
Building structure	Detached; Terraced
HVAC type	Heating Only, Natural Ventilation; Heating Only, Mechanical Ventilation; Heating and Cooling, Mechanical Ventilation
Wall condition	Good (defined as having a U-value <0.6 W/m^2K); Poor (defined as having a U-value ≥0.6 W/m^2K)
Window condition	Good (defined as having a U-value <2.8 W/m^2K); Poor (defined as having a U-value ≥2.8 W/m^2K)

Two steps were taken to obtain a tractable number of final archetypes for the commercial and public sectors, in order to represent the two sectors with adequate resolution without posing significant challenges in terms of data entry and model processing time:

- The options shown in *Table 4* were chosen to represent the archetypes.

  The options were chosen so that the largest possible percentage of final energy use is represented. For instance, solid boilers are not included as a heating fuel option because the Energy Balances data show that total solid fuel use made up less than 1% of total fuel use across the commercial and public sectors in 2019. Further examples of this are illustrated in *Table 5*, which shows the share of heating fuel use covered by the attribute options chosen to represent each attribute, according to the non-domestic BER database. The calibration step (described later in this section) ensured that total modelled energy consumption matched the Energy Balances.

- Even with a limited number of options in each category, the number of possible archetypes remained large, at 1152 (more than ten times as many archetypes as the residential sector).

  The final number of archetypes was minimised as much as possible, whilst still representing the largest possible percentage of final heating fuel use and floor area in each subsector – with a minimum target of 80%. This was done via an optimisation process, which discounted archetypes that represent very small fractions of final energy use. The calibration step then effectively accounts for those discounted archetypes.

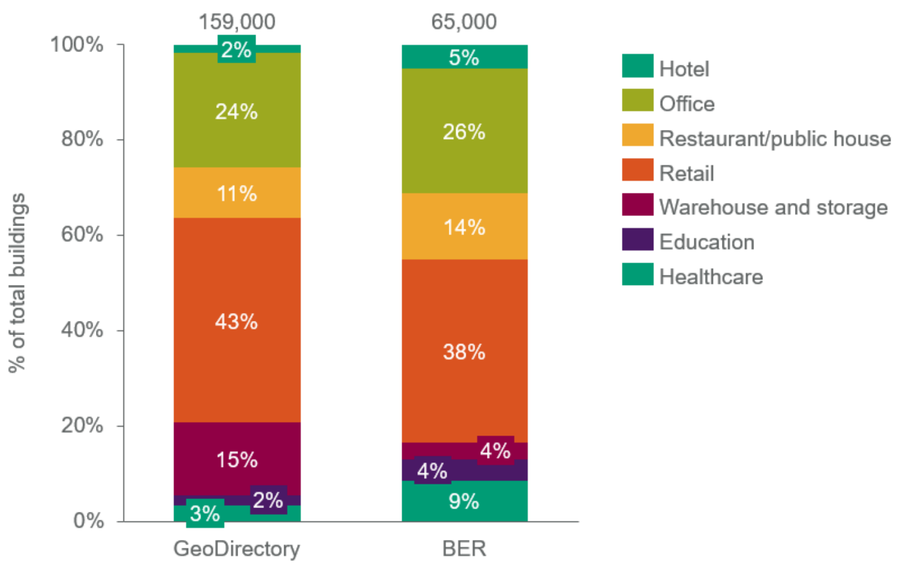
Table 5: Share of total final heating fuel use represented by the chosen attribute options for each attribute, based on the non-domestic BER database

Attribute	Share of total final heating fuel use represented by selected attribute options (%)
Building activity	85%
Heating fuel	98%
Building size	N/A (binary distinction)
Building structure	N/A (distinction not available in non-domestic BER data)
HVAC type	>99%
Wall condition	N/A (binary distinction)
Window condition	N/A (binary distinction)

The final number of commercial and public archetypes used in the modelling was 161, of which 115 were commercial and 46 public.

The primary data source used for profiling heating and cooling demands was the non-domestic BER database, specifically a recent extract (January 2021) containing 73,900 records. The level of coverage provided as a share of total buildings is equivalent to that provided by the domestic BER database, at about 50%. As with the residential sector, the building stock distribution in the non-domestic BER database closely matches comprehensive GeoDirectory data on the total number and type of non-residential buildings. The database was therefore deemed to well-represent the sector. This is illustrated in *Figure 42*, which compares the stock distribution by building activity based on GeoDirectory data and non-domestic BER data. The non-domestic BER data were used to calculate heating and cooling demands, in addition to non-heating electricity demand, for each archetype.

Figure 42: Distribution of buildings by activity type according to GeoDirectory data and non-domestic BER data



Note:

- *GeoDirectory data for 159,000 buildings; BER data for 65,000 BER records.*

Because BER records do not exist for every non-residential property in Ireland, GeoDirectory Small Area data [5] was used to obtain the total number of buildings for each building activity. This was combined with building size split obtained from the survey, giving the total number of non-residential buildings for each building activity-size combination (e.g. large hotels). Non-domestic BER data were subsequently used to determine the number of buildings in each archetype, based on the distribution of non-domestic BER ratings in each building activity-size combination.

Finally, in line with the approach for the residential sector, a calibration was undertaken to ensure total final energy consumption by fuel type matches 2019 Energy Balances data, an extract of which is shown in *Table 6*. As for the residential sector, this was a necessary step to ensure the model captured all the energy consumption from the commercial and public sectors in Ireland. Given that *National Energy Balances* data [3] lists energy consumption separately for the commercial and public sectors, the two sectors were calibrated separately in this work. For the commercial sector, the total final energy use quoted for electricity in *Table 6* excludes energy use from the Information and Communication category. This was assumed to primarily come from data centres, which are handled separately in the modelling due to their lack of representation in the non-domestic BER database (see *Section 6*).

Table 6: 2019 Energy Balances data on total final energy consumption in the commercial and public sectors, by fuel type

Sector	Fuel type	Total final energy use in 2019 (TWh)	Total redistributed final energy use in 2019 (TWh)
Commercial	Oil	1.5	1.5
	Natural gas	2.4	2.5
	Electricity	6.2	6.4
	Solid fuels	0.01	0
	Renewables	0.3	0
Public	Oil	1.6	1.7
	Natural gas	2.3	2.3
	Electricity	4	4.1
	Solid fuels	0	0
	Renewables	0.2	0

Notes:
- *Final energy consumption from renewables and solid fuels (2.5% of the total) was divided amongst the other fuels, pro rata.*
- *Total for columns may not match exactly due to rounding.*

The calibration methodology used is outlined in *Figure 43*.

Figure 43: Outline of calibration methodology for the commercial and public sectors

Process	Key aspects	Key data sources
Derive total fuel consumption for heating and cooling	• Derive final fuel consumption for heating (i.e. delivered energy) for entire commercial and public stock from non-domestic BER data, and sum over all archetypes for each fuel type. • Derive final electricity consumption from cooling (i.e. delivered energy) from non-domestic BER data, and add to electricity consumption for heating.	• GeoDirectory database. • Non-domestic BER database.
Derive total electricity consumption	• Add final non-thermal electricity consumption (delivered energy) from lighting, pumps & fans and equipment (from non-domestic BER data) to electricity consumption from heating and cooling to obtain total commercial and public electricity consumption.	• Non-domestic BER database.
Calibrate with Energy Balance data	• Calibrate total final energy consumption (delivered energy) independently for each fuel to match fuel consumption in Energy Balances data. • Calibrate non-thermal electricity consumption (including equipment) separately from heating and cooling electricity consumption.	• 2019 National Energy Balance, SEAI.

The first step gives the estimated final energy consumption for each of the three fuel types attributable to heating, based on the BER data. The second, third, and fourth steps add estimated final electricity consumption from non-heating sources (including cooling, lighting, and equipment) to give the total energy consumption for electricity, based on the BER data. With all contributions to energy consumption accounted for, a direct comparison with Energy Balances data is possible. The final two steps involve the calibration.

For oil and gas, energy used for space and water heating is the only contributor to total fuel consumption. For electricity, several end-uses contribute to the total fuel consumption, all of which are reported in the non-domestic BER data. These include heating, cooling, lighting, pumps and fans, and equipment.

The calibration calculation scales all energy consumption by the relevant calibration factor (i.e. a simple linear calibration). This approach is slightly different from that used for the residential sector (see *Section 2.1*), as the former is based on the observation that BER ratings for residential homes tend to over-estimate heating demand [11]; by contrast, there is no evidence for the same phenomenon in the commercial and public buildings. As with the residential sector, the calibration factor for heating/cooling electricity is set as the average calibration factor for heating of the other two fuels. Electricity use due to other end-uses, namely lighting, pumps, fans and equipment, was calibrated separately using a single factor.

The calibration approach for electricity is different than that for the other fuels. This is because electricity consumption covers both demand from heating (for buildings that use electricity as the main heating fuel) and demand from non-heating (for all buildings, due to lighting, pumps, fans and equipment, in addition to cooling in some cases). The approach used for electricity assumes electric heating is more 'similar' to gas or oil heating than it is to non-heating uses of electricity.

Table 7 shows the final calibration factors for the commercial and public sectors. The calibration factors for oil, gas and electric heating/cooling are all smaller than one; this is in line with the trend seen for the residential sector. The disparate calibration factors seen for non-thermal electricity in the commercial and public sectors suggest a mismatch in this area between Energy Balances data and non-domestic BER data, with BER records for public buildings (hospitals, schools, public offices) likely over-representing buildings with low electricity use and vice-versa for BER records for commercial buildings.

Table 7: Final calibration factors by fuel for commercial and public archetypes

Sector	Fuel	Calibration factor
Commercial	Oil	0.60
	Gas	0.73
	Electricity (heating and cooling)	0.67
	Electricity (lighting, pumps and fans and equipment)	0.13
Public	Oil	0.74
	Gas	0.97
	Electricity (heating and cooling)	0.85
	Electricity (lighting, pumps and fans, and equipment)	1.14

Compared to previous work in this area, the approach outlined above constitutes a major advancement. This is due to the incorporation of the latest non-domestic BER data, which now includes more than 70,000 records – compared with only 10,000 in 2015, when the survey work was carried out. This is, therefore, representative of all commercial and public buildings, justifying its use as the primary data source. The much larger dataset led to a more straightforward, streamlined approach to archetyping and profiling of energy demand, removing the need to rely on survey results.

3.2 Stock, heating, cooling and electricity demand

This section contains breakdowns of the total stock, heating demand, cooling demand and electricity consumption for the commercial and public sectors. This shows the differences between building types within these sectors and presents the range in energy use across the various commercial and public buildings in Ireland. Graphs showing the total consumption for each building type are provided, as well as an average consumption for each building type within buildings in these sectors. A heating demand breakdown by fuel use for each building type is also provided.

3.2.1 Commercial and public stock

Figure 44 shows the stock breakdown of commercial and public buildings by building activity. Four of the building activities (retail, restaurant/public house, warehouse and storage, and hotel) are only applicable for commercial archetypes, whilst two (education, healthcare) are applicable only for public archetypes. Offices are included in both commercial and public archetypes. Commercial buildings form the majority of total buildings, making up 85% of the total number of buildings across these two sectors.

Figure 44: Non-domestic (commercial and public) stock breakdown by building activity

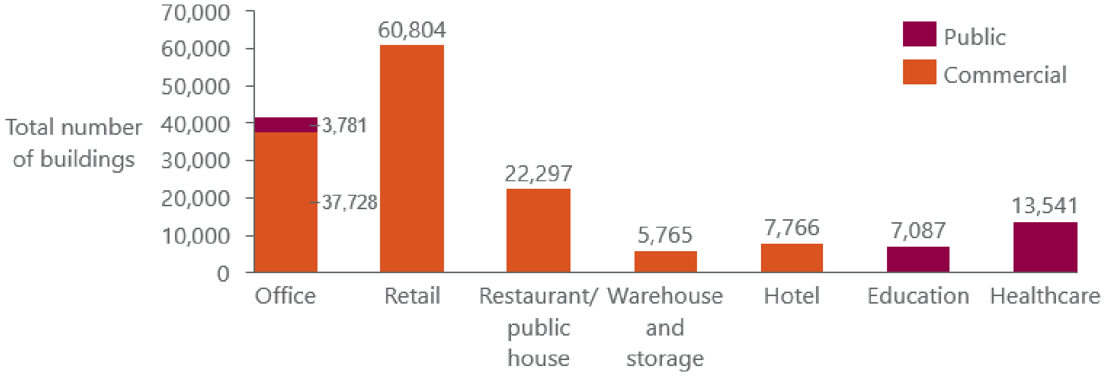
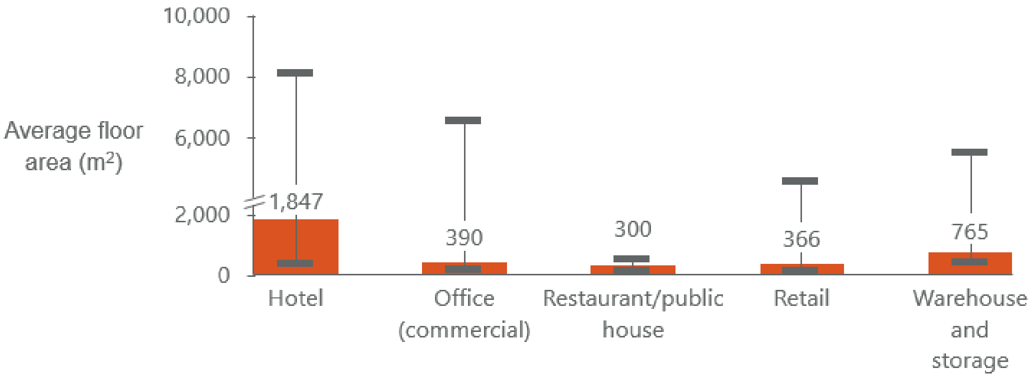


Figure 45 and *Figure 46* below show the average floor area for buildings in the commercial and public sectors respectively, for each building type. Public buildings tend to have larger floor areas on average compared to commercial buildings. Apart from restaurants, there is significant variation in floor area within archetypes covering a single building type. For instance, the healthcare archetype with the smallest floor area (125 m^2) is over 60 times smaller than the archetype with the largest floor area (7,785 m^2).

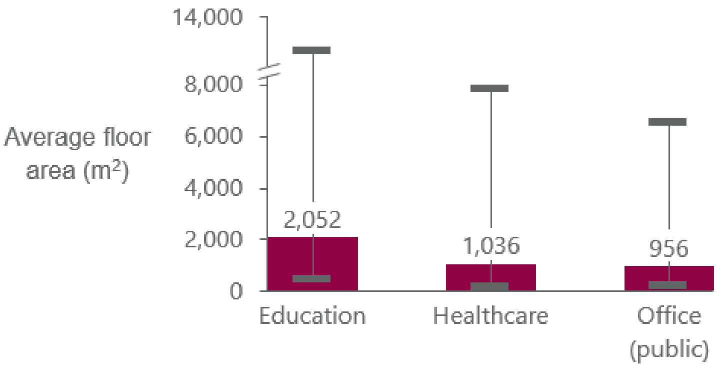
Figure 45: Stock-weighted average floor area (m^2) for each building activity type in the commercial sector



Note:

- *Bars indicate the maximum and minimum areas of archetypes for each building activity type.*

Figure 46: Stock-weighted average floor area (m^2) for each building type in the public sector



Note:

- *Bars indicate the maximum and minimum areas of archetypes for each building activity type.*

3.2.2 Commercial and public heating demand

Figure 47 shows the total annual heating demand (GWh) across the commercial and public sectors by building activity. There is large variation in heating demand between different building activities, with warehouses and public offices having particularly low heating demand, despite relatively high average floor areas. This is primarily due to the relatively small number of buildings in these two sectors.

Figure 47: Total annual useful heating demand (GWh) for commercial and public sectors, by building activity

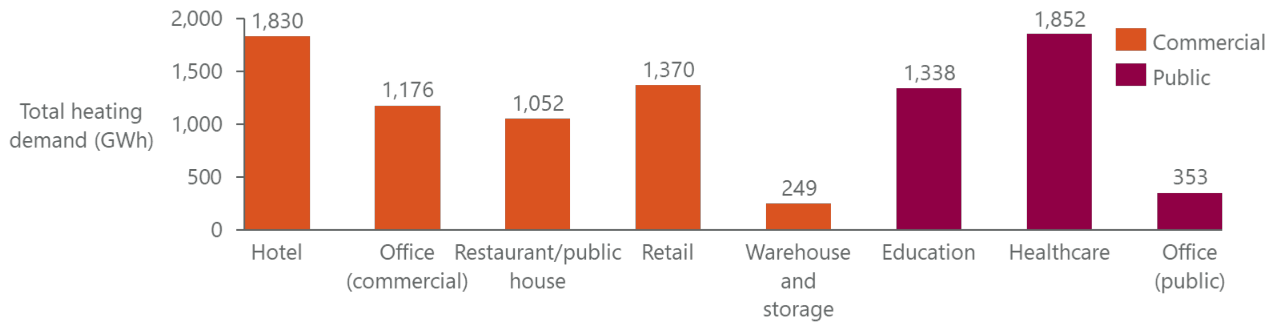


Figure 48 shows the contribution of each fuel to total fuel consumption for heating, by building type. No common trends are seen for the full building stock; all three of the modelled heating fuels are dominant in at least one building type. Oil accounts for at least 50% of the total fuel consumption in the Education and Restaurant/public house building activities. In commercial offices, retail buildings and warehouses, electricity accounts for most fuel consumption for heating.

Figure 48: Percentage breakdown of fuel used for space heating and hot water in in the commercial and public sectors, by building activity

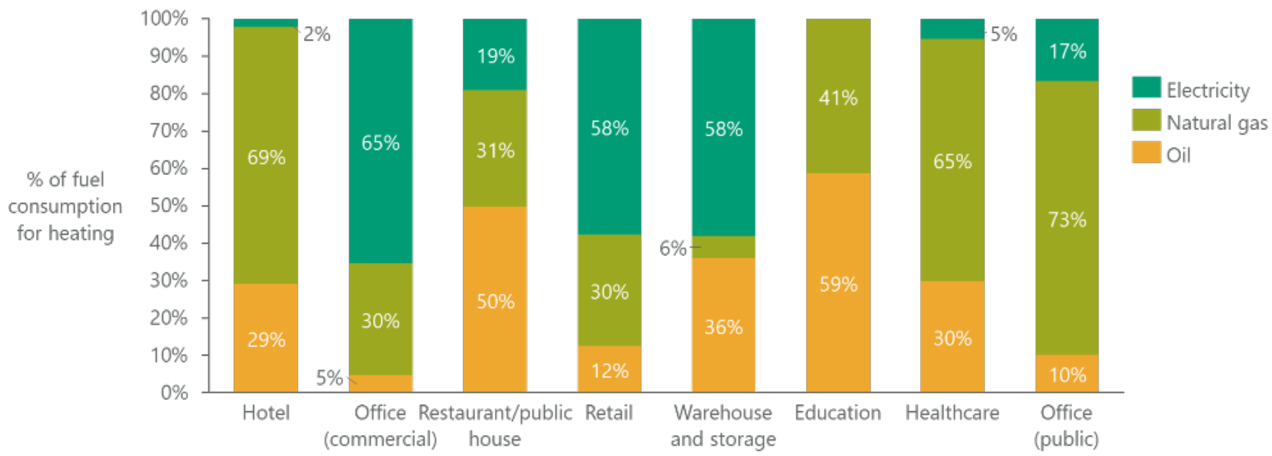
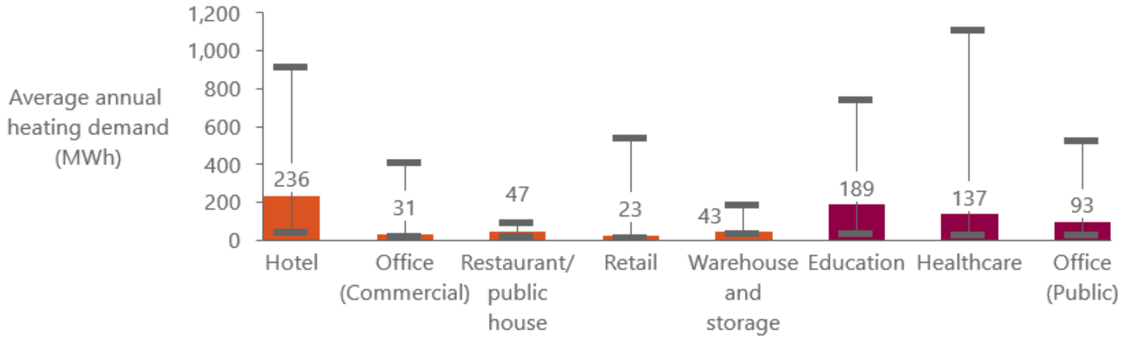


Figure 49 gives the average annual heating demand (MWh) of commercial and public archetypes by building activity. As with floor areas, there is a large variation across archetypes for each building activity; this is most acute in the hotel and healthcare building types.

Figure 49: Stock-weighted average annual useful heating demand (MWh) in commercial and public buildings, separated by building activity



Note:

- *Bars indicate the maximum and minimum heating demands of archetypes within each building activity.*

Figure 50 shows the total emissions from fuel use for heating ($ktCO_2$/annum) in the commercial and public sectors by building activity and fuel used. There is no dominant fuel causing emissions across all sectors, with emissions from gas consumption making up 40% of total heating emissions across the two sectors, emissions from oil 33% and electricity 27%. There is also at least one building activity type with most emissions resulting from use of each of the three fuels: emissions from electricity dominate in commercial offices, emissions from natural gas make up the largest proportion in healthcare buildings and hotels, whilst oil is the largest emissions contributor in education buildings.

Figure 50: Total emissions from fuel use for heating per annum ($ktCO_2$/annum) in the commercial and public sectors, by building activity and fuel used

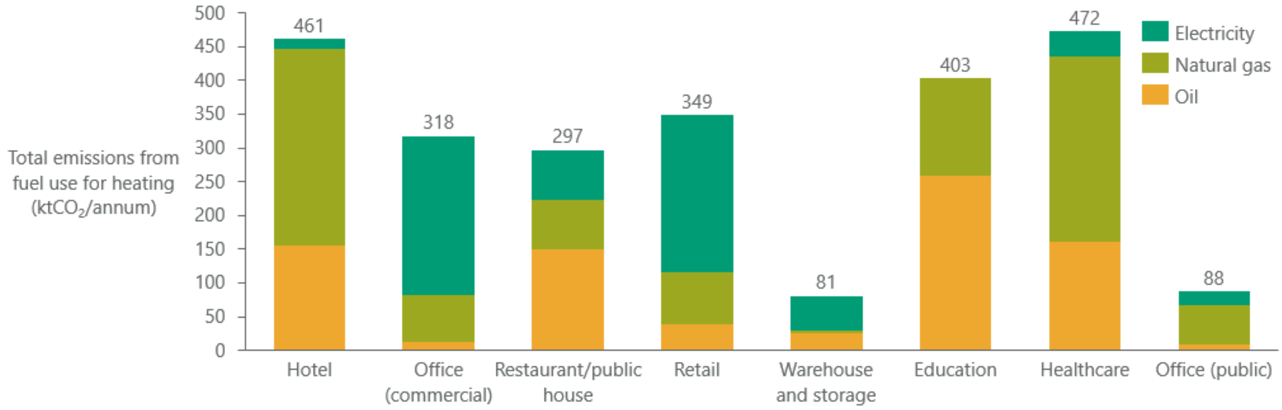
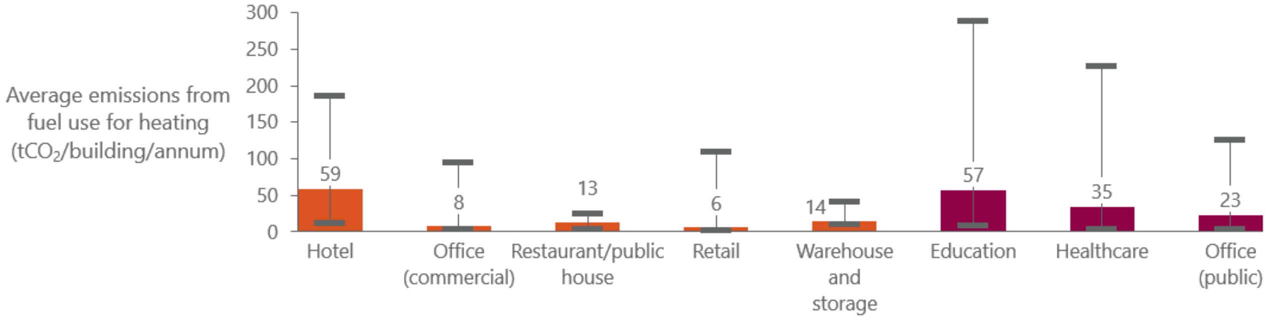


Figure 51 shows the average emissions from fuel use for heating in the commercial and public sectors by building activity. As with previous graphs showing average heating demand and floor area, the variation by archetypes in each building type is shown. The higher average emissions of hotels, education buildings and healthcare buildings are caused by high emissions at a relatively small number of sites.

Figure 51: Average emissions from fuel use for heating per annum (tCO_2/annum) in the commercial and public sectors, by building activity



3.2.3 Commercial and public cooling demand

The non-domestic BER dataset contains information on the current cooling demand in each building. This information has been included in the development of the commercial and public archetypes. *Figure 52* shows the total annual cooling demand in the commercial and public sectors by building activity. The cooling demand from retail archetypes exceeds that of all other archetypes combined. This points to the large amount of energy used for cooling in the retail sector, which is likely attributable to refrigeration.

Figure 52: Total annual cooling demand (GWh) for commercial and public sectors, by building activity

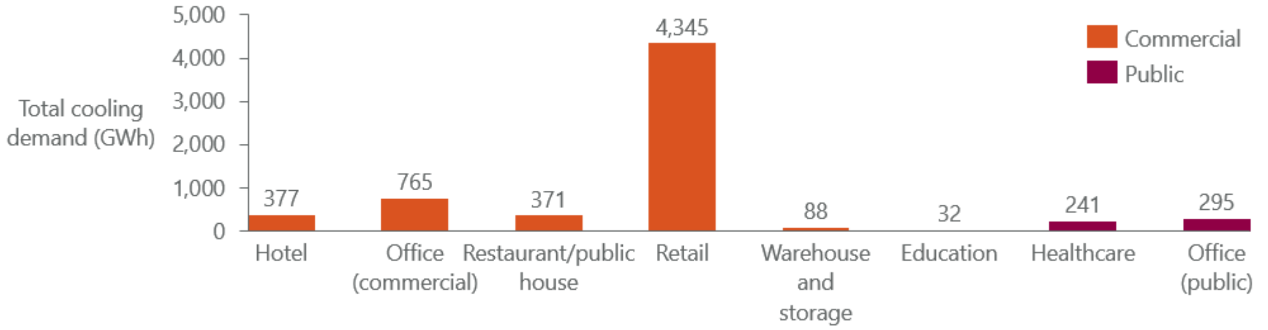
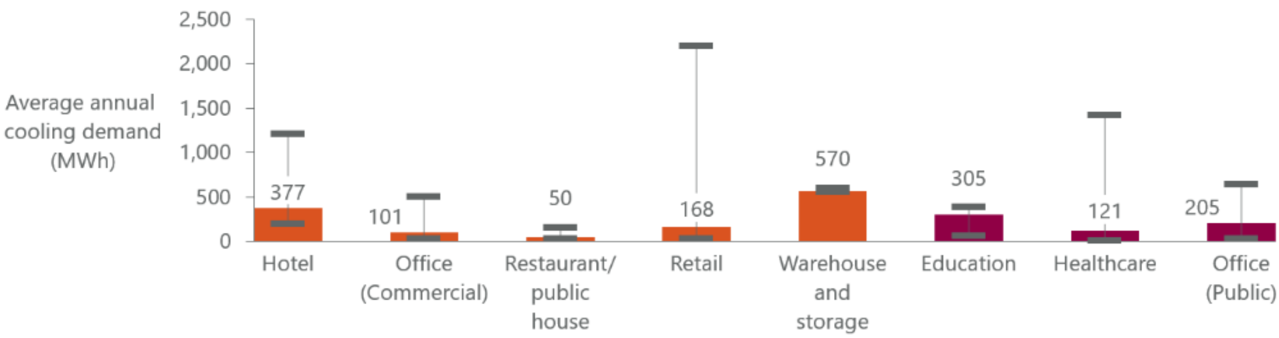


Figure 53 shows the average annual cooling demand for commercial and public archetypes by building type. As with floor area and heating, there is large variation in average cooling demand within archetypes for each building type. Fewer of the archetypes required cooling; only 62 of the 161 archetypes have a cooling demand; archetypes with no cooling demand are excluded from the data in the graph.

Figure 53: Stock-weighted average annual cooling demand (MWh) in commercial and public buildings with non-zero cooling demand, separated by building activity



Note:

- *Bars indicate the maximum and minimum cooling demand for archetypes within each building activity.*

In line with the evidence regarding marginal increase in cooling degree days and reasoning presented in *Section 2.2.3* above, this study assumes no growth in commercial and public cooling demand at an archetype level (an increase in the number of buildings, by contrast, could lead to an increase in cooling demand). The cooling demand for each archetype in the commercial and public sectors between now and 2050 is therefore assumed to be constant.

3.2.4 Commercial and public non-thermal electricity consumption

As the BER data set has information on a wide range of energy demand drivers, it has been possible for us to examine the amount of electricity used for purposes other than heating and cooling. *Figure 54* shows the total annual non-thermal electricity consumption (GWh) in the commercial and public sectors by building type. Public buildings consume significantly more non-thermal electricity than commercial buildings, despite being fewer in number. However, this is offset by the higher consumption of thermal electricity in (for heating and cooling) in commercial buildings.

Figure 54: Total annual non-thermal electricity consumption (GWh) in the commercial and public sectors, by building activity

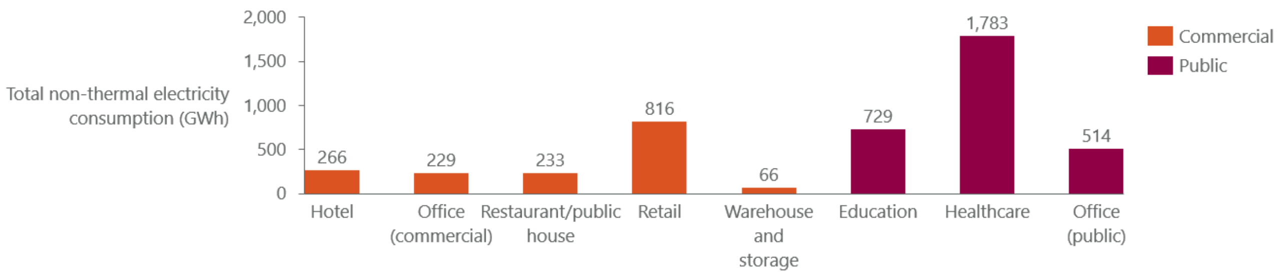
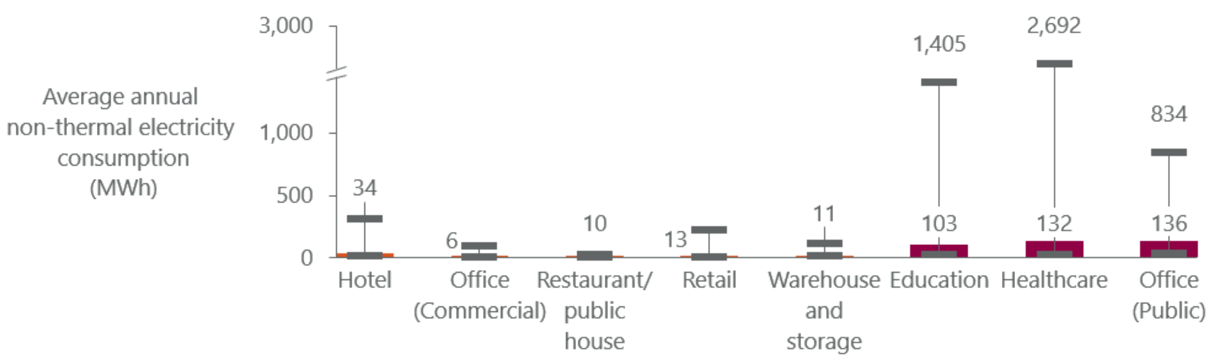


Figure 55 gives the average annual electricity consumption (MWh) for archetypes in the commercial and public sectors by building type.

Figure 55: Average annual non-thermal electricity consumption (MWh) in commercial and public buildings, separated by building activity



Note:

- *Bars indicate the maximum and minimum electricity consumption of archetypes within each building activity.*

4 Industry sector heating and cooling profiles

The heating demands from the Industry sector in Ireland have previously been modelled using the limited data available. As part of this analysis, we have been able to build on this previous work and have developed a significantly more granular and detailed data set of industrial archetypes than has existed previously. This work models the wide variety of heating processes and technologies at a much more granular level to provide a more representative view of heating in the Irish industrial sector, categorising the heating demand by process, equipment type and temperature/grade of heat. This section describes the methodology for profiling heating and cooling demand in industry and highlights the main results.

4.1 Archetyping methodology and assumptions

There are a wide range of industrial processes and applications, and different industrial processes have different options for decarbonisation. To address this, in this analysis we characterise industrial heating and cooling demand by process and equipment type, which is a significant advance on previous modelling.

4.1.1 Industrial archetyping

For the Industry sector, archetypes focused on representing the key industrial subsectors involving heating and cooling within Ireland and also the different processes which generate heat within these industrial sites. Due to this, subsectors were categorised slightly differently for the purposes of this project when compared to the Irish Energy Balances. The representation used was chosen to balance the scale of a subsector's heating demand and emissions in Ireland with how homogenous the processes or heating equipment in a subsector is. For example, the cement subsector is separated from other non-metallic mineral subsectors due to the scale of its heating demand in Ireland and the differences between processes on a cement site and an asphalt/ceramics site.

Each archetype represents a process category in an industrial subsector, shown below in *Table 8*. Archetypes are additionally split by ETS[10] status and fuel type. This means that the 'stock' within the industry sector represents the stock of a specific type of heating equipment, e.g. a boiler, rather than the stock of sites/buildings. This is helpful when analysing what the decarbonisation options are for industry, as it allows a more granular understanding of the technology options that are suitable for different heating processes occurring within industry. This enables different uptake options to be specified for the different equipment types at a single site in the modelling work for the National Heat Study. This also represents the staged approach to decarbonisation and capital stock replacement likely to occur within industry. This led to a total number of 396 heating 'archetypes' within Irish industry.

Table 8: High-level summary of the industrial archetypes included in the modelling

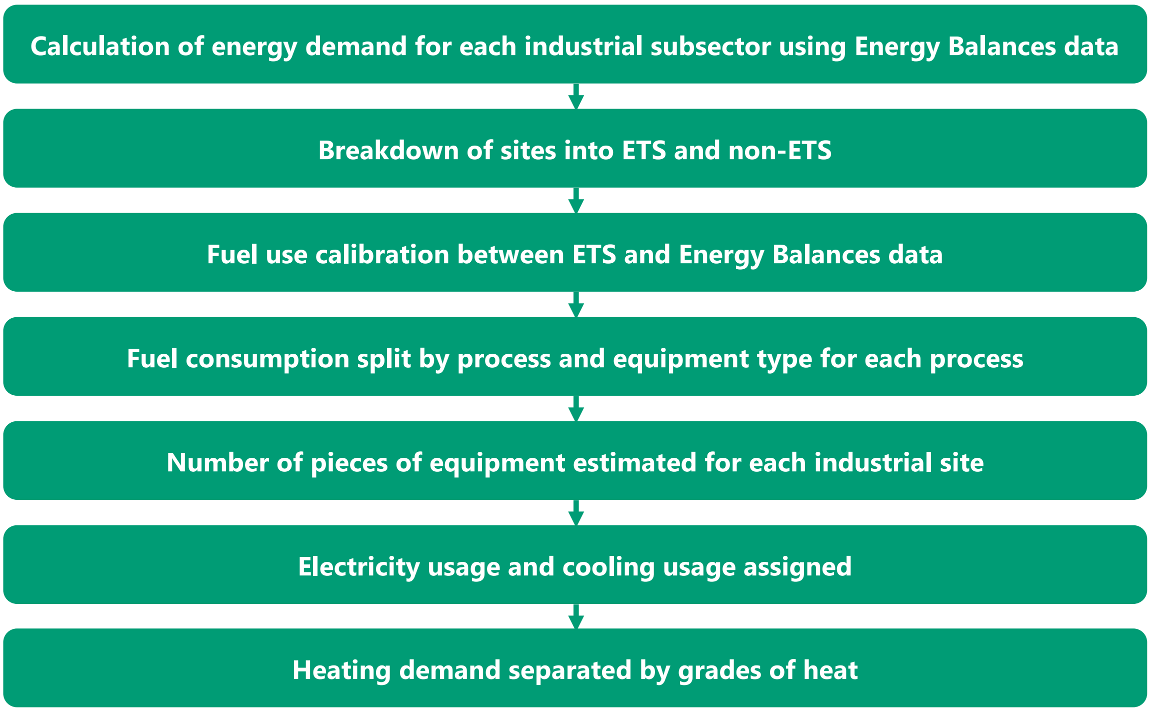
Industrial subsector	NACE codes	Processes present
Metals	24-25	Boiler, combined heat and power (CHP), Furnace
Cement	23 (partial)	Cement/Lime Kiln, Dryer
Refining	19.2	Boiler, CHP, Furnace
Chemicals	20-22	Boiler, CHP, Oven
Wood products	16	Boiler, Dryer

[10] ETS = Emissions Trading Scheme. This categorisation for the archetypes is effectively a gauge of the size of sites, with sites participating in the ETS generally comprising the ~60-70 largest sites within Irish industry.

Industrial subsector	NACE codes	Processes present
Other minerals	05-09, 23 (partial)	Other Kiln, Boiler, Dryer
Food and drink	10-11	Boiler, CHP, Oven, Dryer
Lime	23 (partial)	Cement/Lime Kiln, Other Kiln, Furnace
Other industry	12-15, 17-18, 26-33,	Boiler, CHP, Dryer

The methodology to calculate the full archetype data is illustrated in Figure 56 with each stage described in more detail in the text below.

Figure 56: Process flow diagram showing an overview of the method used to determine the fuel consumption, heating demand, electricity consumption and cooling demand of industrial archetypes



The *National Energy Balance* for Ireland [3] was used to estimate the overall energy demand for the entire industry sector, with the industry sector in the energy balance accounting for energy end use. The end-use data does not cover all industry energy demand – fuel is also used in refining processes and to cogenerate electricity and heat on site. To understand the full energy demand of the industry sector, the industry end-use data are combined with proportions of the energy use detailed in the CHP plants sector in the energy balance. This used CHP data from a confidential database on Irish CHP installations to estimate the proportion of CHP fuel use detailed in the energy balance within each industrial sector. This was further supplemented with ETS data that allows an estimation of the refinery fuel usage.

Large energy users with thermal inputs of more than 20 MW operate in the EU's emissions trading scheme (ETS). These sites publish data on greenhouse gas emissions each year. As an accurate source of data on emissions for the largest industrial sites within Ireland, this ETS data were used to estimate the number of larger ETS sites within the subsectors and the fuel used on these sites. As sites operating in the refining, cement and lime subsectors are typically large energy users, it was assumed that all sites in these sectors are included in the ETS. The difference between the total fuel use and the estimated fuel use on ETS sites was used to estimate the total fuel use in each sector on non-ETS sites. The number of non-ETS sites was estimated – using the Irish Business statistics for number of enterprises at NACE code level 3 (as shown in *Table 8*).[11]

Fuel consumption in each of the subsectors was then split between different processes and equipment types. This assignment differed in some subsectors between ETS and non-ETS sites, and was based on ETS permits [19], EU BREFs (Best available technology reference documents) [20], external industrial stakeholder engagement and expert project team experience.

The number of pieces of each equipment type on a site was also estimated. In conjunction with the number of sites in each subsector, this allowed the stock of different equipment types in Irish industry to be calculated for the archetypes. This differed between ETS and non-ETS sites, with the ETS estimates based on external industrial stakeholder engagement and the number of pieces of equipment stated within the ETS permit, whilst non-ETS sites were assumed to have single pieces of each equipment type relevant to the subsector.[12]

Electricity usage was allocated to subsectors from the Energy Balances data in the same way as fuel use. It was then split between ETS and non-ETS sites proportionally to their fuel usage. The proportion of electricity used for cooling in each subsector was also estimated based on studies on the cooling demand in Dutch [21] and EU industry [22] and UK energy use statistics [23].

Finally, the grades of heat required within the commission recommendation [24] were defined for the different processes, based on the EU BREFs, ETS permits and external industrial stakeholder engagement. This illustrates the different temperatures/grades of heat required in the industrial sectors present in Ireland, with implications for the suitability of different decarbonisation technologies.

4.2 Stock, heating, cooling and electricity demand

This section contains breakdowns of the total stock, heating demand, cooling demand and electricity consumption for the industrial sector. This shows the differences between the distinct industrial subsectors and indicates the range in energy use across the various industrial subsectors present in Ireland. Graphs showing the total stock of sites within each industrial subsector are provided, as well as stock of the different equipment types, heating demand in the industrial sectors by temperature of heat, heating demand by equipment type and the use of different fuel types by industrial subsector.

4.2.1 Industrial site stock

Figure 57 and *Figure 58* show the site breakdown of all industrial archetypes, by Industry subsector and by ETS status. The stock numbers are given by the totals above each bar in the graph. Within each industrial site has multiple pieces of equipment, which corresponds to the 'equipment stock' used in further calculations.

[11] There are uncertainties in estimating the number of non-ETS industrial sites in Ireland this way – some enterprises classified within Industry NACE codes might not have 'industrial' heating demand and could be better classified as commercial. In addition, some enterprises could have more than one industrial site.

[12] This assumption was made due to the significant uncertainties around numbers and types pieces of equipment on non-ETS sites.

Figure 57: Industrial site stock breakdown by subsector (ETS)

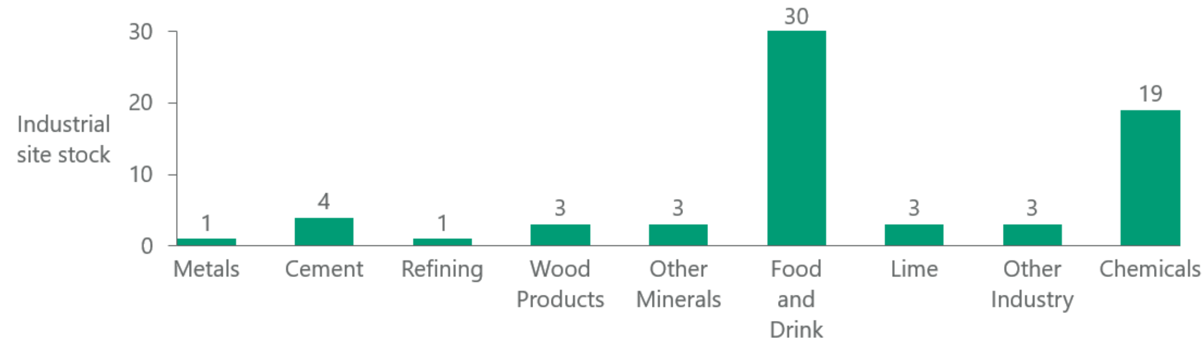
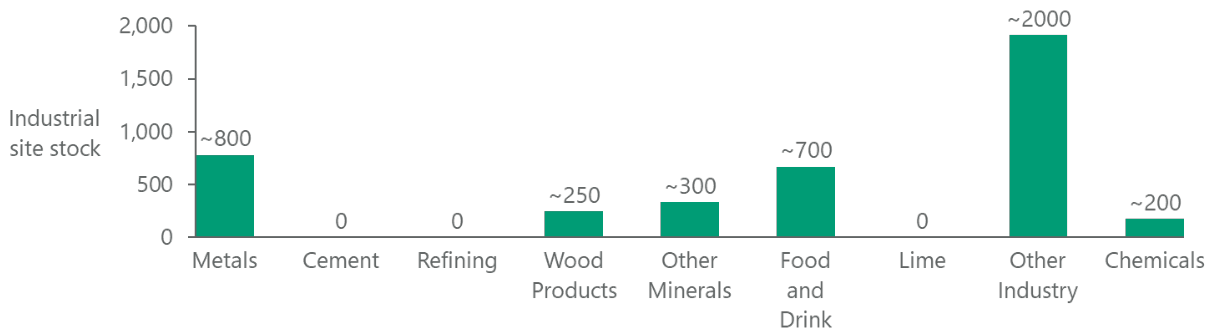


Figure 58: Industrial site stock breakdown by subsector (non-ETS)



Note:

- *Figures have been rounded due to the level of uncertainty (see footnote 11).*

4.2.2 Industrial heating demand

Figure 59 illustrates the total heating demand in different industrial subsectors by grade of heating, whilst *Figure 60* shows the associated emissions. The grade of heat can be used to gauge the suitability of different low-carbon heating technologies for different subsectors.[13] Generally low or medium grade heat dominates the heat demand, commonly supplied through steam from boilers/CHP. High grade heat does dominate in some industrial subsectors, especially Cement, and the heat for this is largely supplied by direct fired equipment like Kilns or Furnaces.

[13] Note that in our analysis this is not directly used to influence the suitability of low carbon heating technologies. The equipment type is the deciding factor on the suitability of low carbon heating technologies.

Figure 59: Annual Emissions (thousand tonnes of CO_2) in Industry, split by subsector and fuel

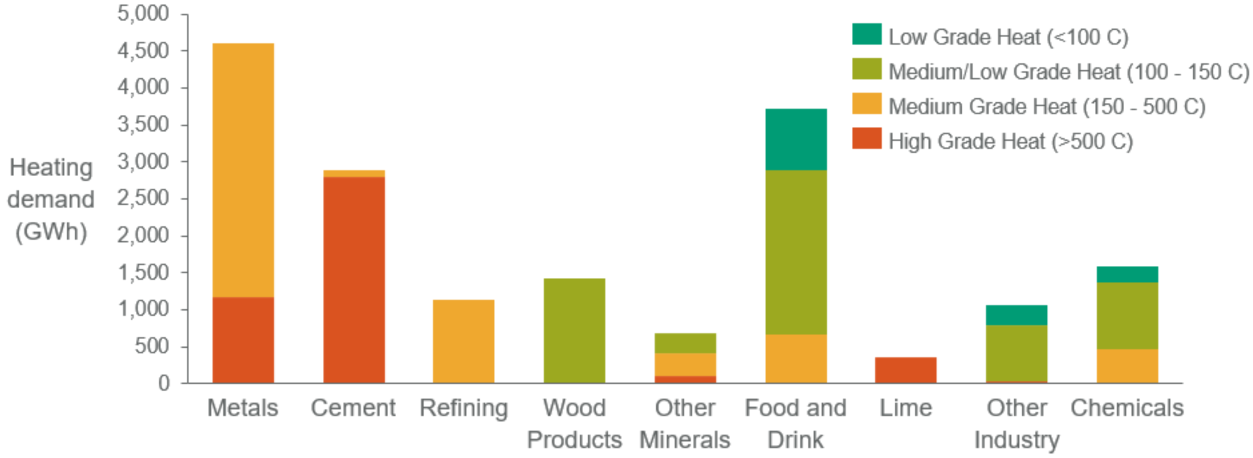
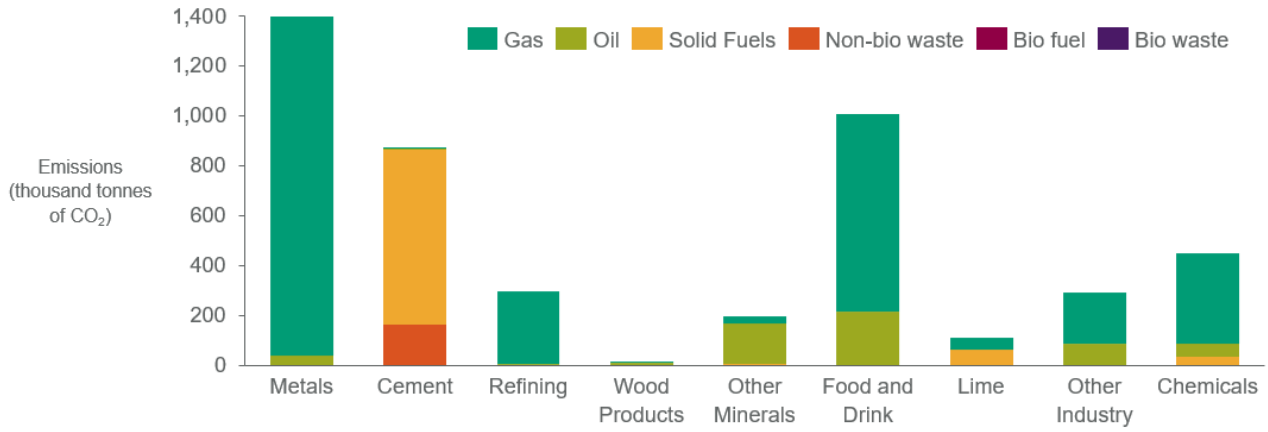


Figure 60: Annual heating demand (GWh) in industry, split by subsector and heating grade



Within the different types of equipment, there is a significant difference between the heating demands and emissions on ETS and non-ETS sites, as shown below in *Figure 61* and *Figure 62*. Indirect heating, where heat is supplied through a medium such as steam/hot water, dominates the non-ETS heat demands, with boilers being the largest component of this. Direct fired heating equipment, where combustion gases come into direct contact with the product being heated, such as furnaces or kilns, play a larger role on ETS sites. Additionally, CHP plays a significantly greater role on larger sites, accounting for ~80% of the operational CHP capacity.

Figure 61: Annual heating demand in industry (GWh), split by equipment type and ETS status

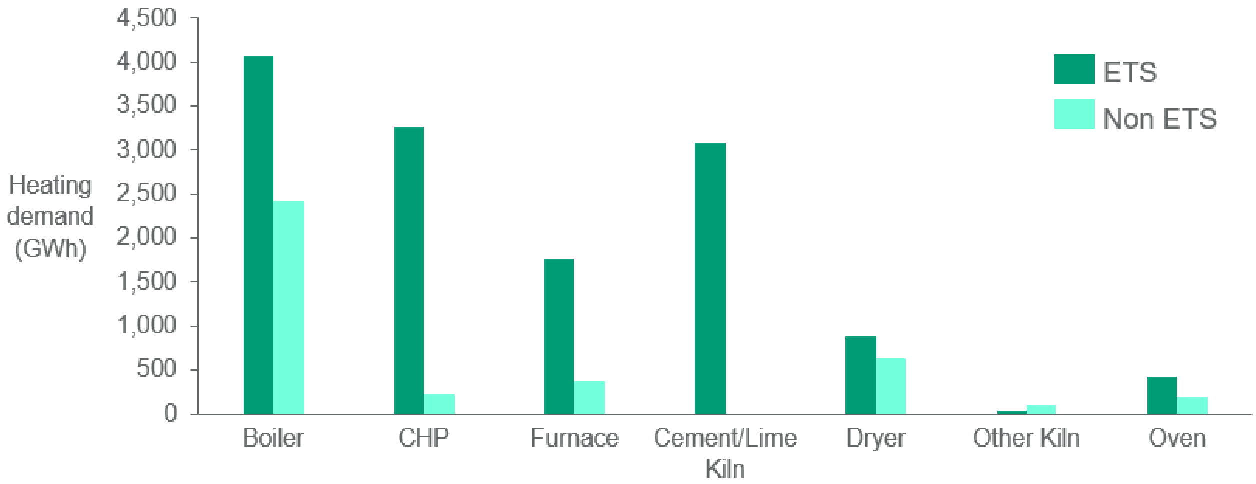
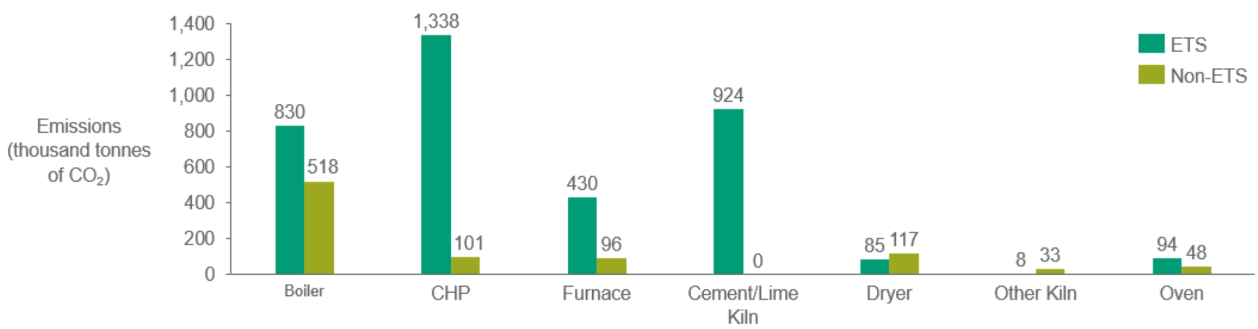
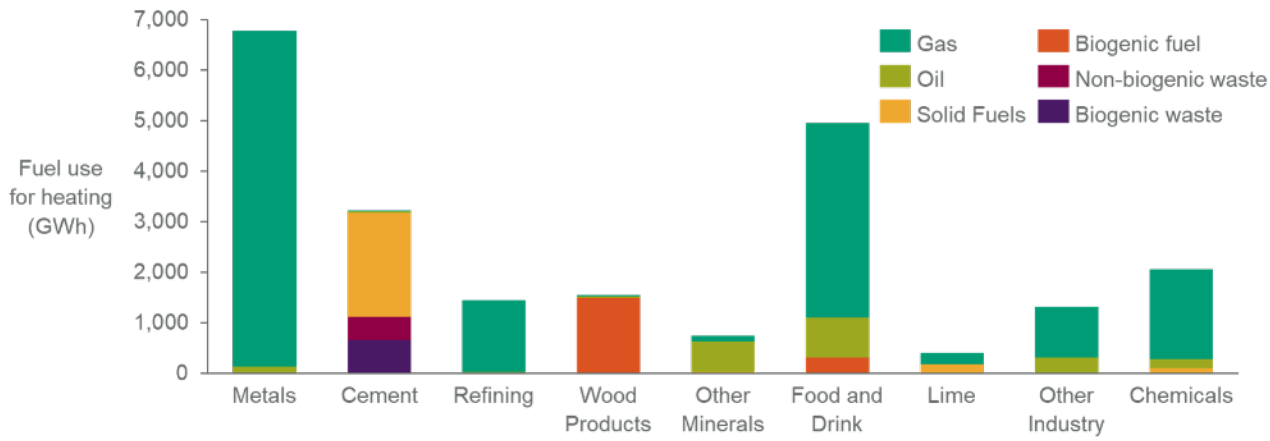


Figure 62: Annual emissions (thousand tonnes of CO_2) in Industry (GWh), split by equipment type and ETS status



The industrial subsectors also differ by the types of fuels used for heating, shown in *Figure 63*. This generally reflects the breakdown of different fuel types across the *National Energy Balances* data [3].

Figure 63: Annual fuel use in industry (GWh), split by industrial subsector and fuel type



4.2.3 Industrial cooling demand

The cooling demand within industry is uncertain. In industry, many pieces of equipment are 'cooled' by heat loss to their surroundings without any input of energy towards the 'cooling', or cooled through the extraction of heat for further use (e.g. in a heat exchanger). Some alternative methods for cooling use energy to cool equipment through cooling systems, fans and other equipment. The classification boundary between simple heat loss and cooling that requires input energy is uncertain. Thus, the archetypes here consider cooling demand and cooling fuel use as the electricity requirements for cooling, rather than as the overall thermal energy needing cooling. Within this study, the proportion of electricity demand in each industrial subsector used for cooling processes was estimated. This was based on studies about the cooling demand in Dutch [21] and EU industry [22] and UK energy use statistics [23]. The outputs are shown in the subsequent section in *Figure 64*.

4.2.4 Industrial electricity consumption

Figure 64 depicts the total annual electricity consumption (MWh) for the industrial sector by industrial subsector and by use for cooling or other demands (including heating). Cooling electricity demand is concentrated in the Food and Drink sector, with a significant proportion in the Chemicals subsector. *Figure 65* indicates the electricity usage net of any on-site electricity generation, effectively the import of electricity on to industrial sites. This is important because some industrial sites in Ireland generate their own electricity on site, through the use of CHP systems. This is clearly shown when comparing *Figure 64* and *Figure 65*, for example, in the net negative electricity import in the metals sector (due to large-scale electricity export from on-site CHPs).

Figure 64: Total annual electricity consumption (MWh) in industry, by industrial subsector and electricity use for cooling

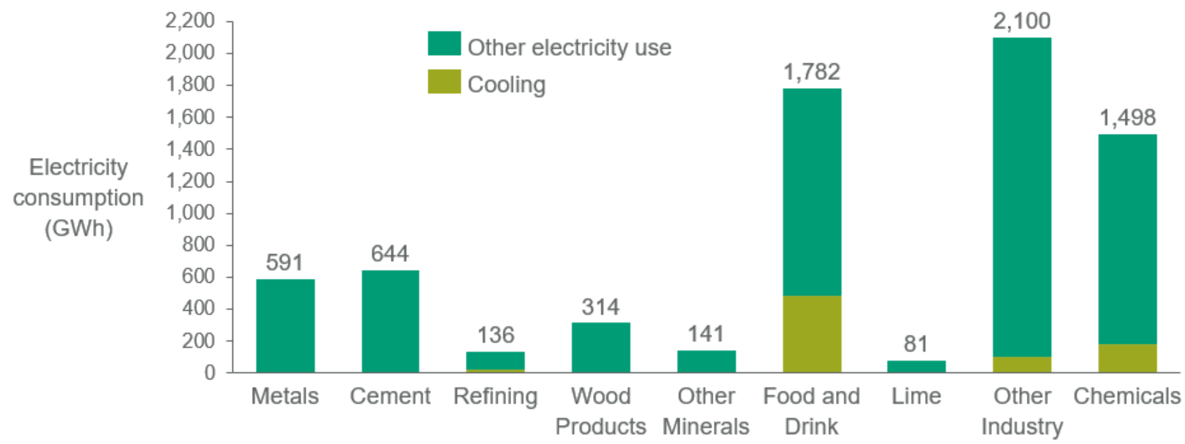
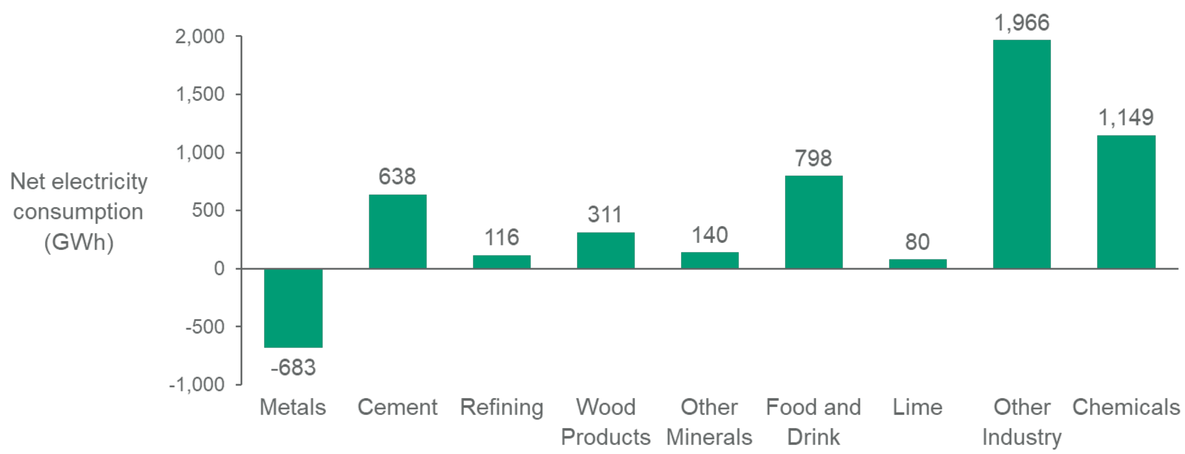


Figure 65: Net annual electricity consumption (MWh) in industry, by industrial subsector



Note:

- *Does not include the electricity consumption for cooling.*

5 Agriculture sector heating and cooling profiles

Agriculture is a sector that has not been modelled (or has only been modelled relatively coarsely) in previous work; there has typically been a lack of available data in this area and, as such, it has traditionally been difficult to model. This work has accounted for bottom-up modelling of the most relevant farm types that contribute to heating and cooling in Ireland, making use of the latest available data. This section describes the methodology for profiling heating and cooling demand in agriculture and highlights the main results.

5.1 Archetyping methodology and assumptions

For this sector, each archetype represents a farm type, with the term 'stock' in this case referring to the number of farms of said type. Additionally, archetypes (i.e. farms) are differentiated by size, which is generally based on the number of animals hosted on a farm. The following three sections detail the methodology and assumptions behind the novel modelling of three key farm types in the agricultural sector.

5.1.1 Agricultural archetyping

Archetypes for the agricultural sector focused on the representation of key agricultural activities with significant heating or cooling loads, or both. The archetypes are split into three main farming types: Dairy, Poultry and Pigs; each farm type is split into different size groupings; the high-level summary of modelled archetypes is presented in *Table 9*. The archetypes considered were chosen as the most relevant in terms of substantial heating and cooling demand; however, this should not be considered an exhaustive list. In total, 11 agricultural archetypes were modelled.

Table 9: High-level summary of the characteristic breakdown of modelled agricultural archetypes

Farm type	HVAC type	Heating system	Number of sizes modelled
Dairy	Heating and Cooling, Mechanical Ventilation	Electric cooling	4
Poultry	Heating only, Natural Ventilation	Oil boiler	3
Pigs	Heating only, Natural Ventilation	Oil boiler	4

Archetypes for each of the three farm types were developed using a new methodology based on the publicly available datasets. The following three subsections briefly outline the process undertaken for each.

5.1.1.1 Dairy

The process to develop the archetypes to represent the Dairy sector's cooling demand is presented in *Figure 66* below; various sources, including recent Teagasc study data were used [25] [26] [27]. Of the three modelled farm types, Dairy is the only one to have cooling demand (i.e. for milk cooling), which uses electricity as a fuel. It is also the most numerous farm type, in terms of archetype stock (or number of farms), as there are many farms with relatively few cows. Regarding heating, considering that the gasoil use in this sector is likely associated with machinery and other non-heating applications, electricity use is modelled as the primary heating fuel as well.

Figure 66: Process flow diagram for the method used to define archetypes for dairy farms, and to calculate the cooling demand and number of farms in each archetype

Process	Key aspects	Key data sources
Data collection for total stock & electricity consumption	• Total stock of dairy farms taken to be 16,146. • Total dairy electricity use taken to be 302 GWh.	• 2019 National Farm Survey Results, Teagasc (2020).
Herd sizes split into archetypes	• The range of herds was split into four sizes to represent different farms based on Teagasc & AgriLand data. • The average sizes chosen are as follows (unit: dairy cows per farm): Small (47), Medium (75), Large (118), Very Large (290).	• 2019 National Farm Survey Results, Teagasc (2020). • Kiernan, Aisling: "70% of dairy farm households in Ireland have an off-farm income source", June 2019.
Electricity consumption broken down by end use	• Electricity consumption of a typical farm broken down into cooling loads (milk cooling), water heating loads, and non-cooling, non-water-heating loads (milking, lighting, other, and pumping). • All gasoil consumption assumed to be for non-heating & non-cooling processes.	• 2019 National Farm Survey Results, Teagasc (2020).
Total farm stock attributed across archetypes	• The total farm stock was attributed across the size categories. • The demand per cow was assumed constant. • Total demand per archetype was determined.	

5.1.1.2 Poultry

The steps undertaken to develop the archetypes to represent the main heating demand from poultry farming is in *Figure 67* below; CSO [28] and recent Teagasc study data [29] were used. As can be expected, compared to other farm types, table birds are farmed in a relatively low number of large broiler houses with relatively high numbers of animals per farm. As noted, the primary heating fuel modelled for poultry farming is kerosene (i.e. via oil boilers).

Figure 67: Process flow diagram for the method used to define archetypes for poultry farms, and to calculate the heating demand and number of farms in each archetype

Process	Key aspects	Key data sources
Poultry data collection	• Table birds were considered the most relevant poultry category, in terms of large broiler houses that have significant heating loads. • Total applicable stock of farms was taken to be 500, with 7.7 million applicable birds, based on CSO survey data.	• CSO: Farm Structure Survey 2016, Table 4.5 (2016).
Archetype farm sizes calculated	• Three sizes of poultry farms were selected as representative based on the regional distribution of farm sizes in Ireland (i.e. 200 large farms at the border counties, 100 medium farms in the mid-west and 200 small farms in the south-west and other locations). • The average sizes chosen are as follows (unit: birds per farm): ~5,600 (small), ~11,100 (medium), and ~27,300 (large).	• CSO: Farm Structure Survey 2016, Table 4.5 (2016).
Archetype heating demand calculated	• Average broiler house oil and electricity fuel use taken from Teagasc data, based on 27,000 birds/house. • Ratio of fuel use per bird applied to the three farm sizes to determine fuel use per stock for each size. • Assumed that kerosene is solely used for heating and electricity for non-heating applications; no cooling was assumed.	• Teagasc Energy Fact Sheet: Energy Efficiency on Poultry Farms (August 2018).

5.1.1.3 Pigs

The methodology used for the development of the archetypes to represent the heating demand from Irish pig farms is presented in *Figure 68*; CSO [30] and recent Teagasc study data [25] were used. The relative variation of number of animals per farm, within pig farms, is the greatest amongst all three modelled farm types. However, similar to poultry farms, the primary heating fuel modelled is kerosene (i.e. via oil boilers).

Figure 68: Process flow diagram for the method used to define archetypes for pig farms, and to calculate the heating demand and number of farms in each archetype

Process	Key aspects	Key data sources
Total farm and animal stock taken	• Total applicable stock of pig farms taken to be 1300. • Total number of pigs taken to be 1.6 million.	• CSO: Farm Structure Survey 2016, Table 4.4 (2016).
Archetype farm sizes calculated	• Archetypes separated based on size of pig on each farm, based on CSO data. • Average pig farm sizes modelled are as follows (unit: pigs per farm): Small (5), Medium (213), Large (448), and Very Large (914). • These average farm sizes also correspond to pig types in the farm – i.e. small, medium, large, and very large farms host boars, female breeding pigs, pigs <20 kg, and pigs >20 kg respectively.	• CSO: Farm Structure Survey 2016, Table 4.4 (2016).
Archetype heating demand calculated	• Total oil and electricity fuel use was taken from Teagasc data. • Average fuel use per pig was applied to the four farm sizes to determine fuel use per stock for each farm size. • Kerosene was assumed solely for heating and electricity use for non-heating applications; no cooling was assumed.	• 2019 National Farm Survey Results, Teagasc (2020).

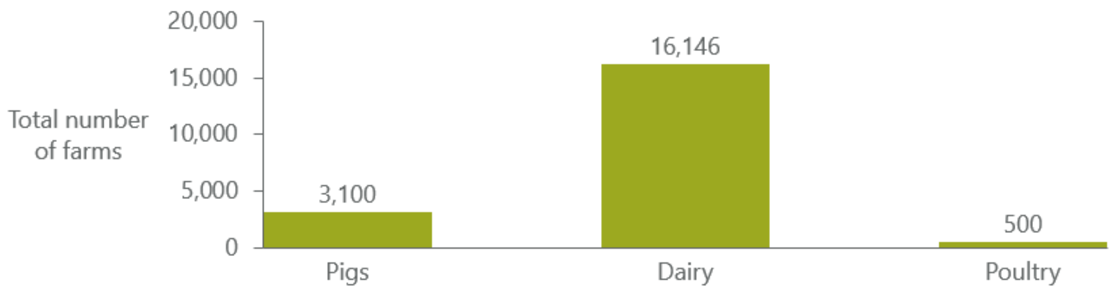
5.2 Stock, heating, cooling, and electricity demand

This section contains breakdowns of the total archetype stock, heating demand, cooling demand and electricity consumption for the agriculture sector in Ireland. Graphs showing the total archetype stock of farms within each agricultural subsector are provided, as well as total and average heating demand and electricity consumption.

5.2.1 Agricultural stock

Figure 69 gives the breakdown of total agricultural stock (i.e. the number of farms), by farm type. There are significantly more dairy farms than poultry or pig farms.

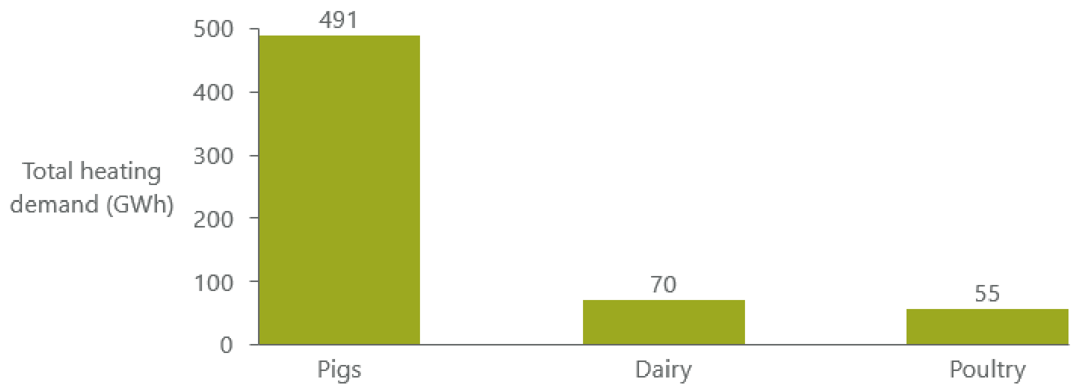
Figure 69: Agricultural building stock breakdown by type of animal product



5.2.2 Agricultural heating demand

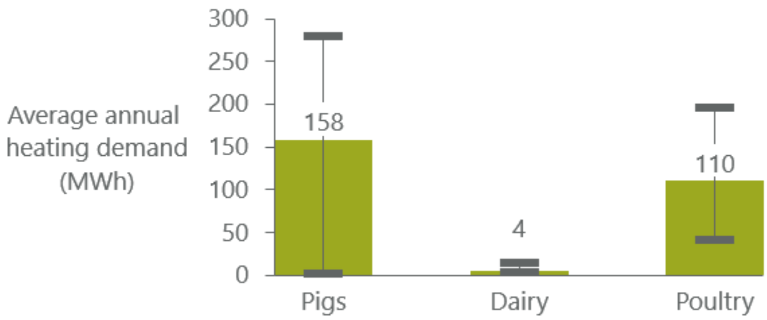
Figure 70 gives the total annual heating demand (MWh) of all farms across the three chosen agricultural subsectors. Note that most of the heating demand comes from agricultural archetypes with pigs; dairy and poultry having heating demands an order of magnitude lower. Additionally, whereas pig and poultry farms have heating demands due to space heating, dairy farms predominantly use heat for water heating.

Figure 70: Total annual useful heating demand (GWh) in the Agricultural sector, by type of animal product



In terms of the fuel-use breakdown to provide this heating demand, based on the quantitative fuel use data used (as noted in the above sections), electric heating is modelled to supply the entire heating demand for dairy, whereas for poultry and pigs, the heating is supplied entirely by oil boilers.

Figure 71: Annual useful heating demand (MWh) in agricultural archetypes, by type of animal product



The emissions breakdown for archetype stock in the agricultural sector is provided in *Figure 72* and *Figure 73*. The emissions from pig farms form the majority of emissions from heating in the agriculture sector, making up 80% of total agriculture emissions from fuel used for heating. Emissions from oil use contribute 89% of all emissions from heating in the agriculture sector. The average emissions from fuel used for heating per building in the diary sector are significantly lower than the other two agriculture sectors considered here. This is due to the high number of low heating demand archetype stock in the Dairy sector.

Figure 72: Total emissions from fuel use for heating per annum ($ktCO_2$/annum) in the agriculture sector, by type of animal product and fuel used

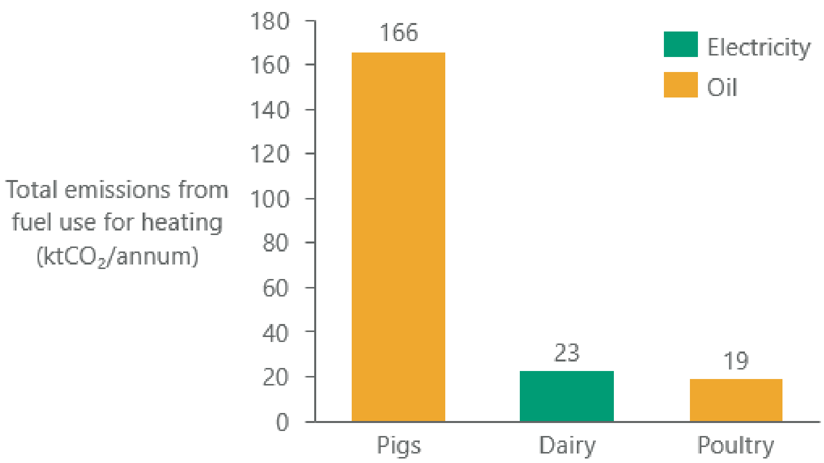
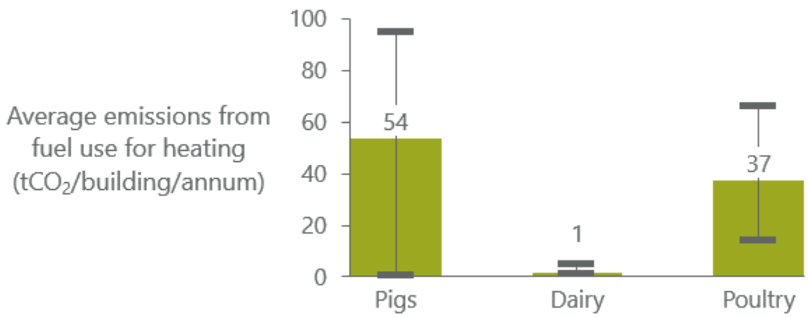


Figure 73: Average emissions from fuel use for heating per annum (tCO_2/annum) in the agriculture sector, by type of animal product



5.2.3 Agricultural cooling demand

The only modelled cooling demand in the Agriculture sector is in the dairy industry; poultry and pigs do not have any cooling demand. The dairy industry uses electricity to cool milk and other dairy products through refrigeration. The Dairy sector has a total of 93 GWh of electricity consumption for cooling, split over the modelled 16,146 farms for an average of 5.8 MWh per property. The minimum electricity consumption for cooling in the modelled dairy archetypes is 3.0 MWh, and the maximum is 18.3 MWh. The historical data [25] shows growth in the heating and cooling demand increasing linearly with the increase in dairy production. As such, it is expected that this trend is likely to continue.

5.2.4 Agricultural non-thermal electricity consumption

Figure 74 shows the total annual electricity consumption (MWh) in the agricultural sector by type of animal product. Dairy farms have the highest total electricity consumption; although on a per-archetype-stock basis, dairy farms have the lowest average electricity consumption (9 MWh) compared to poultry (20 MWh) and pig farms (14 MWh), as shown in *Figure 75*.

Figure 74: Total annual electricity consumption (MWh) in the agricultural sector, by type of animal product

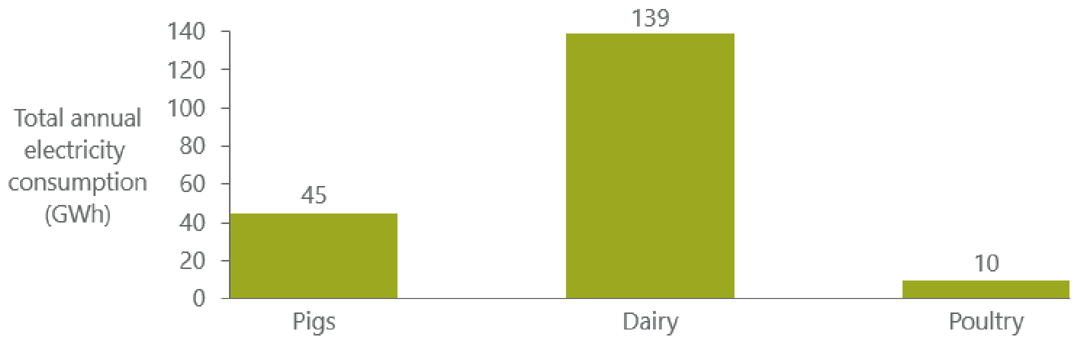
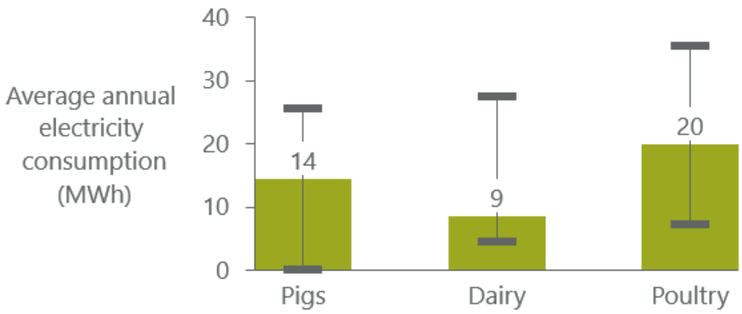


Figure 75: Average annual electricity consumption (MWh) in the agricultural sector, by type of animal product



6 Data centres

Data centres can have significant cooling demand requirements, but their heating and cooling demands are significantly different from the other Irish sectors considered in this study. As a by-product of the data management processes that occur within data centres, large amounts of low-grade excess heat are generated. Because of this, and due to improved data centre operation at low temperatures, up to 40% of a data centre's total electricity consumption can be on cooling, depending on the efficiency of the data centre's servers and cooling method [31].

The expected growth in electricity demand from data centres in Ireland over the coming years is higher than in any other sector. According to the *All-Island Generation Capacity Statement 2020-2029* [32], EirGrid analysis estimates that 27% of Ireland's total electricity demand in 2029 could come from data centres, with over 5 TWh of additional annual electricity consumption by data centres estimated in their 'Median Demand' scenario.

Data centres were not included in the same archetype processing as the rest of the building stock. An alternative bottom-up approach was taken to produce an estimate of the total electricity consumption of data centres each year to 2050. This annual electricity consumption profile was broken down into four different data centre archetypes, as described in the following section. Each data centre archetype has its own cooling demand based on this electricity consumption, which was used to produce a data centre cooling demand projection in Ireland until 2050. A description of the methodology used, and results produced is given below.

6.1 Archetyping methodology and assumptions

Data centres were split into four archetypes based on their size and type of client. The archetypes modelled in this study are 'Private', 'Co-location', 'Hyperscale' and 'Co-location wholesale' data centres. These four archetypes were chosen based on feedback from expert external stakeholders and aligned to the segmentation used in the industry.

Private data centres are built for a specific type of operation, such as telecoms operations or financial transaction processing, and are operated by a single company. Co-location data centres are facilities which can be leased by third parties for partial use. Hyperscale data centres are built and managed by large companies with large data requirements; for example, in Ireland, Microsoft, Google, Amazon and Facebook [33]. Co-location wholesale data centres are built on the same scale of Hyperscale data centres, but by third parties, and the space in these buildings is leased to companies that have exceeded their own installed data centre capacity.

The process of building a data centre involves agreeing a Maximum Input Capacity (MIC) with the electricity network operator. The MIC is the maximum amount of grid electricity demand that a single site is allowed by the electricity network operator. According to EirGrid's *All-Island Generation Capacity Statement 2020-2029* [32], the typical electrical load of Irish data centres is 40% of their MIC; however, this load generally increases throughout the lifetime of a data centre, as the data centre's total installed electrical capacity increases over time. This leads to increasing demand, even without new data centre installations. Because of the varying electricity demand of individual data centres throughout their lifetime, the total annual electricity consumption of all data centres belonging to each archetype was modelled, with a description given in the following section.

To calculate the breakdown of data centre electricity consumption into the four archetypes (Private, Co-location, Hyperscale, Co-location wholesale), a Bitpower report on *Ireland's Data Hosting Industry* (2020) [34] was used, which provides an overview of the state of the data centre sector in Ireland [34]. In line with growth from their similar report in 2017, the electricity consumption of private data centres was assumed to be constant between now and 2050. The growth in data centre demand was therefore assumed to come entirely from the other three data centre archetypes (Co-location, Hyperscale, and Co-location wholesale). The breakdown of demand growth for these three archetypes is equal to the breakdown of the non-private data centre installed capacity in Bitpower's 2020 report. This is given below in *Table 10*.

Table 10: Data centre archetype installed capacity (2019) and share of future growth in electricity consumption

Data centre archetype	2019 electricity consumption (GWh)	Assumed share of future growth in data centre electricity consumption
Private	220	0%
Co-location	210	12%
Hyperscale	1,470	82%
Co-location wholesale	110	6%

The archetype groups used here are in line with standard industry and academic separation of data centre types [32] [35], which allows for comparison with similar studies. The EirGrid scenarios that the data centre electricity consumption projection is based upon are the most reliable sources of data centre demand growth, according to expert stakeholder engagement, especially in the near term (to 2030).

The lack of publicly available data on energy consumption and cooling demands in individual data centres restricts the ability to model data centres at an individual building level, in line with the method used in the rest of this study; there is not enough information in the non-domestic BER database to model individual data centres. Furthermore, there is not enough available data to model the use of specific technologies for cooling in data centres in Ireland. The approach to model the electricity consumption and cooling demands of these data centre archetypes, described in the following sections, attempts to alleviate the issues caused by lack of data from individual data centre sites or on specific cooling technologies.

6.2 Electricity consumption and electricity consumption for cooling

This section provides a description of the methodology used to calculate the current electricity consumption of data centres in Ireland. It also outlines a method to estimate how this demand may evolve between now and 2050. Also included is the methodology to determine the electricity consumption for cooling in data centres. Heating demand is not considered, as it is insignificant compared to electricity consumption and cooling demand in data centres. Graphs are presented showing the estimated distribution of electricity consumption across the four data centre archetypes, described in the previous section, and for the proportion of estimated data centre electricity consumption used for cooling in each year between now and 2050.

6.2.1 Electricity consumption

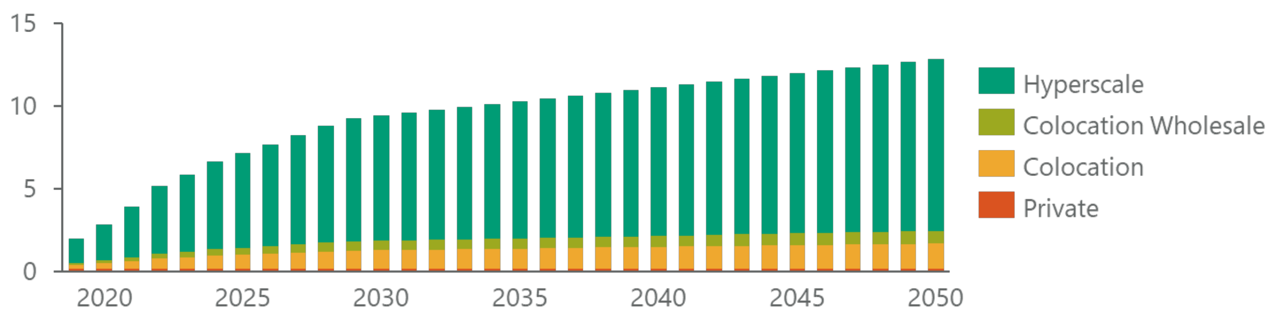
The process to model the electricity consumption projection for the data centre archetypes is given in *Figure 76* below. Electricity consumption projections to 2029 are taken based on data from the latest *All-Island Generation Capacity Statement* [32], which are then extended to 2050 using data from EirGrid's latest *Tomorrow's Energy Scenarios report* [35]. The EirGrid electricity consumption projections include electricity consumption by other large energy users; these have been removed from the projections given below, as they are covered in the other sectors considered in this study.

Figure 76: Process flow diagram for the method used to produce the data centre electricity demand projection

Process	Key aspects	Key data sources
Data centre demand projection to 2029	• Data centre electricity demand projection until 2029 taken from All-Island GCS, Median scenario. • No demand assumed to come from Northern Ireland.	• All-Island Generation Capacity Statement, 2020-2029, EirGrid & Soni (2020).
Demand projection extended to 2050	• Growth in data centre demand from 2029 to 2040 taken from Central scenario in EirGrid's TES. • Linear growth assumed from 2040 to 2050.	• Tomorrow's Energy Scenarios 2019, EirGrid (2019).
Current demand estimation for other large energy users	• Installed capacity of data centres estimated from data in Bitpower reports. • Installed capacity multiplied by average capacity factor of data centres (40%).	• Ireland's Data Hosting Industry – Biannual Report, Bitpower (2020). • Ireland's Data Hosting Industry 2017, Bitpower (2017).
Removal of demand of other large energy users	• No demand growth assumed for other large energy users. • Demand profile adjusted to remove current non-data centre demand.	

The resulting total electricity consumption is shown below in *Figure 77* by data centre archetype, according to *Table 10* above. Hyperscale data centres form most of the electricity consumption out to 2050.

Figure 77: Total annual data centre electricity consumption (TWh), by data centre archetype



6.2.2 Electricity demand for cooling

A metric commonly used in relation to data centre efficiency is the Power Usage Effectiveness (PUE), given by the following equation:

$$PUE = \frac{IT\ load + other\ loads\ (including\ cooling)}{IT\ load}$$

For a perfect data centre with no energy losses, the PUE is 1. In a more realistic case, of the 'other loads', 70% was assumed to be from electricity used for cooling, with the remaining 30% assumed to be from power losses and non-IT, non-cooling loads, such as lighting. This was based on review of scientific papers [31] [36] and external expert stakeholder feedback.

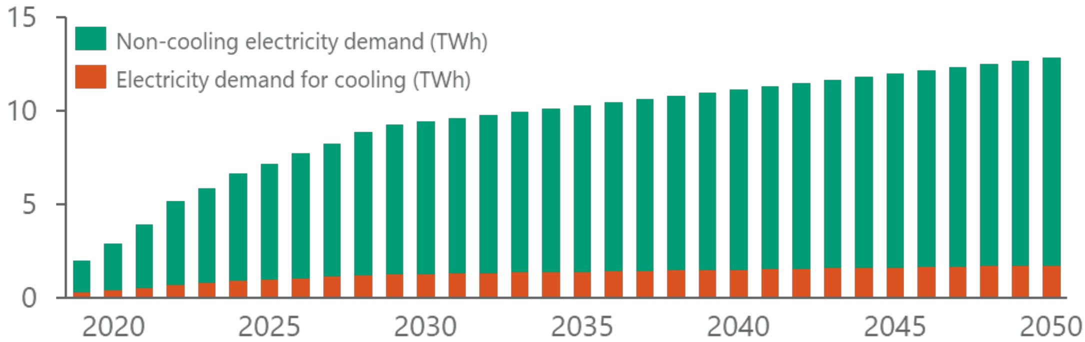
A PUE value was assumed for each of the four archetypes, in line with academic [31] and technical reports [36] [37], and expert external stakeholder engagement with Bitpower. The values are in *Table 11* below.

Table 11: PUE values and percentage of electrical load used for cooling, for each data centre archetype

Data centre archetype	PUE value	Percentage of electricity used for cooling
Private	1.6	26%
Co-location	1.5	23%
Hyperscale	1.2	12%
Co-location wholesale	1.3	16%

Combining these PUE values with the total electricity consumption projections detailed in the previous section, the total electricity consumption for cooling purposes in data centres in Ireland until 2050 was modelled. The results are in *Figure 78*.

Figure 78: Total electricity consumption and electricity consumption for cooling (in TWh) projections for data centres in Ireland until 2050



In the other sectors modelled for this study, cooling demand is presented instead of electricity demand used for cooling purposes; for data centres, electricity demand for cooling is instead shown. This is for two reasons: first, an industry standard is to describe energy use in data centres via the PUE, so for ease of comparison with other work, this is followed here. Second, there is little publicly available information regarding the efficiency of cooling techniques used in data centres, and so it is more accurate to present electricity demand for cooling (for which there is more available information).

7 Summary of Irish heating and cooling demand

This section is intended to bring the various breakdowns shown in previous sections together, to provide a holistic view of Irish heating and cooling demand across the entire Irish building stock. It covers the residential, commercial services, public services, industry and agriculture sectors and data centres. Extensive bottom-up modelling has been developed for each of these sectors, as described in the prior sections of this report. This section compliles the results to provide a detailed depiction of heating and cooling in Ireland today.

The data developed using the methods outlined here are a fundamental input for other parts of the National Heat Study. The data are vital inputs for SEAI's National Energy Modelling Framework (NEMF). The NEMF is the analytical tool used to examine various decarbonisation pathways in the National Heat Study to reach net zero by 2050, in line with the Irish Government's ambitious targets to reduce national emissions [38] and the *National Energy and Climate Plan* [39] in 2020.

The extensive modelling of the current heating demand presented in this report fulfils two purposes in advance of the NEMF modelling work: to fully understand the current energy demands (and associated CO_2 emissions) of heating and cooling in Ireland; secondly, to enable the NEMF modelling to be carried out at the same level of detail as the work presented in this report.

Table 12 below shows a summary of the stock, heating demand, cooling demand and electricity consumption of each of the sectors profiled in this study, according to the methods outlined in the previous sections. Graphs representing this data, along with further breakdowns of fuel type for heating in each sector, follow in this section of the report.

Table 12: Summary of the current stock, annual heating demand, annual cooling demand and annual electricity consumption in each of the profiled sectors in Ireland

Sector	Stock	Current heating demand (TWh/ annum)	Current cooling demand (TWh/ annum)	Current electricity demand (TWh/ annum)	Current heating fuel use (TWh/ annum)	Current heating emissions ($MtCO_2$/ annum)	Current cooling emissions ($MtCO_2$/ annum)	Current electricity emissions ($MtCO_2$/ annum)
Residential	1,773,559	19.4	0	7.3	26.3	6.8	0	2.3
Commercial	134,361	5.7	5.9	1.6	5.9	1.5	0.9	0.5
Public	24,409	3.5	0.6	3.7	4.2	1.0	0.3	1.2
Industrial	16,332	17.5	0.8	4.5	20.7	4.6	0.03	1.5
Agriculture	19,746	0.6	0.1	0.2	0.8	0.2	0.1	0.1
Data Centres	Not broken down by stock	0	0.3	1.7	0	0	0.1	0.6

Note:

- *The electricity columns above (demand and emissions) are non-thermal and so do not include the values for electricity used for heating and cooling, as these are separated out in additional columns.*

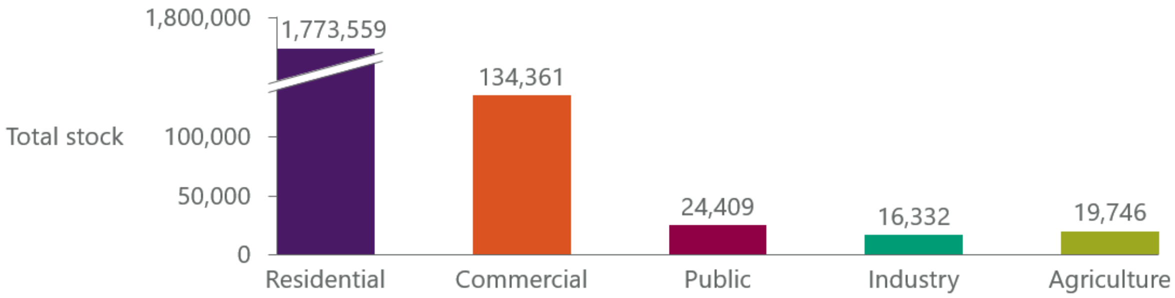
7.1 Archetype breakdown and sectoral split

This section provides visualisation of the summary given in *Table 12* above. Presented below are graphs summarising the total stock in each sector, as well as the total heating demand, cooling demand and electricity consumption across all sectors modelled.

7.1.1 Stock by sector

This section provides a summary for the stock breakdown of Irish buildings across all modelled sectors. The following graph, *Figure 79* depicts the breakdown of overall stock by each of the five profiled sectors. Most properties in Ireland (90%) are residential. For all sectors except Industry and Agriculture, one stock represents one building. For the Industry sector, one stock represents one piece of equipment within an industrial site and the total number of industrial sites in Ireland is approximately 4,200 (see *Section 4*). For the Agriculture sector, one stock represents one farm.

Figure 79: Overall stock by sector



7.1.2 Heating demand by sector

This section provides the main heating demand breakdowns, overall and for each sector. The following graph (*Figure 80*) depicts the breakdown of overall heating demand (GWh) by each of the five profiled sectors. The majority of heating demand (44%) comes from residential buildings, but as expected, this is significantly lower than the share of stock in the residential sector (90%).

Figure 80: Total annual heating demand (GWh) in each sector

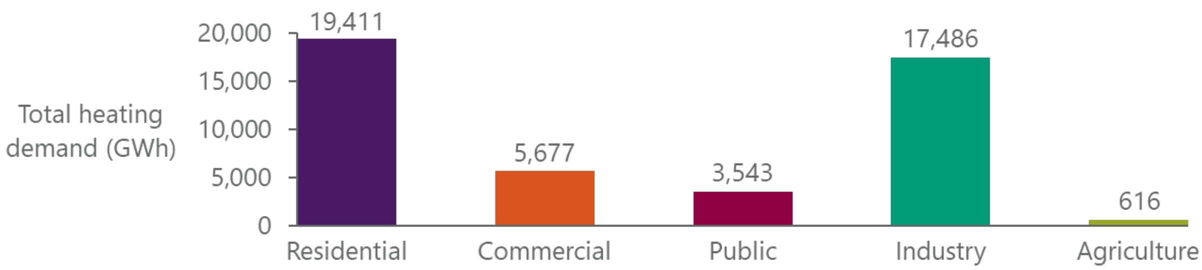


Figure 81 gives the breakdown of primary fuel consumption for heating purposes in each sector. These show the percentage breakdown of the fuel used to provide the heating in *Figure 80* above. Both space heating and hot water heating demand are included in this fuel consumption breakdown. The industrial sector breakdown is in *Section 4.2*.

Figure 81: Percentage breakdown of fuel use for heating purposes (including space heating and hot water) by sector

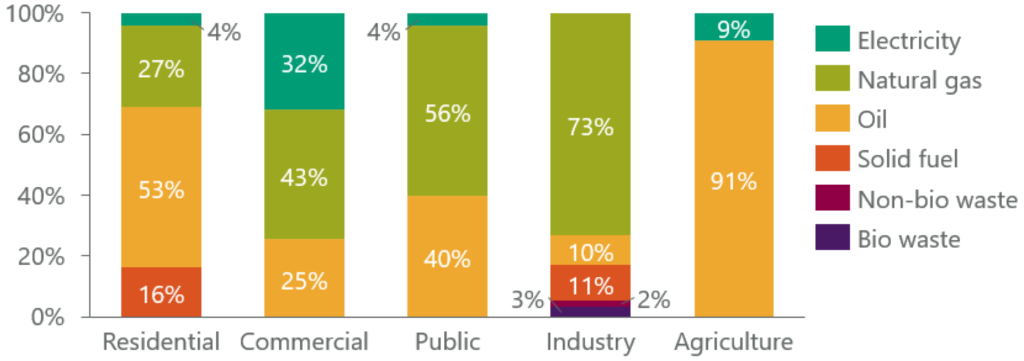
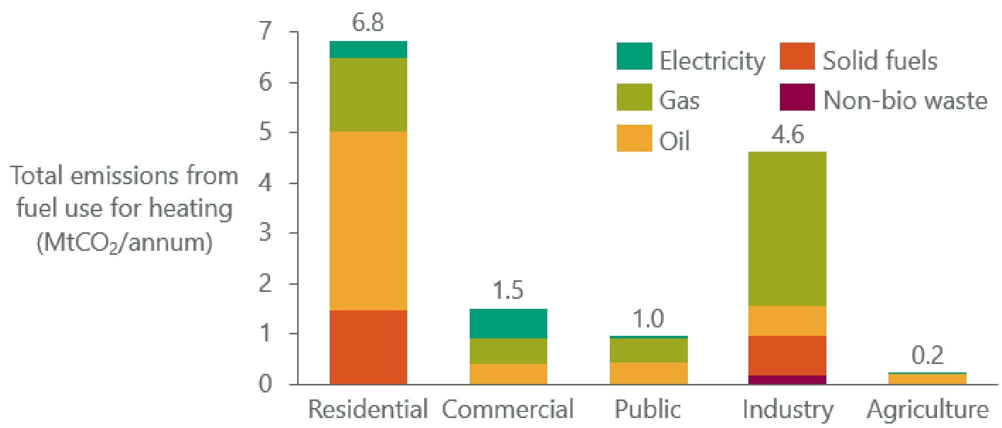


Figure 82 shows the total emissions from heating in all sectors described above by fuel type. As with heating demand, the residential sector contributes the most to emissions from fuel use for heating in Ireland, with 48% of the total. In terms of fuels, emissions from gas are the highest, contributing to 39% of total emissions from fuel use for heating across these five sectors, due to a high gas consumption in industry. Oil has the second highest contribution, with 36% of total emissions from fuel use for heating across these five sectors.

Figure 82: Total emissions from fuel use for heating per annum ($MtCO_2$/annum) in all sectors, by fuel type



7.1.3 Cooling demand by sector

Figure 83 shows the total annual cooling demand in Ireland by sector. The cooling demand for the commercial sector is significantly larger than for all other sectors within Ireland; this is mainly due to the cooling demand of Retail archetypes. *Figure 84* shows the associated emissions from cooling by sector. All cooling demand is assumed to be met by electricity.

Figure 83: Total annual cooling demand (GWh), by sector

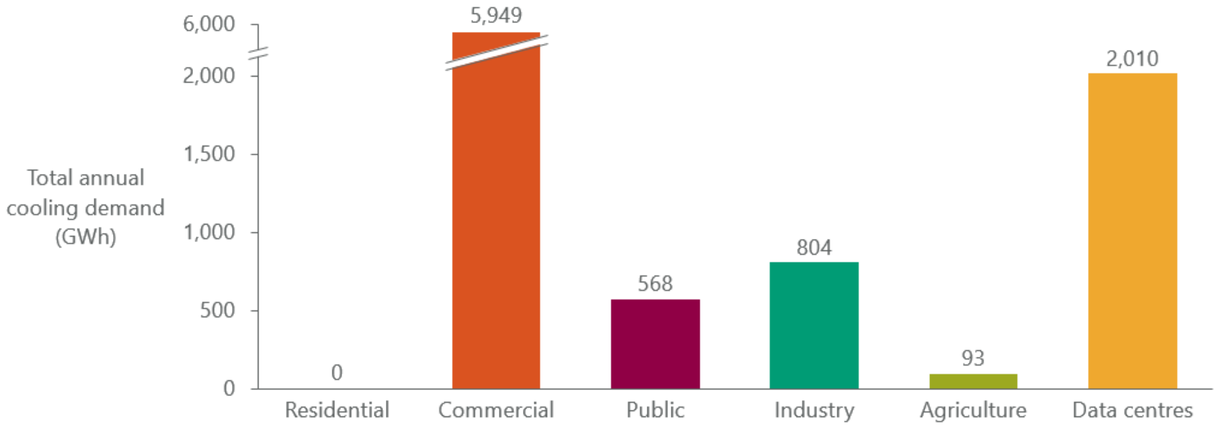
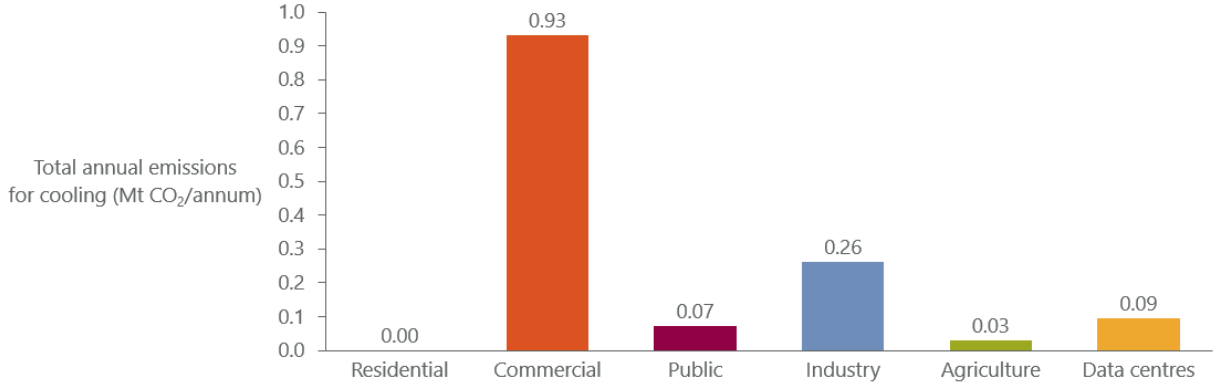


Figure 84: Total emissions from fuel use for cooling per annum ($MtCO_2$/annum) in all sectors



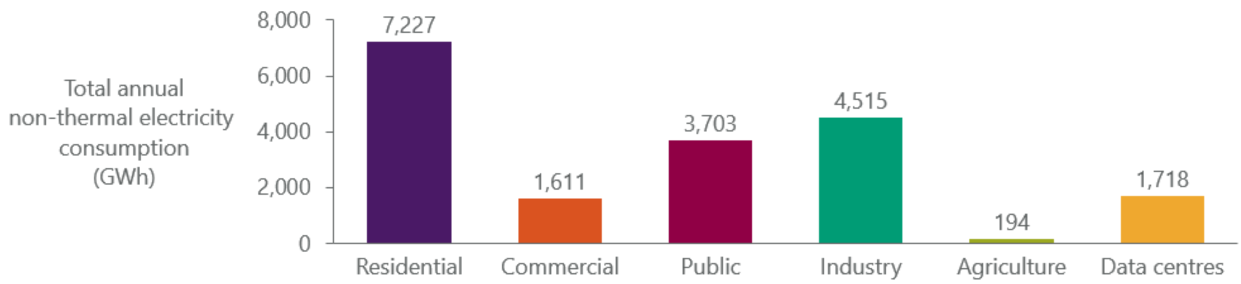
Note:

- *All cooling assumed to be provided by electricity.*

7.1.4 Non-thermal electricity consumption by sector

This section provides a summary of the non-heating, non-cooling electricity consumption breakdowns for each sector. *Figure 85* depicts the breakdown of overall electricity demand (GWh) by each of the five profiled sectors, and also includes data centres. The residential sector has the highest electricity consumption – 38% of the total across these five sectors. Despite the commercial sector having a significantly higher stock, heating and cooling demand than the public sector, the electricity consumption in the public sector is more than double that in the commercial sector; this is because all three building types in the public sector (Healthcare, Education and Offices) have significant electricity consumption, as a consequence of the calibration process.

Figure 85: Total annual electricity consumption (GWh), by sector



8 Spatial mapping of existing thermal demand

Following from the determination of the existing Irish heating demand across the relevant sectors, this section focuses on spatial mapping of the existing thermal demand. Other related aspects, such as the mapping for future demand scenarios, determination of waste and geothermal heat, and considerations of network infrastructure, are discussed in detail in the *District Heating and Cooling* report[14], which forms part of the National Heat Study.

8.1 Review of the existing heat map

The existing SEAI heat map [40] was developed by AECOM in 2015 as part of the previous National Comprehensive Assessment (NCA) for Ireland. This section provides an overview of the existing heat map followed by discussion of the IrDEA Irish *Heat Atlas* [41] and Codema's *Dublin City Spatial Energy Demand Analysis* [42].

8.1.1 The 2015 AECOM heat map

In 2015, AECOM was commissioned by SEAI to produce a spatial heat demand map of Ireland. The approach taken by AECOM was based on a bottom-up approach, which was then verified with national statistics for energy usage. Heat usage was split into domestic, public, commercial and industrial sectors with demand for each of these four sectors spatially distributed over small areas, as defined by the Irish 2011 CSO Census. Due to lack of data, this study did not consider the demand for cooling across any of these four sectors.

8.1.1.1 Domestic sector

The number of properties within each small area was taken from the 2011 CSO Census data. However, the only types of properties stated in the 2011 Census were houses and apartments with no further distinction. Property types were then further broken down using BER data to estimate the number of apartments, detached houses, semi-detached houses and terrace houses in each of the small areas. Benchmarks (Annual kWh per household) for each property type and the BER rating were used to calculate the domestic demand for heat in each small area. Though the 2011 Census also provided the distribution of domestic fuel use on a small area level (electricity, natural gas, oil, solid and LPG), no attempt was made to assign fuel use distributions to each property type.

8.1.1.2 Public sector

The evaluation of the public sector heat demand was carried out at a high level. Public Sector Energy Efficiency Performance submissions consisted of natural gas meter readings submitted to SEAI by a selection of public buildings (such as hospitals and schools). This data set included 3,062 gas meters from 2,718 unique buildings. However, only 1,472 of these unique buildings were successfully paired with a small area. Therefore, this data only represented a small percentage of the overall public sector buildings in Ireland. Gas consumption for these buildings was used to estimate heat demand and develop the public sector heat demand of each small area. The method likely underestimated the public sector heat demand.

8.1.1.3 Commercial sector

Data from the Valuation Office (VO) was used to estimate the total number of commercial buildings in a small area, as well as the floor area of each building. The VO dataset contained information for 70% of the small areas. For small areas that lacked data, the county average was used. Clearly defined assumptions were made regarding what proportion of each building type (hotel, office, restaurant, public house, retail, warehouse) were either small or large, and in poor or good condition. Benchmarks (Annual kWh per floor

[14] Available from www.seai.ie/NationalHeatStudy/

area) for each type of commercial building, were then used to calculate the commercial heat demand in each small area.

8.1.1.4 Industrial sector

Industrial sector heat demand was split into two types, small and large industrial sites. For small industrial sites, such as workshops, the floor area of each site was used to estimate the heat demand, similarly to the commercial sector analysis. Data on small industrial sites was sourced from the VO. The heat demand for large industrial sites was taken from ETS data. Power generation sites were excluded from the analysis. Combined, these two methods allowed for the industrial heat demand per small area to be evaluated.

8.1.1.5 Limitations

Overall, the methodology followed by AECOM in the 2015 spatial heat mapping is comprehensive and accurate. The greatest limitation of the work is the underestimated public sector heat demand, caused by the use of an incomplete dataset for the number of public buildings in each small area. The AECOM work did not consider cooling demand.

8.1.2 IrDEA Irish Heat Atlas - Version 2.1

The Irish *Heat Atlas* [41] is an interactive online heat map of Ireland that draws data from a range of sources. The fundamental heat map data comes from the 2015 study by Stratego, *Mapping the Heating and Cooling Demand in Europe* [43]. This report develops a heat map for residential and service heat demand in five European nations, including Ireland. Rather than evaluating the heat demand at a small area scale, this study uses a 100 m^2 resolution.

The population density of each 100 m^2 was estimated using soil sealing. Soil sealing describes how much of the soil in any area has been covered with buildings, etc. Using the soil sealing of each 100 m^2, the population density was estimated. This population density was then paired with per-capita heat demand to calculate the residential heat demand in each 100 m^2.

The soil sealing and population density per 100 m^2 were then used to estimate the number of service buildings in each area. This is based on the principle that as the population density increases, so does the density of service sector properties. The number of service sector building per area is then used to evaluate the service heat demand.

The methodology presented in this report is very brief, and hence the finer details concerning how these calculations were performed is not clear. The work aimed to model the heat demand of five different countries using one unified method. The results have been useful in assessing high-level potentials across countries. However, as a result, the approach is less comprehensive at a local level and may lead to a greater degree of error at that resolution.

The calculations that underpin the Irish Heat Atlas and the 2015 AECOM heat map have adopted different methodologies. Firstly, the Irish Heat Atlas only considers residential and service heat demand, where the AECOM study includes the domestic sector, the public sector, the whole commercial sector (not just service) and the industrial sector. The Irish Heat Atlas uses soil sealing to estimate population density in each 100 m^2 area. This method is deemed to be less accurate than that performed by AECOM, which makes use of data sets specific to Ireland for each sector. Therefore, the spatial mapping performed in this project aims to follow the general approach taken by AECOM, whilst addressing some of the key limitations of the work.

8.1.3 Codema Dublin City Spatial Energy Demand Analysis

Dublin's energy demand agency, Codema, have carried out extensive work on energy demand mapping. Codema published a study in 2019, *Dublin City Spatial Energy Demand Analysis* [42]. In this work, Codema produced a heat demand map for the city of Dublin. It includes residential and commercial heat demand per small area. The methodology adopted is very similar to that used by AECOM. A combination of 2011 Census data and BER ratings were used to estimate the residential heat demand in each small area, split between apartments, detached, semi-detached and terrace houses. The VO dataset was used to estimate the commercial heat demand, based on floor area. This work did not consider public or industrial sector heat demand.

8.2 Updates to the existing heat map for Ireland

This section covers the methodology for updating the existing heat map for Ireland. Two key assumptions have been made whilst creating the heat and cooling demand map:

1. All fuel consumed at industrial sites is assumed to be used to generate heat.
2. The thermal efficiency for heat generation was assumed to be based on industrial boilers efficiency, which is taken as 70% (NCV).[15] This assumption is a conservative minimum and in line with the harmonised reference efficiencies listed in the commission delegated regulation 2015/2402.[16]

8.2.1 Methodology and assumptions

This section describes in detail the datasets and methodology used to undertake the spatial mapping of existing demand.

A small area (SA) is the smallest administrative land area in Ireland, over which Census data are published, typically containing 80 to 120 dwellings. Using Census data aggregated at this geographical level allows for detailed sectoral and spatial building segmentation, whilst at the same time ensuring compliance with data protection. As of 2016, Ireland has comprised 18,641 SAs, created by the National Institute of Regional and Spatial Analysis (NIRSA) on behalf of the Ordnance Survey Ireland (OSi). The SAs correlate well with heat demand analysis, each area with increased housing density and a smaller land area, allowing a higher resolution view of higher density heat demand areas.

To meet one of the objectives of this work, the heating and cooling consumption in each SA for the residential, commercial, public and industrial sectors needed to be determined. The share of national building stock located within each SA, for various archetypal sector subdivisions (dwelling types, heating fuels, BER ratings, service and industry subsectors) was calculated by combining the national residential and service sector stock (estimated as described in *Sections 1-3*), with various published 2016 CSO Census tables, a dataset derived by SEAI from the BER map and ETS data. Results were collated to produce a heating and cooling map.

By understanding how Ireland uses heat at high spatial resolution, more specific opportunities for de-carbonisation can be evaluated. In particular, the results are a key input into the district heating potential work undertaken as part of the SEAI National Heat Study (see *District Heating & Cooling Infrastructure* report on National Heat Study website).

The results of thermal demand by sector, broken down into heating and cooling, linked to the SA reference from the 2016 Census SA CSV file, showing were used in the spatial mapping.

For each sector, the total heating and cooling consumption in kWh/annum was divided by SA land area in m^2 to calculate the heat density in kWh/annum/m^2 and plotted on a colour-coded density scale to show which areas have the highest heating and cooling density.

The current thermal demand analysis covers the residential, commercial, public and industrial sectors.

[15] Best practice assumption based on a historical set of confidential projects

[16] COMMISSION DELEGATED REGULATION (EU) 2015/ 2402 - of 12 October 2015 - reviewing harmonised efficiency reference values for separate production of electricity and heat in application of Directive 2012/ 27/ EU of the European Parliament and of the Council and repealing Commission Implementing Decision 2011/ 877/ EU (europa.eu).

8.2.1.1 Residential heat and cooling demand

The main sources of data used to model residential heating are listed below.

Building Archetypes Dataset:

This dataset is based on the compilation of quantitative outputs of the previous sections in this report. For the residential sector, it provides data for 112 archetypes, split by four dwelling types, four heating fuel and technology types and seven BER ratings, as described in *Section 2*. For each archetype, it provides data on the number of dwellings and the space and water heating per dwelling. This data also informs the NEMF model.

For each SA, the heat use per dwelling was multiplied by the number of dwellings to estimate the heat demand per SA. The method for disaggregating the stock of dwellings by SA is described in the following sections.

CSO Census 2016 Table E1055

CSO Census 2016 Table E1055 [4] provides the total number of dwellings in Ireland observed in the 2011 and 2016 censuses for all combinations of the following dwelling types, (*Table 13*) heating fuels and technologies (*Table 14*). Dwelling and heating fuels were mapped to the four dwelling types and four heating fuel and technology types in the NEMF *buildings archetype dataset*.

Table 13: Dwelling types

E1055 Type of private accommodation	NEMF dwelling type
Detached house	Detached house
Semi- detached house	Semi-D house
Terraced house	Terraced house
Flat or apartment in a purpose-built block	Apartment
Flat/apartment in a converted dwelling (including bedsits)	Apartment

Table 14: Heating fuels and technologies

Type of central heating	NEMF heating fuel and technology
Oil	Oil boiler
Natural gas	Gas boiler
Electricity	Electric heating
Coal (incl. anthracite)	Solid boiler
Peat (incl. turf)	Solid boiler
Liquid petroleum gas (LPG)	Oil boiler
Wood (incl. wood pellets)	Solid boiler

This is the only dataset that enumerates dwellings by dwelling type and heating fuel simultaneously - and this split is not available at county or SA level in other tables. This table gives a 2016 dwelling stock total 1,649,408, which is less than the total of 1,773,559 in the NEMF, due to the addition of new build, since the 2016 Census as explained in *Section 2*.

CSO Census 2016 Table E1005

CSO Census 2016 Table E1005 [44] provides the number of dwellings for each dwelling type in each of Ireland's 31 local authority areas for the following dwelling types (see *Table 15*). The table provides dwelling stock total 1,649,408. For the current analysis, this dataset is used only to estimate the stock split by house type at SA level for which data are not separated between the different house types, as explained below.

Table 15: Dwelling types

Type of private accommodation	NEMF dwelling type
Detached house	Detached house
Semi-detached house	Semi-D house
Terraced house	Terraced house
Flat or apartment in a purpose-built block	Apartment
Flat/apartment in a converted dwelling (including bed sits)	Apartment

CSO Census Small Area Population Statistics

The CSO *Small Area Population Statistics* table [45] provides the number of dwellings in each SA for 800 different information fields, which need to be decoded using the glossary [46]. These fields include the dwelling type and separately, the heating fuel and technology type. The relevant fields in this table are shown in *Table 16* below, with the mapping to the modelled dwelling type, heating fuel and technology types.

Table 16: Relevant fields extracted from CSO Census Small Area Population Statistics Table (SAs 18,641)

SAPS2016_SA2017 column names	Glossary	NEMF dwelling and heating fuel and technology
T6_1_HB_H	House/Bungalow (No. of households)	House (split using E1005 above)
T6_1_FA_H	Flat/Apartment (No. of households)	Apartment
T6_1_BS_H	Bed-Sit (No. of households)	Apartment
T6_1_CM_H	Caravan/Mobile home (No. of households)	Excluded
T6_1_NS_H	Not stated (No. of households)	Excluded
T6_5_NCH	No central heating	Excluded
T6_5_OCH	Oil	Oil boiler
T6_5_NGCH	Natural gas	Gas boiler
T6_5_ECH	Electricity	Electric heating
T6_5_CCH	Coal (incl. anthracite)	Solid boiler
T6_5_PCH	Peat (incl. turf)	Solid boiler

SAPS2016_SA2017 column names	Glossary	NEMF dwelling and heating fuel and technology
T6_5_LPGCH	Liquid petroleum gas (LPG)	Oil boiler
T6_5_WCH	Wood (incl. wood pellets)	Solid boiler
T6_5_OTH	Other	Excluded
T6_5_NS	Not stated	Excluded

The total stock in this Census 2016 *Small Area Population Statistics* dataset for all dwelling types is 1,702,289 and the total in Census 2016 table E1005 for all heating fuel and technology type is 1,697,665. So, these Census 2016 datasets are not exactly consistent internally and, naturally being the stock in 2016, are somewhat less than the current stock total of 1,773,559 estimated in the *Building Archetypes Dataset*. However, the Census 2016 datasets are only used to apportion the latter across all archetypes and SAs. So the total stock estimate across all archetypes matches the up-to-date estimated total. Furthermore, whilst not identical, these two Census 2016 datasets are very closely aligned in percentage terms, so we are confident they are the most appropriate datasets to use for apportioning current stock estimates by archetype.

In addition, this *Small Area Population Statistics* dataset does not give a breakdown of stock for the different house types, only the totals for one 'House/Bungalow' category in each SA. Therefore, *Census 2016 table E1005* above was used to estimate the percentage split in the county within which each of the SAs lie. This necessitated a mapping between counties and SAs.

SEAI BER Small Area Map

This dataset was compiled by SEAI and provides information on the number of dwellings in each SA that have BERs by dwelling type, heating fuel and technology type, and the BER rating [47]. This dataset covers approximately one-third of total dwellings in Ireland and was used to estimate the proportions of dwellings in each SA by BER rating.

Combination of datasets to apportion stock to archetypes

The above datasets were combined to apportion the total estimated current stock of 1,773,559 dwellings to each archetype (dwelling type, fuel type and BER rating). It is impossible to simultaneously align the dwelling ratios of dwelling type, fuel type and BER rating with the national and SA ratios in the *Building Archetypes Dataset* and in the Census 2016 tables. Therefore, an iterative approach was used to apportion dwelling stock in line with each dataset in turn and repeating until the ratios converged on the best compromise.

A macro was developed to cycle through the estimated dataset, redistributing stock to match each of the following four distributions in turn:

1. Redistribute stock by applying a factor for each of the 16 combinations to all SAs to match the totals in *Census 2016 table E1055*.
2. Redistribute stock in each SA to match the SA heating fuel splits for each SA in the *Small Area Population Statistics* table.
3. Redistribute stock in each SA to match the SA dwelling type splits for each SA deduced *Small Area Population Statistics* and *Census 2016 table E1005*.
4. Redistribute total dwelling stock distribution across all SAs to match the total stock distribution in *Census 2016 table E1005*.

Each cycle of the macro repeats the above four steps in turn. The result of each redistribution step results in the stock distribution matching in the step that has just been undertaken, but mismatching the other distributions. So, at the end of each iteration cycle, the estimated stock is aligned on the distribution criteria in the final step (in this case total stock distribution). This ordering also matches the dwelling type distribution. The macro repeats until converging on a distribution matching the distribution calculated at the end of the previous cycle within +/-0.01%

Using this method, the macro was able to match the fuel distributions within each SA, to within 5% of those indicated in the *Small Area Population Statistics* table, as well as the distribution of national total stock for the 16 dwelling and fuel and technology combinations, to within 8% of the distribution indicated in *Census 2016 table E1055*.

The macro could, alternatively, be set to carry out the redistribution in a different order (e.g. to prioritise fuel and technology type distribution over dwelling type distribution)., However, it was judged that correctly distributing total stock numbers and stock type would result in the most accurate spatial distribution of heating and cooling consumption.

As the stock distribution of the 16 dwellings, heating, fuel and technology type combinations in the *Building Archetypes Dataset* differs from the distribution in *Census 2016 table E1055*, the calculated totals differ from the *Building Archetypes Dataset* considerably more than they differ from Census 2016 *table E1055*. The accuracy of the method described above can be shown by *Table 17*, which shows the variation of the calculated numbers by the model against the actual numbers.

Table 17: Variation of calculated vs. actual stock distribution (matching with Census 2016 Table E1055)

Stock breakdown	Calculated/actual stock share	
	Min	Max
SA dwelling type fraction of SA dwelling total	1.0000	1.0000
SA fuel + technology fraction of SA dwelling total	0.9593	1.0413
SA total dwellings % of national dwelling total	1.0000	1.0000
National total dwelling and heating fuel + technology type fraction of national stock according to table E1055	0.9788	1.0726
National total dwelling and heating fuel + technology type fraction of national stock according to the Building Archetypes Dataset	0.5167	1.1033

The calculated dwellings stock for each of the 16 dwelling, heating fuel and technology categories in each SA were then further divided by energy efficiency ratings, A-G to calculate the stock for the 112 archetypes in the *Building Archetypes Dataset*; this is using the proportions of the BER rated dwellings in each of the 16 dwelling, fuel and technology combinations, which have each BER rating. For one of the 112 archetypes (terraced houses with solid fuel boilers with BER rating A), there were no BER ratings, so no stock was allocated to that archetype. Also, for two of the SAs there were no BER ratings, so for these SAs, the stock was allocated across the 111 remaining archetypes, to the same proportion as the totals for the remaining 18,639 SAs.

8.2.1.2 Commercial and public heating and cooling demand

The main sources of data used to model the commercial and public sector demand for heating and cooling include:

Building Archetypes Dataset:

This dataset is based on the compilation of quantitative outputs of the previous sections in this report. For the commercial and public services sectors it provides data for 161 archetypes, as described in *Section 3*. For each archetype it provides data on the number of units, and the heating and cooling demand. This data also informs the NEMF model.

The heat use per building was multiplied by the number of buildings to estimate the heat demand per SA. The following sections describe the method for disaggregating the commercial and public services sectors' building stock by SA.

GeoDirectory Dataset:

The national stock totals in the GeoDirectory dataset differ somewhat from those in the *Building Archetypes Dataset*, so were only used to spatially disaggregate those in the *Building Archetypes Dataset*.

For each of the eight commercial and public sectors, the number of buildings in each SA was divided by the national total to calculate the percentage of buildings in each SA. This was then multiplied by the corresponding subsector totals in the *Building Archetypes Dataset* to estimate the number of buildings in each SA for each subsector. These were then multiplied by the average heating and cooling consumption per building for each subsector, to calculate the total heating and cooling consumption for each subsector in each small area.

8.2.1.3 Industrial heating and cooling demand

In order to assess industrial heat and cooling consumption, the following sectors were evaluated: cement, chemicals, food and drink, lime, metals, pharmaceuticals, refining, wood products, other minerals and other industry.

To develop the industrial demand for heat, data for sites within the EU-ETS were used. The non-ETS heat demand was not included as part of this analysis, due to lack of data. Further information and data are needed to incorporate the non-ETS industrial thermal demand at the SA level.

The ETS data contained a list of industrial sites that consume large quantities of fuel in Ireland. From latitudes and longitudes, it was possible to determine the small area within which each site is located. It was then assumed that all fuel consumed is used to generate heat, and that all existing generating plant had a thermal efficiency of 70%. This allowed the industrial heat demand in each small area to be estimated.

The Building Archetypes Dataset did provide the total demand for cooling per industrial sector, though no information was given regarding the location of demand. Therefore, this total cooling was paired with the location of industrial sites in the ETS data. The total cooling demand for each sector divided between sites based on fuel consumption.

8.3 Summary of results of spatial existing thermal demand

Table 18 shows the total annual heat and cooling consumption by sector; these results are of the magnitude expected and are consistent with the 2015 Irish heat map. The overall total current thermal demand of heating and cooling for Ireland at small area resolution, covers an area of 70,264 km^2 over 18,641 small areas of variable size.

Table 18: Total demand by sector [MWh/year]

Requirement	Residential	Commercial	Public	Industrial (ETS only)
Heat MWh/year	19,411,123	5,677,295	3,543,041	12,740,213
Cooling MWh/year	0	5,945,328	568,065	803,950

Out of the 18,641 areas, all have a 'thermal heat demand' and 4,053 areas returned 'no thermal cooling demand'. The area heat density range was from 3.1 x 10^{-6} kWh/m^2 to 3,571 kWh/m^2 with an average value of 17.0 kWh/m^2 and a median of 9.0 kWh/m^2 and excluding zero demand values, area cooling density ranged from 0.01 kWh/m^2 to 597.7 kWh/m^2 with an average value of 3.5 kWh/m^2 and a median of 0.04 kWh/m^2. Sample results are shown in *Figure 86* and *Figure 87*.

Figure 86: Heat density map (all sectors)

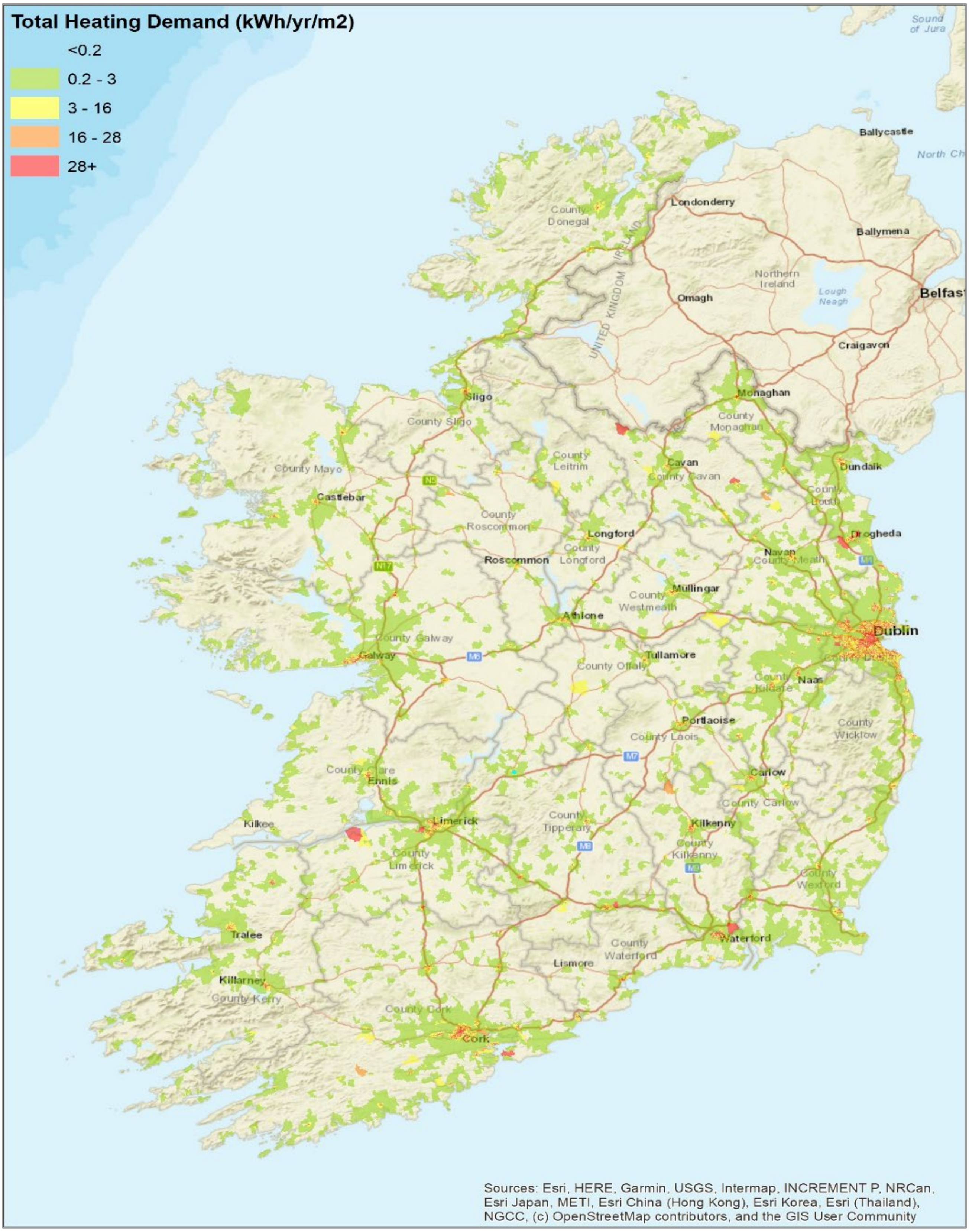
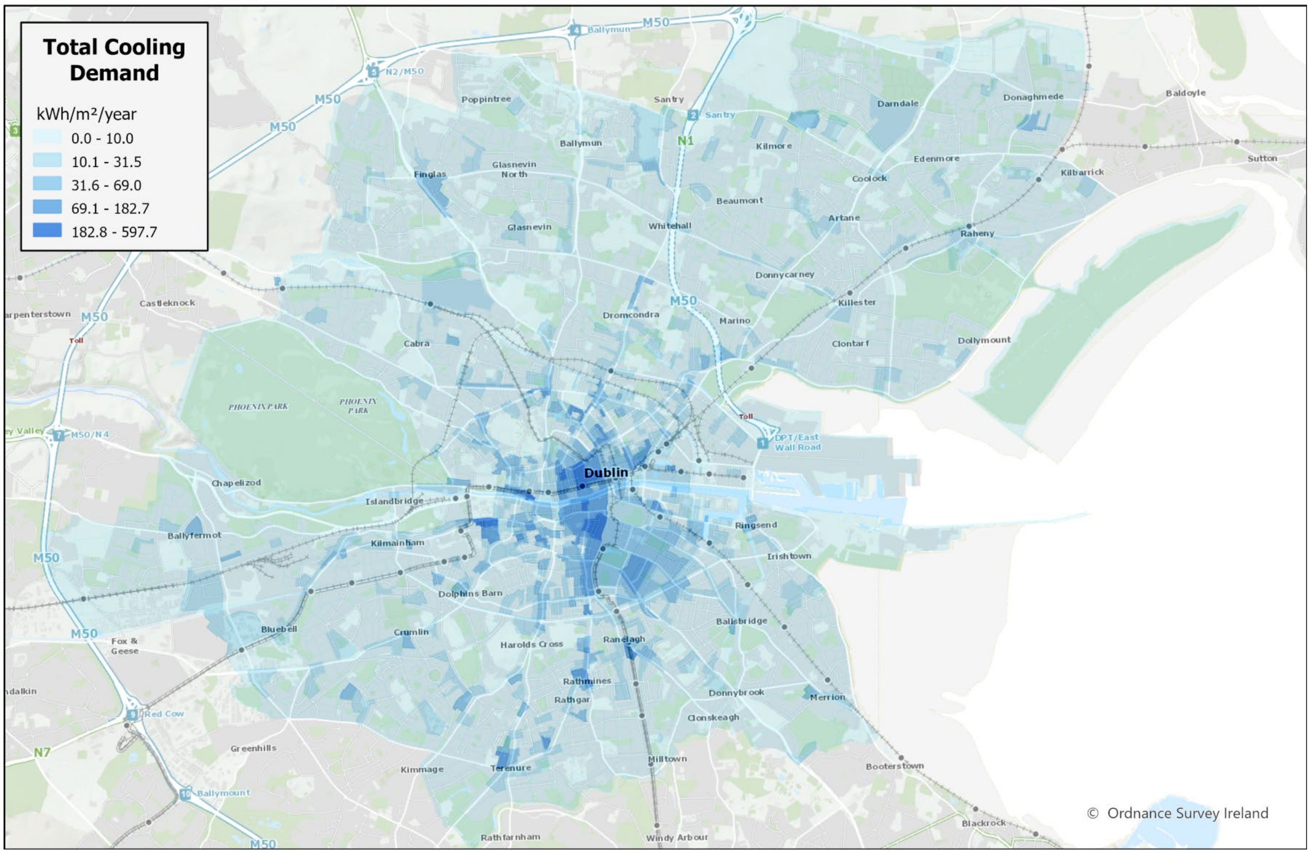


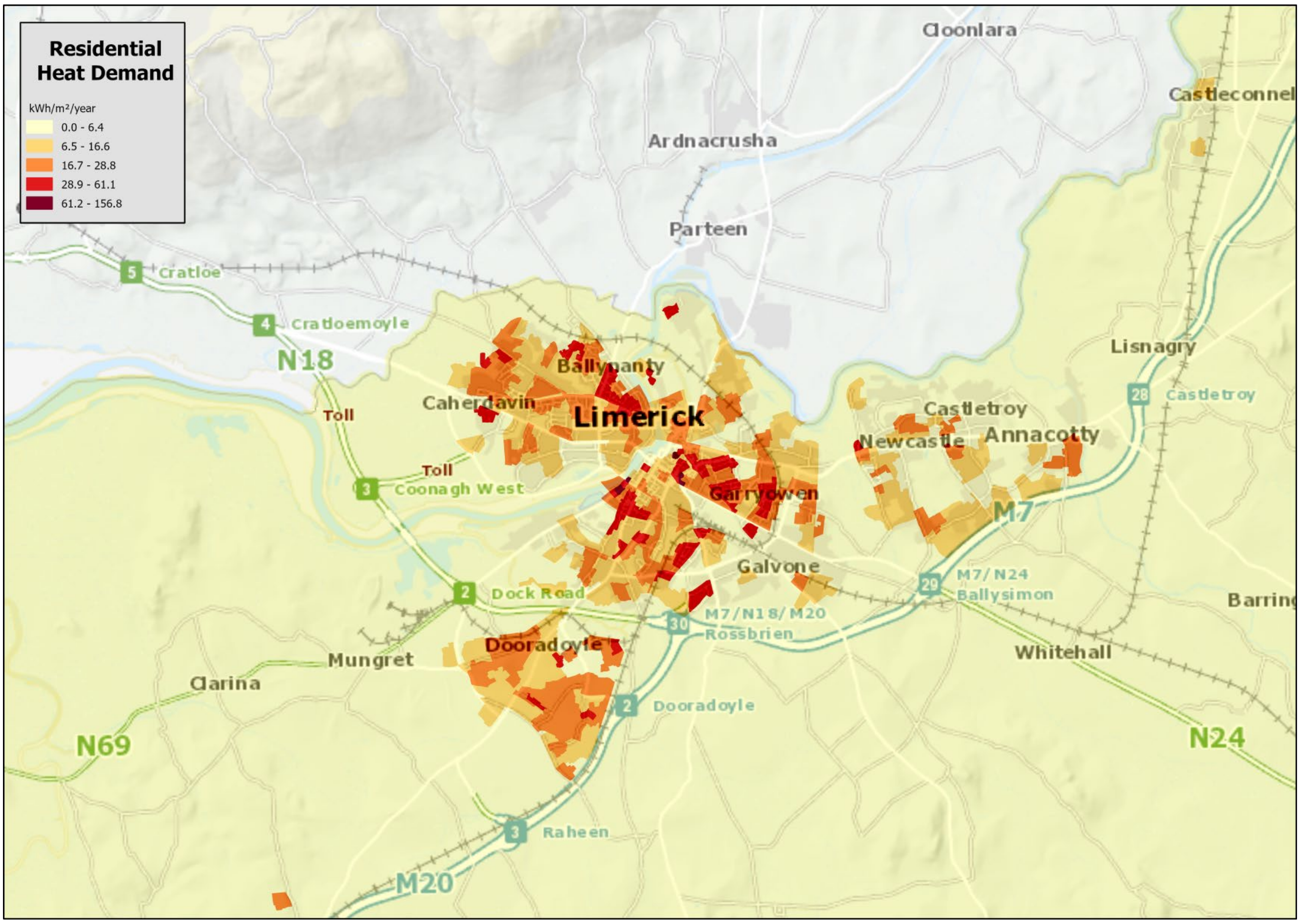
Figure 87: Cooling density maps (all sectors)



8.3.1 Residential

For the residential sector, out of the 18,641 small areas covered, all have a 'heat thermal demand' and none have cooling. The area heat density range was from 3.1 x 10^{-6} kWh/m^2 to 245.2 kWh/m^2 with an average value of 11.8 kWh/m^2 and a median of 5.7 kWh/m^2. Results shown in *Figure 88*.

Figure 88: Residential heat density demand maps



8.3.2 Commercial

See *Figure 89* and *Figure 90* for commercial heating and cooling area density maps. For the commercial sector, there is current demand for both heating and cooling. Out of 18,641 areas, 5,921 returned as having 'no thermal heat demand' and 6,087 returned as having 'no thermal cooling demand'.

Figure 89: Commercial heat demand maps

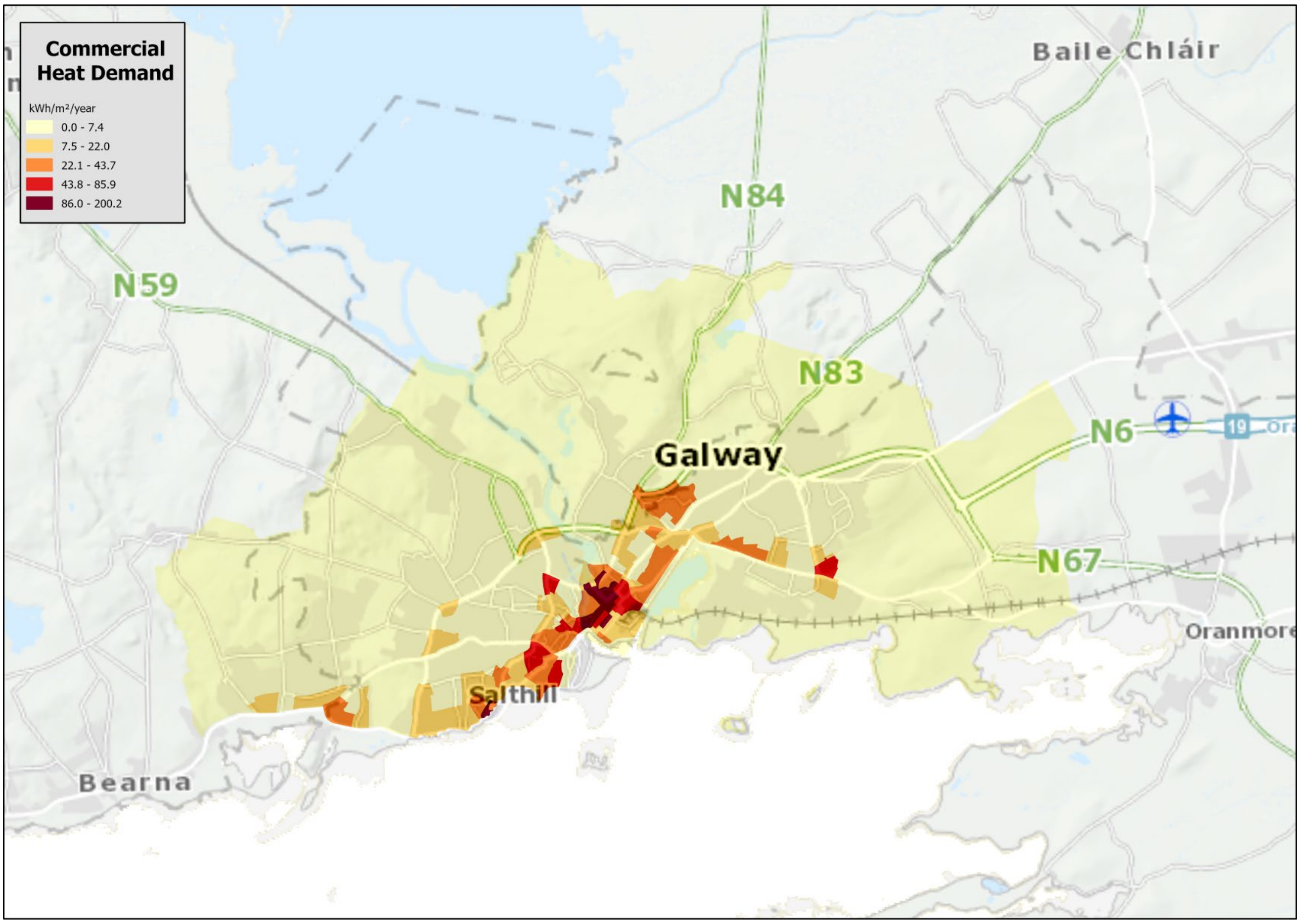
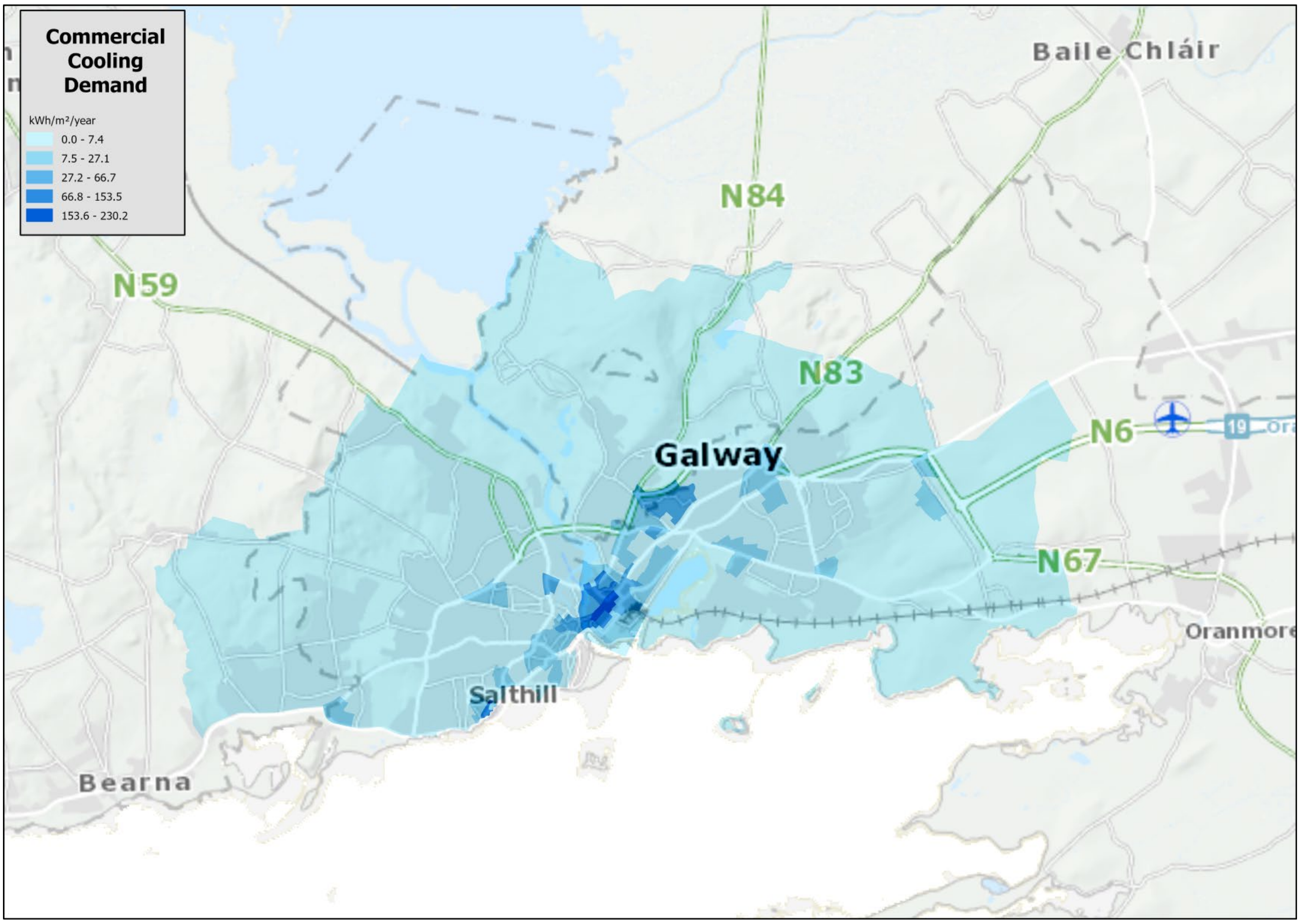


Figure 90: Commercial cooling demand maps



Excluding zero demand values, for heat demand, the range was from 0.01 kWh/m^2 to 326.5 kWh/m^2 with an average value of 2.9 kWh/m^2 and a median of 0.04 kWh/m^2. For cooling, excluding zero demand values, the range was from 0.01 kWh/m^2 to 274.9 kWh/m^2 with an average value of 3.1 kWh/m^2 and a median of 0.03 kWh/m^2.

8.3.3 Public

There is current demand for both heating and cooling within the public sector. Out of 18,641 areas, 11,487 returned as having 'no thermal heat demand' and 13,286 returned as having 'no thermal cooling demand'. Excluding zero demand values, for heat demand, the range was from 0.01 kWh/m^2 to 467.5 kWh/m^2 with an average value of 1.9 kWh/m^2 and a median of 0.0 kWh/m^2. For cooling, excluding zero demand values, the range was from 0.01 kWh/m^2 to 60.9 kWh/m^2 with an average value of 0.3 kWh/m^2 and a median of 0.0 kWh/m^2. See *Figure 91* for public heating and cooling demand maps.

Figure 91: Public heat demand maps

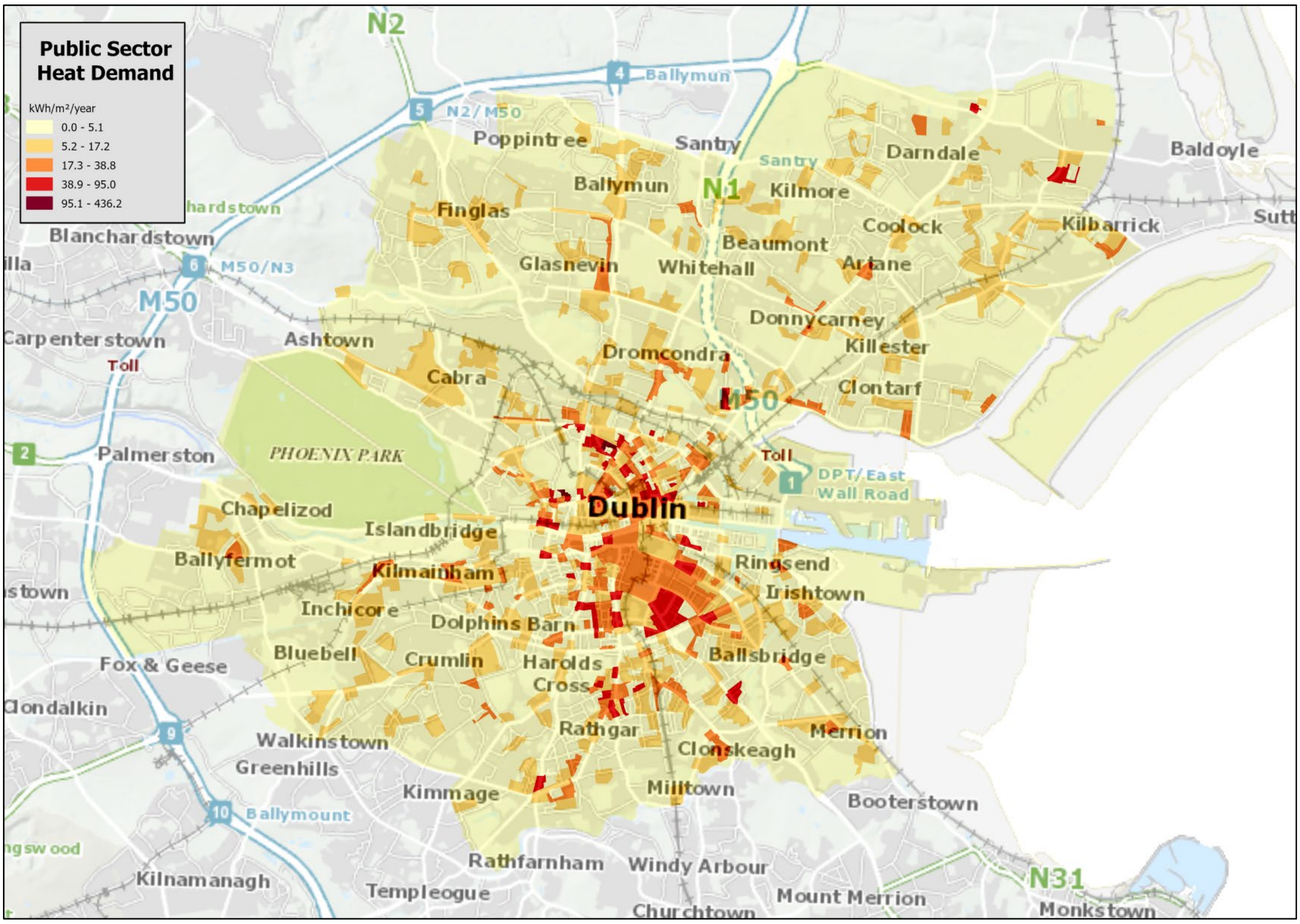
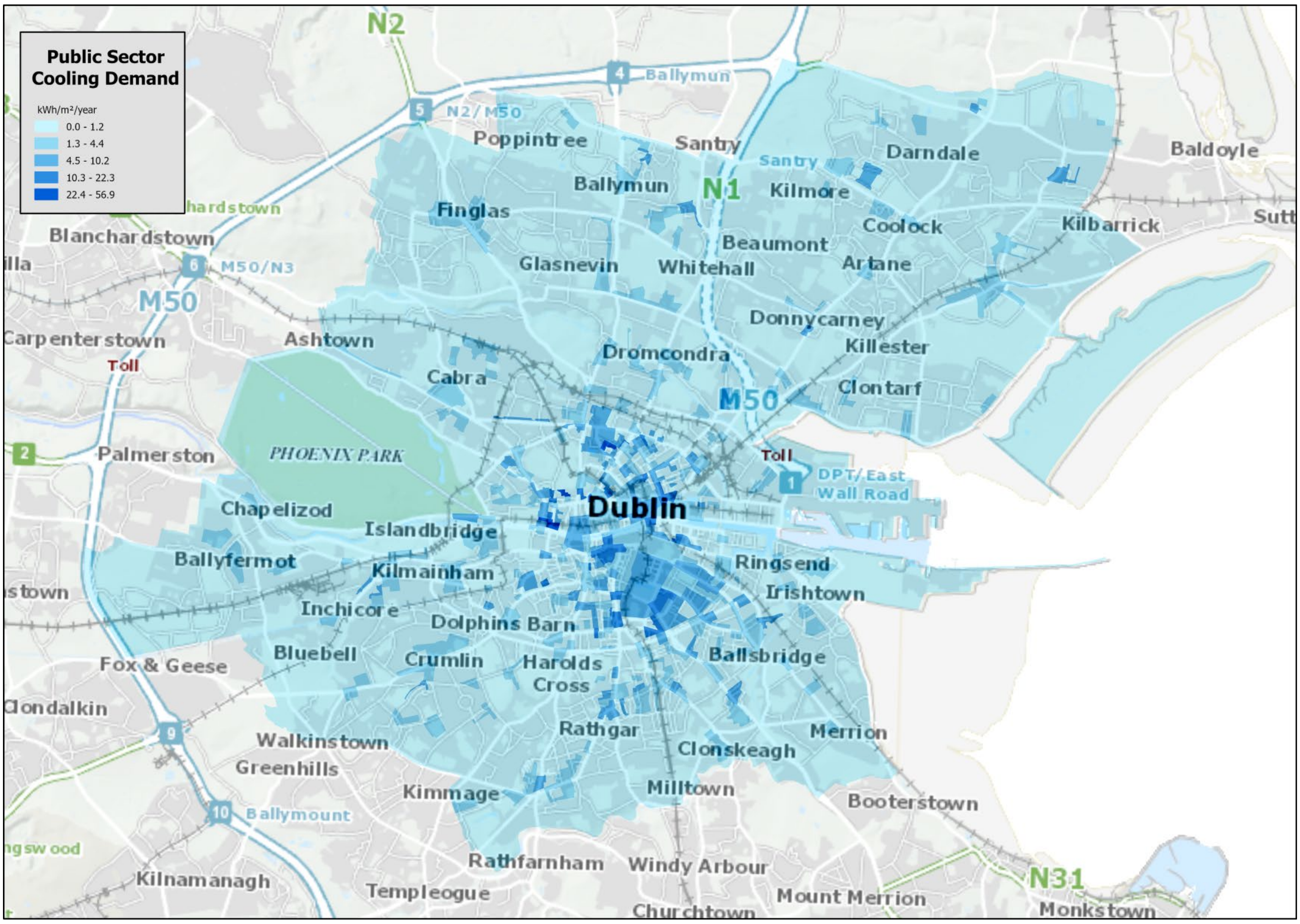


Figure 92: Public cooling demand maps



8.3.4 Industrial

There is current demand for both heating and cooling within the industrial sector. Out of 18,641 areas, 18,580 returned as having 'no thermal heat or cooling demand'. Excluding zero demand values, for heat demand, the range was from 0.4 kWh/m^2 to 3,559 kWh/m^2 with an average value of 0.46 kWh/m^2 and a median of 0.0 kWh/m^2. For cooling, excluding zero demand values, the range was from 0.04 kWh/m^2 to 589.1 kWh/m^2 with an average value of 0.07 kWh/m^2 and a median of 0.0 kWh/m^2. See *Figure 93* for industrial heating and cooling demand maps.

Figure 93: Industrial heat and cooling demand maps

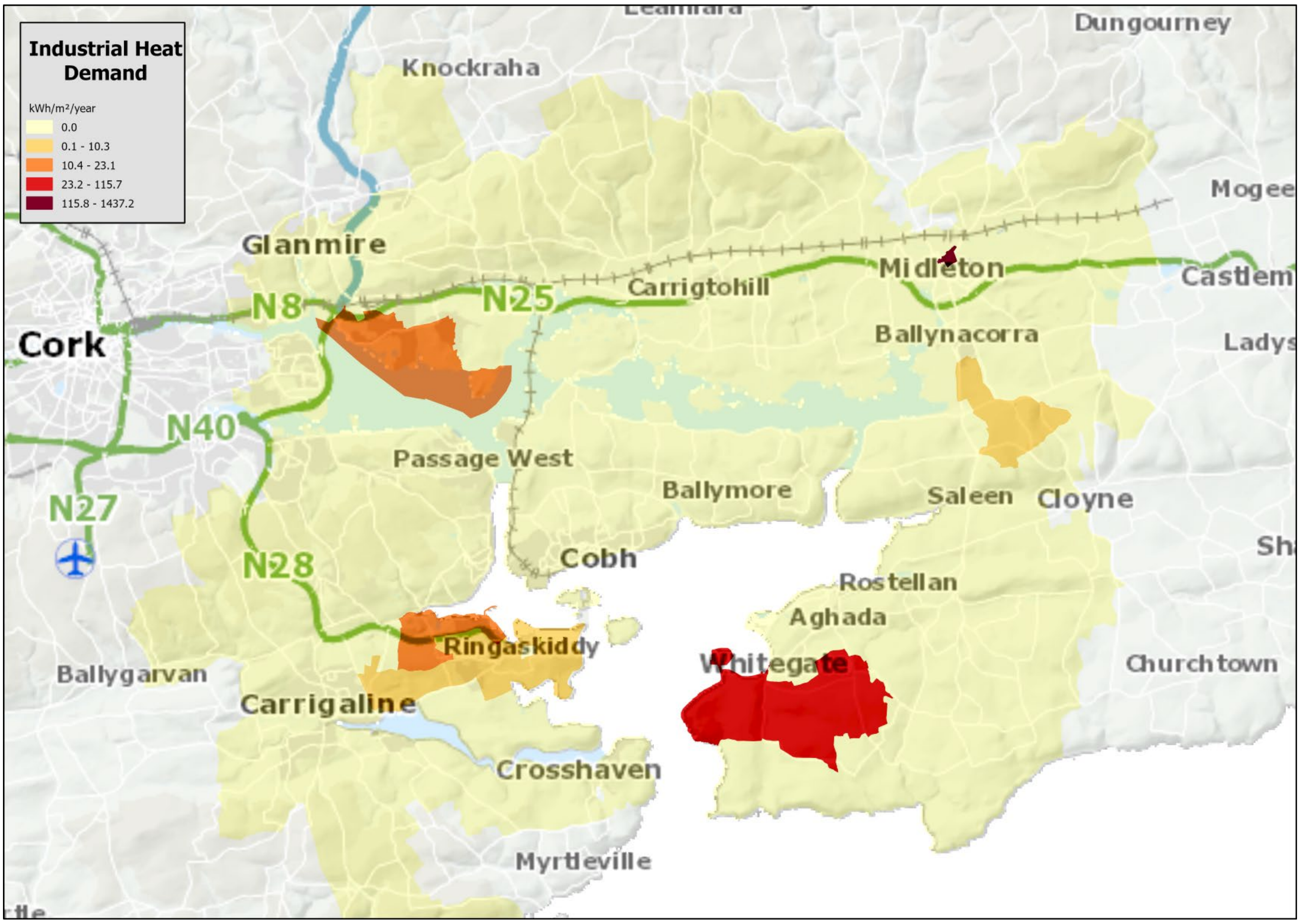
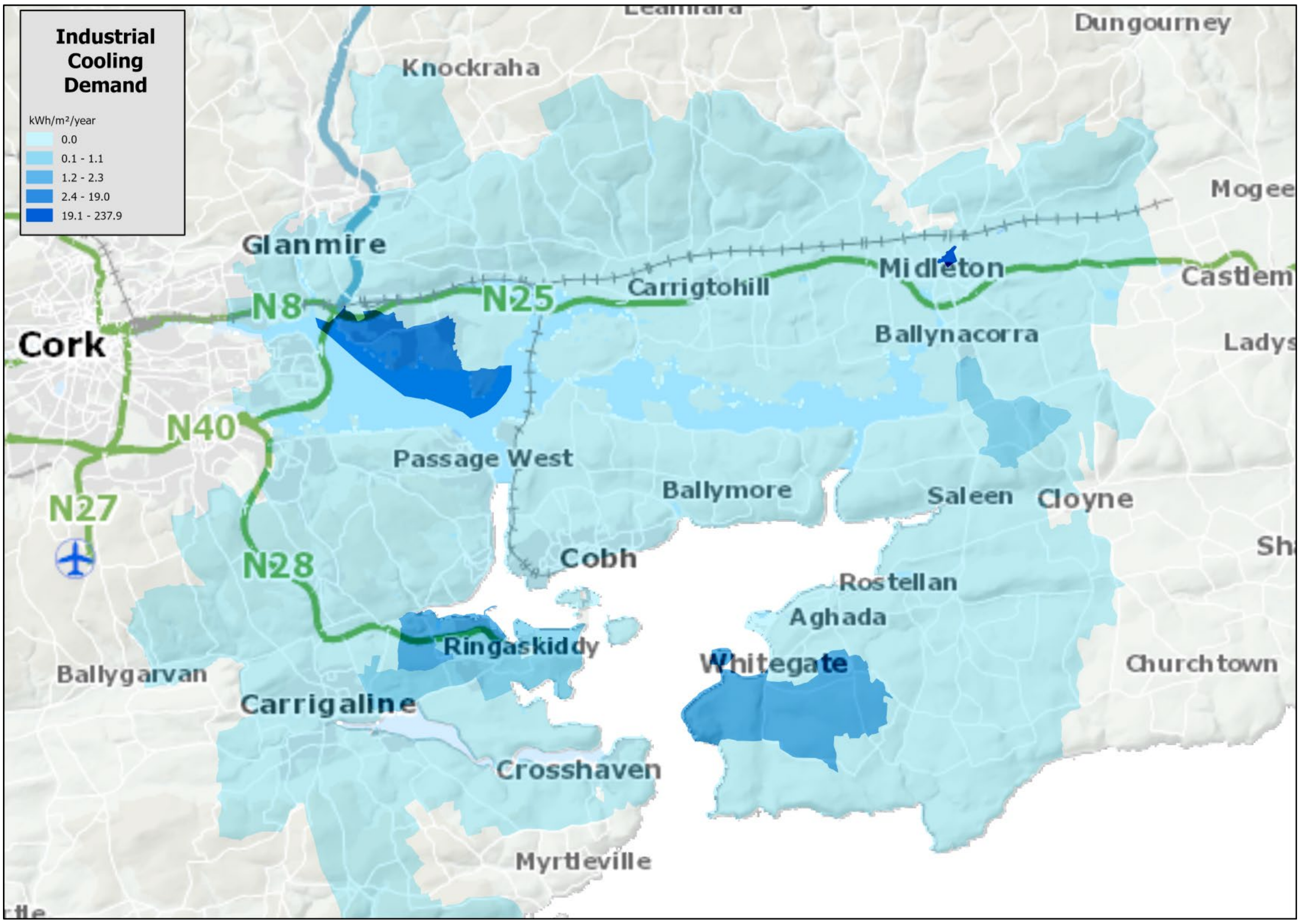


Figure 94: Industrial heat and cooling demand maps



The four different sectors were sorted to ascertain the small areas with the largest thermal demand. The top ten areas for both heat and cooling were isolated and assessed.

The current demands for residential heating, commercial heating and cooling and public heating and cooling did not show a concentration within the top ten areas for demand, with less than 3% of each sector's total current requirement being required within these 'highest current demand' areas.

The industrial heat and cooling identified that the top ten areas for demand were responsible for 70% of the current total industrial heating demand for Ireland and 54% of the country's current total industrial cooling requirement.

There are 11 small areas that appear in the top ten demand areas for multiple categories of heat and cooling (see *Table 19*).

Table 19: Small area references appearing in the top ten across multiple categories of thermal demand

Small area reference	County	Category small area reference appears in top 10 demand areas
268097001	Dublin City	Commercial and public heat and cooling
267078012	Laoghaire-Rathdown	Commercial and public heat and cooling
48008012	Cork City	Public heat and cooling
268141003	Dublin City	Commercial heat and cooling

Small area reference	County	Category small area reference appears in top 10 demand areas
48014004	Cork City	Commercial heat and cooling
267158012	Fingal	Commercial heat and cooling
267142014	South Dublin	Commercial heat and cooling
267107002	South Dublin	Commercial heat and cooling
27004003	Cavan	Industrial heat and cooling
97009001	Kilkenny	Industrial heat and cooling
47258010	Cork County	Industrial heat and cooling

9 Energy efficiency technical potential

The energy demand summarised in *Section 7* reflects the current state of heating and cooling demand in the building and industrial equipment stock in Ireland. There is significant potential for reducing this demand via energy efficiency measures, including improvements to the fabric efficiency of buildings and industrial process improvements. The *National Climate Action Plan* [38] and *National Energy and Climate Plan 2021-2030* [39] lay out ambitious targets for the deployment of energy efficiency measures in the coming decade. This includes a contribution towards the EU-wide target of achieving 32.5% improvement in energy efficiency by 2030 compared to 2007 levels, and 50% energy efficiency improvements in the public sector by 2030. This is besides the legally binding target of 20% energy efficiency improvements by 2020 compared to 2007 levels.

9.1 Treatment of energy efficiency in the National Heat Study

The National Heat Study considers various energy efficiency measures for the different archetypes in the sectors described in the previous sections of this report. The following summarises the process taken to determine the savings, costs and suitability of the measures, and the eventual application and impact of the measures applied.

a. As outlined in previous sections, an archetype-based stock model is developed to represent the Irish stock of buildings and industrial sites across the residential, commercial, public, agricultural and industrial sectors. This stock model allows for the understanding and quantification of an archetype's heating demand, fuel use and physical fabric characteristics/suitability.
b. The heat demand savings and cost of each measure are estimated by calculating the pre-intervention (before a measure is applied) and post-intervention (after a measure is applied) heating demand of the archetype to which it is being applied.
c. To ensure that only appropriate measures can be applied to an archetype, the suitability of each measure for each unique archetype is mapped based on physical constraints (e.g. cavity wall insulation maps as unsuitable for a solid wall house) and practical feasibility (i.e. measures which do not offer significant improvement are unsuitable – where the post-intervention U-value is close to the initial pre-intervention U-value).
d. Using the above steps, the NEMF model determines the maximum technical potential heat demand saving, where all suitable measures, on an archetype level, are manually applied (regardless of cost effectiveness) to the entire stock.
e. Considering consumer behaviour, the rebound effect is applied to the technical potential savings in the residential sector to account for the likelihood that, in reality, a consumer may take some of their energy savings as increased comfort by raising the internal temperature of their homes.

The above steps cover the estimation of energy efficiency technical potential and the inputs required for the NEMF model. These steps are described in more detail in this section. The below steps outline the continuation of this process, as part of the larger National Heat Study, to model the uptake of energy efficiency measures based on consumer decision-making across a range of scenarios.

f. To model energy efficiency uptake at a consumer archetype level in the NEMF, measures are dynamically grouped into three different 'packages' based on cost effectiveness, unique for each archetype. The uptake modelling uses a payback criterion to determine packages.
    - Three packages are dynamically created (shallow, medium and deep), each with increasing savings and increased cost.
    - Payback periods of three, five and ten years are used respectively for the shallow, medium and deep packages as the thresholds to determine what measures get included within each package.

    - Paybacks for measures vary across archetypes – for example, the measures included in a shallow package in an uninsulated semi-detached house are likely to differ from those in a well-insulated, detached house.
    - The NEMF carries out the measure-to-package mapping dynamically each time it runs. This allows for changes in fuel prices and other inputs to influence the measures included in packages.

g. Finally, based on the above, as well as the wider set of assumptions and inputs included in the modelling, energy efficiency package (and measure) uptake is based primarily on a payback period as the decision variable and sectoral willingness-to-pay curves as the constraint on the variable.
    - Consumers who are aware, make an energy-related decision in that year, have the budget and, for whom the economics make sense, will take up a package.
    - Consumers that accept longer payback periods will tend to take on deeper packages.
    - Consumers that have lower payback period thresholds will tend not take up the deeper (or any) energy efficiency packages.

This report describes the work done to estimate the maximum technical energy efficiency potential for a sub-set of all possible energy effiency measures with a focus on improved building fabric, industrial processes, lighting and appliances. For each sector, it outlines the measures that were considered and methodology used to estimate the savings potential. These estimates of technical potential represent an upper bound of the range of energy efficiency savings that are possible. The residential sector of the report also describes the methodology to account for the direct rebound effect, whereby a portion of the energy efficiency improvement is taken by the occupants as increased internal temperature, rather than energy savings. The report does not consider rebound effects for the other sectors due to data gaps.

The report does not consider the efficiencies of the heating systems in buildings and industrial sites. They are a separate set of inputs that are also considered within the NEMF during the modelling stage, undertaken to illustrate the net-zero pathways in the final report of this series. Therefore, the energy efficiency savings presented here do not include the potential for switching to more efficient heating technologies, such as heat pumps.

9.2 Savings and suitability of energy efficiency measures

The potential improvement in energy efficiency across the Irish building stock is estimated by modelling individual energy efficiency measures and their application to all suitable buildings and industries within the archetype stock model. The measures represent improvements to the fabric of buildings (such as installing additional wall or floor insulation, high-efficiency glazing), improvements in electrical efficiency of lighting and appliances, and improvements to the efficiency of key processes within industrial sectors.

Each implemented measure results in a per-archetype saving for the fuel used for space heating, or the non-heating and non-cooling electricity consumption of that archetype. Energy efficiency improvements in cooling in each sector are considered separately as part of the detailed modelling exercise described in the final National Heat Study report, *Net Zero by 2050*[17].

This approach allows estimation of the maximum technically possible level of energy savings (or 'technical potential') of suitable energy efficiency measures in each archetype across the five sectors considered. It provides a significant level of detail by including energy savings and cost of each measure in the specific context of each archetype. This builds upon and improves the method used in previous studies of this nature, including *Unlocking the Energy Efficiency Opportunity* [2] applied to the most recent stock data and improved archetype methodology described in *Section 9* of this report.

[17] Available at www.seai.ie/NationalHeatStudy/

9.2.1 Energy efficiency in the residential sector

This section summarises the methodology used to calculate the energy savings and suitability of all fabric improvement and electrical appliances measures in residential archetypes. Separate methods have been used to calculate the energy savings for fabric measures (such as wall insulation) and non-fabric efficiency measures (such as more efficient lighting or appliances).

For fabric measures in residential archetypes, we estimated the technical energy savings potential using a model that is based on the DEAP methodology for assessing energy demand in residential buildings in Ireland [48]. This model estimates a building's energy consumption and heat loss through all external-facing fabric areas, based on the building fabric properties, geometry, activity, HVAC system, lighting systems, space heating, cooling, ventilation, lighting, equipment, hot water and auxiliary energy demand, solar irradiance and weather data in Ireland.

The DEAP model estimates the energy savings potential of fabric energy efficiency measures by replacing the in-model building's fabrics with better-insulating fabrics. The model then calculates the updated annual space heating demand, and applies the percentage savings of each measure to each archetype's energy consumption values.

Section 2.1 highlighted that the DEAP methodology used for calculating the BER of a dwelling estimates fuel consumption based on a set of standard assumptions on internal temperature and occupancy. This calculation is designed to provide an asset rating for each dwelling, but not a reliable estimate of the actual energy use in real-world operating conditions. The DEAP methodology tends to overestimate the energy use of dwellings with poorer BER ratings. In reality, it would usually be uneconomical to heat more poorly insulated dwellings to the degree of comfort that DEAP assumes as standard [49]. *Section 2.1* explains the methodology used in this study to correct for this phenomenon by calibrating the results of the process described above with overall energy use of the dwelling stock to the *National Energy Balance* [3].

9.2.1.1 Rebound effects

The term 'rebound effect' is used broadly to describe the phenomenon whereby the reduction in energy use observed after carrying out an energy efficiency measure is less than predicted by simple engineering models. This phenomenon is linked to the tendency of such simple engineering models to over-estimate the energy use of poorer performing dwellings, thus overestimating the savings that are achievable.

In this study, we account for rebound effects in the residential sector by applying the calibration methodology described in *Section 2.1* to the dwelling energy demand estimated by DEAP, both before and after carrying out the energy efficiency measures.

The calibration is applied to all fuel use above a threshold of 49 kWh/m^2, which corresponds to the maximum heating demand for a house with an A2 BER rating, and the calibration factor varies by main space heating fuel type, as described in *Section 2.1*. This reduces the predicted energy savings, as illustrated in *Figure 95*. This approach ensures that the model treats under-heating and rebound consistently throughout.

We only consider rebound for measures that target space heating demand; we do not consider rebound for efficiency measures that target electric appliances.

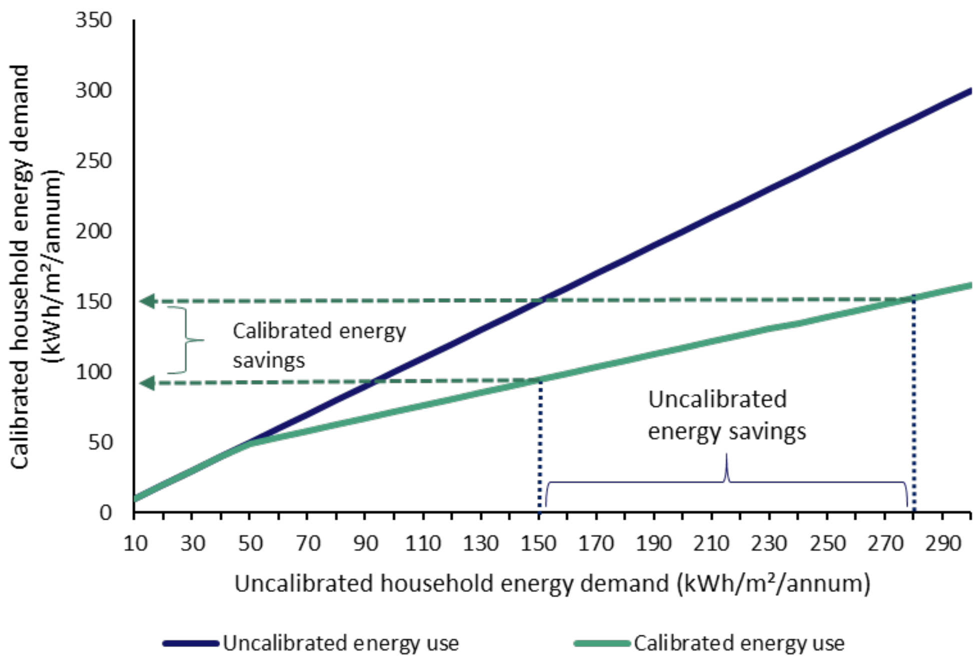


Figure 95: Heating fuel consumption after rebound effects

9.2.1.2 Suitability of energy efficiency measures

Not all energy efficiency measures are suitable for all archetypes. This can be because the building already has the measure installed or due to the characteristics of the measure and the archetype (for example, cavity wall insulation is not applicable to buildings without cavity walls). *Table* 20 below shows the suitability criteria, with the number of suitable stock in line with the most recent BER database. For the residential analysis, a measure is only applicable for an archetype if the target U-value is less than the existing U-value, even if this difference is minimal (resulting in marginal energy savings). This is a different approach to that taken in the commercial and public sectors, where the target U-value and threshold U-value for each measure differ slightly (see *Table 22*).

We took the target U-value for each fabric measure from the Ireland Cost Optimal Report [17] and the U-value for each measure given in *Table* 20. The number of properties suitable for each measure was calculated in previous work for SEAI [2] and updated in line with the latest BER dataset.

The average fuel savings shown in *Table* 20 are for the savings before the calibration to account for the rebound effect. The savings after the calibration for the rebound effect are calculated dynamically and, as the calibration varies depending on the combination of energy efficiency measures installed, the table does not show the average fuel savings for each individual measure after this calibration.

The only residential sector measures not included within this DEAP model are the two measures regarding energy-efficient appliances. To determine the savings of these measures, we took the breakdown of appliance electrical consumption by appliance type in each sector from the previously reviewed *Unlocking the Energy Efficiency Opportunity* study [2], assumed unchanged within each sector. We also took the efficiency improvements in each type of appliance from this previous work. We then applied these savings across appliance types to the electricity consumption values for each archetype.

Table 20: Suitability constraints and average fuel savings for energy efficiency measures in the residential sector

Measure	Target value	Total properties suitable for measure	Average measure fuel savings / % (before calibration for rebound effect: (SH) = space heating fuel savings, (E) = total electricity fuel savings)
Cavity wall insulation	0.31 wall U-value [17][a], only cavity walls suitable	200,000	11% (SH)
Solid wall insulation	0.13 wall U-value [17][b], only solid walls suitable	535,000	17% (SH)
High efficiency glazing	0.9 window U-value [17][c]	1,310,000	15% (SH)
Floor insulation	0.14 floor U-value [17][a]	316,000	6% (SH)
Roof insulation	0.13 roof U-value [17][b]	981,000	5% (SH)
Draught proofing	Infiltration rate of $5m^3/m^2$.hr	894,000	3% (SH)
Energy efficient lighting	100% efficient lighting (LED lightbulbs)	1,193,000	5% (E)
Energy-efficient appliances – 'Cold' and 'Electrical cooking'	According to previous work [21]; updated in line with archetype updates	1,407,000	7% (E)
Energy-efficient appliances – 'Wet' and 'Consumer electronics'	According to previous work [21]; updated in line with archetype updates	1,099,000	5% (E)

[a] *Option 1, Table 3.2*
[b] *Option 2, Table 3.2*
[c] *Option 3, Table 3.2*

Table 21 shows the average heating demand in the residential sector before and after maximum energy efficiency uptake, for each combination of building structure (terraced, semi-detached and detached house; apartment) and heating system (electric heating; gas, oil and solid boiler).[18] The table also gives the variation within each combination, with the minimum and maximum energy savings (across applicable archetypes) – after energy efficiency measures have been taken up – given in the final two columns. The before and after heating demand is calibrated to account for underheating and the savings include the rebound effect, as described in *Section 9.2.1.1* above.[19]

These savings represent the technical potential savings if all of the measures described in *Table* 20 were implemented in all suitable buildings, and do not represent the cost-effective uptake of these measures

[18] This table is a summary of the technical potential savings in archetypes within these sectors; the savings are modelled individually for each archetype, with the results aggregated in this table.

[19] Note that the heating demand increase from energy efficient lighting and appliances is not considered, as this does not have a significant effect in residential properties; this heating demand increase is considered for energy efficiency measures in the commercial and public sectors as the effect is more significant in these sectors.

based on consumer decision-making; they represent the upper bound of the possible savings with the considered measures.

Table 21: Average heating demand (accounting for underheating) before and after maximum uptake of energy efficiency measures by building type and heating system in the residential sector

Building structure	Heating system	Stock	Heating demand (kWh/yr) before energy efficiency	Heating demand (kWh/yr) after energy efficiency	Average Savings (%)	Max Savings (%)	Min Savings (%)
Terraced	Electric heating	28,976	7,473	6,742	9.8%	18.1%	0.1%
Terraced	Gas boiler	182,930	7,534	6,991	7.2%	17.2%	0.1%
Terraced	Oil boiler	65,724	9,857	7,968	19.2%	38.9%	0.6%
Terraced	Solid boiler	30,272	7,291	5,560	23.7%	36.3%	0.0%
Semi-detached	Electric heating	33,362	7,391	6,988	5.4%	17.8%	0.1%
Semi-detached	Gas boiler	260,646	9,141	8,427	7.8%	18.6%	0.0%
Semi-detached	Oil boiler	176,257	10,667	8,706	18.4%	41.0%	0.4%
Semi-detached	Solid boiler	45,311	6,775	5,572	17.8%	31.3%	0.1%
Detached	Electric heating	28,667	12,866	11,860	7.8%	20.2%	0.3%
Detached	Gas boiler	92,370	12,937	11,917	7.9%	20.2%	0.2%
Detached	Oil boiler	474,294	16,389	13,104	20.0%	43.5%	1.0%
Detached	Solid boiler	149,958	11,237	7,949	29.3%	40.8%	0.5%
Apartment	Electric heating	101,100	4,941	4,608	6.7%	15.9%	0.2%
Apartment	Gas boiler	88,903	5,351	5,175	3.3%	15.0%	0.1%
Apartment	Oil boiler	10,470	10,320	8,728	15.4%	36.5%	0.1%
Apartment	Solid boiler	4,318	6,042	4,855	19.6%	32.7%	1.4%

Weighted Average/Total	**1,773,559**	**10,945**	**9,173**	**16.2%**	**N/A**	**N/A**

A wide range (0% to 44%) of potential savings is possible across different building structures and counterfactual heating technology types; this depends on an archetype's pre-existing building fabric condition and its potential for increased energy efficiency. On average, consumers can reduce their heating demand by 16.2% if all fabric measures are considered. Detached homes with oil boilers have a high potential for savings, with an average of 20% savings possible, rising to average savings of 44% for those homes with oil boilers that start with a G BER rating. This is significant because detached homes with oil boilers represent the greatest share of the building stock, heating demand and emissions in the residential sector.

9.2.2 Energy efficiency in the commercial and public sectors

This section provides an overview of the methodology used to calculate the savings and suitability of all measures in commercial and public building archetypes. Separate methods have been used to calculate the energy savings for fabric efficiency measures (i.e. where the materials that make up a building are upgraded) and for non-fabric measures (e.g. installation of efficient lighting).

We calculated the energy savings from fabric efficiency measures in commercial and public archetypes using a model based on the NEAP methodology, previously developed for SEAI to assess energy efficiency measures in the non-domestic building stock in Ireland [50] [51]. This model analyses a building's energy consumption and heat loss through all external-facing fabric areas, and is based on the building fabric properties, geometry, activity, HVAC system, lighting systems, space heating, cooling, ventilation, lighting, equipment, hot water and auxiliary energy demand, solar irradiance and weather data in Ireland. We have tested this NEAP model for several building types in both the commercial and public sector, and the model outputs for baseline consumption are consistent with equivalent estimates in Ireland's non-domestic BER database.

The NEAP model calculates the energy savings of fabric energy efficiency measures by replacing the in-model building's fabrics with better-insulating fabrics. The model then calculated the updated annual space heating demand for all model archetypes in the commercial and public sector. It then applied the percentage savings of each measure to each archetype's energy consumption values based on the most recent non-domestic BER dataset.

Not all measures are suitable for all archetypes; as is the case for the residential sector, this can be because the building already has the measure installed, or due to the characteristics of the measure and the archetype. *Table 22* below gives the suitability criteria for each measure in commercial and public buildings, and presents the percentage of suitable stock in line with the most recent non-domestic BER database and a prior survey of Ireland's commercial buildings [1] [51].

Each fabric measure considered in this study improves a specific fabric within a building, reducing its U-value[20] and therefore reducing the heat loss through the relevant fabric. Buildings are suitable for fabric measures if the existing fabric's U-value is above a certain threshold, which is different for each measure. This is in line with the energy efficiency methodology from the *Unlocking the Energy Efficiency Opportunity* report [2].

The only commercial and public sector measures not included within the NEAP model are the two measures regarding energy-efficient appliances. To determine the savings of these measures, we took the breakdown

[20] The U-value, also known as thermal transmittance, is equal to the rate of transfer of heat through a material or structure, in units of W/m^2K.

of appliance electrical consumption by appliance type in each sector from the previously reviewed *Unlocking the Energy Efficiency Opportunity* study [2], assumed unchanged within each sector. We also took the efficiency improvements in each type of appliance from this previous work. We then applied the savings for more efficient office appliances to the electricity consumption values for each archetype from the latest updates using the non-domestic BER database.

Table 22 below shows the targeted end state for each measure in the commercial and public sector, alongside an average fuel saving for each measure in properties suitable for the measure, given as a percentage. The number of suitable stock for each measure was calculated in previous work [1] [2], and updated to align with the more recent data used in this study. Switching to more energy-efficient lighting appliances can result in an increase in heating demand alongside the reduction in electricity demand, as inefficient lightbulbs produce a significant amount of heat as a by-product. The NEAP model accounts for the increase in heating demand resulting from these measures.

Table 22: Suitability thresholds, target values and average fuel savings for energy efficiency measures in the commercial and public sectors

Measure	Suitability threshold	Target value	Total suitable stock	Average measure fuel savings / % (SH) = space heating fuel savings (E) = electricity fuel savings
Cavity wall insulation	> 0.6 wall U-value, only cavity walls suitable	0.55 wall U-value	26,000	10% (SH)
Solid wall insulation	> 0.6 wall U-value, only solid walls suitable	0.35 wall U-value	70,000	12% (SH)
High efficiency glazing	> 2.8 window U-value	0.9 window U-value	96,000	27% (SH)
Roof insulation	> 0.3 roof U-value	0.25 roof U-value	108,000	16% (SH)
Draught proofing	> 2.8 window U-value	Reduction in infiltration by 1/3 or infiltration rate of 10 m^3/m^2hr, whichever is larger	96,000	6% (SH)
Energy-efficient lighting	All buildings except buildings with 100% energy efficient lighting based on survey [52]	100% energy efficient (LED) lighting	159,000 (not all lighting in all buildings suitable)	23% (E), -9% (SH)
Energy-efficient appliances – Office equipment	All buildings are suitable	Dependent on sector [51]	82,000	4% (E), -2% (SH)
Energy-efficient appliances – Refrigeration	All buildings are suitable	Dependent on sector [51]	78,000 (number of properties with non-zero cooling)	1% (E), -1% (SH)

Table 23 and *Table 24* give the average heating demand in the commercial and public sectors respectively before and after their maximum energy efficiency uptake potential, for each combination of building type and heating system in the respective sectors. Both tables give the variation within each combination, with the minimum and maximum energy savings after taking up energy efficiency measures shown in the final two columns. These tables are a summary of the technical potential savings in archetypes within these sectors; the savings are considered individually for each archetype, with the results aggregated in these tables.

A wide range of potential savings is possible across different building structures and counterfactual heating technology types in both sectors, from 0% to 68% in the commercial sector, and from 0% to 59% in the public sector. On average, these properties can reduce their heating demand by 24.9% in the commercial sector, and by 18.7% in the public sector.

These savings represent the technical potential savings if all measures described in *Table 22* are implemented in all suitable buildings and do not represent the cost-effective uptake of these measures based on consumer decision-making. They represent the upper bound of the possible savings with the considered measures. There is no consideration of the rebound effect in the commercial and public sectors.

Table 23: Average heating demand before and after maximum uptake of energy efficiency measures by building type and counterfactual heating system in the commercial sector

Building type	Heating system	Stock	Heating demand (kWh/yr) before energy efficiency	Heating demand (kWh/yr) after energy efficiency	Average Savings (%)	Max Savings (%)	Min Savings (%)
Hotel	Electric heating	122	374,891	374,493	0.1%	0.1%	0.0%
Hotel	Gas boiler	1,733	737,830	652,622	11.5%	24.1%	0.0%
Hotel	Oil boiler	5,911	85,442	85,287	0.2%	0.3%	0.0%
Office	Electric heating	34,585	23,978	15,311	36.1%	59.2%	0.0%
Office	Gas boiler	2,451	126,493	126,493	0.0%	0.0%	0.0%
Office	Oil boiler	692	53,586	53,317	0.5%	0.7%	0.0%
Restaurant/public house	Electric heating	8,720	36,021	27,208	24.5%	42.0%	0.0%
Restaurant/public house	Gas boiler	4,895	64,157	44,934	30.0%	40.2%	0.0%
Restaurant/public house	Oil boiler	8,683	48,785	29,760	39.0%	41.7%	0.0%
Retail	Electric heating	53,150	16,970	10,027	40.9%	68.4%	0.0%
Retail	Gas boiler	4,583	76,702	57,243	25.4%	54.5%	0.0%
Retail	Oil boiler	3,071	37,959	19,049	49.8%	65.2%	0.0%
Warehouse and storage	Electric heating	4,571	34,764	18,352	47.2%	55.1%	0.0%
Warehouse and storage	Gas boiler	98	159,196	158,845	0.2%	0.5%	0.0%
Warehouse and storage	Oil boiler	1,097	68,245	36,574	46.4%	62.6%	0.0%

Weighted Average/Total	**134,361**	**42,254**	**31,754**	**24.9%**	**N/A**	**N/A**

Table 24: Average heating demand before and after maximum uptake of energy efficiency measures by building type and counterfactual heating system in the public sector

Building structure	Heating system	Stock	Heating demand (kWh/yr) before energy efficiency	Heating demand (kWh/yr) after energy efficiency	Average Savings (%)	Max Savings (%)	Min Savings (%)
Office	Electric heating	2,228	39,557	24,305	38.6%	58.7%	0.0%
Office	Gas boiler	1,246	190,516	118,790	37.6%	57.8%	0.0%
Office	Oil boiler	307	90,978	41,826	54.0%	58.5%	50.8%
Education	Electric heating				0.0%	0.0%	0.0%
Education	Gas boiler	2,116	299,274	270,919	9.5%	41.2%	0.0%
Education	Oil boiler	4,971	141,728	104,799	26.1%	49.9%	0.0%
Healthcare	Electric heating	5,085	26,540	16,304	38.6%	48.0%	0.0%
Healthcare	Gas boiler	5,348	233,355	218,377	6.4%	42.0%	0.0%
Healthcare	Oil boiler	3,108	150,855	102,583	32.0%	38.5%	0.0%
Weighted Average/Total		**24,409**	**145,153**	**117,942**	**18.7%**	**N/A**	**N/A**

9.2.3 Energy efficiency in industry

We took the breakdown of energy consumption and fuel use in the industrial sector in 2019 from the *National Energy Balance* data [3], in line with the method laid out in *Section 4*. To determine the potential for fuel consumption reduction due to energy efficiency measures in industry, the industrial energy consumption provided in the *National Energy Balance* data was broken down by industrial process and subsector according to the 2019 Energy Consumption in the UK (ECUK) dataset [52], in order to assess the potential for energy improvements in each industrial process. The assumption here is that the energy use breakdown by industrial process in each industrial sector is similar in the UK and in Ireland, as no equivalent dataset for Ireland exists. Some alignment between industrial sectors was required, as the sectors in these two datasets did not exactly match; for example, the 'Metals' industry modelled here was aligned with the 'Total iron, steel, non ferrous metals' industrial sector in the ECUK data. Note, we only used this matching of industries to this UK dataset in this industrial energy efficiency modelling, and not in the modelling of the industrial heating and cooling demand described in *Section 4*.

Due to the lack of site-specific energy consumption data at industrial sites in Ireland, we considered energy efficiency measures to reduce the total energy consumption of each industrial process in each sector. We then applied these sector savings to each industrial archetype within that sector, with the percentage reduction in energy demand in each archetype equal to the percentage demand reduction in the entire industrial sector due to implementing each measure. We do not consider the rebound effect to apply to heating demand savings in the industrial processes considered here.

For each industrial process, a single energy efficiency measure was considered; these eight measures (and corresponding industrial processes) are in *Table 25*. We did not consider any energy efficiency measures for the 'Other' industrial process. *Table 25* also provides the potential percentage savings for each energy efficiency measure, taken from previous work and a variety of updated sources [53] [54] [55] [56] [57] [58] including external expert stakeholder engagement.

Table 25: The energy efficiency measures considered for implementation in industry, with the industrial processes for which each measure reduces energy use

Industrial process	Energy efficiency measure	Percentage savings in industrial process / %
High temperature process	Process integration and heat recovery – high temperature processes	Dependent on sector (see *Table 26* below)
Low temperature process	Process integration and heat recovery – low temperature processes	Dependent on sector (see *Table 26* below)
Drying/separation	Process integration and heat recovery – drying/separation	Dependent on sector (see *Table 26* below)
Motors	Improved motor efficiency	20%
Compressed air	More efficient compressed air systems	30%
Lighting	More energy-efficient lighting	19%
Refrigeration	More efficient refrigeration	24%
Space heating	More efficient HVAC	14%
Other	No measure considered	N/A

For the three heat recovery and process integration measures, the percentage savings of the measures depended on the industrial sector but were equal to each other within each industrial sector. The savings for all three heat recovery and process integration measures are in *Table 26* for each industrial sector. The potential savings are equal for high temperature processes, low temperature processes, and for drying/separation. For all other measures, the savings are independent of industrial sector, as shown in *Table 25* above.

Table 26: The potential savings for process integration and heat recovery measures, broken down by industry

Industrial sector	Percentage savings for process integration and heat recovery
Cement	7%
Chemicals	11%
Food and Drink	20%
Lime	7%

Metals	3%
Refining	11%
Wood Products	10%
Other Minerals	7%
Other Industry	15%

9.2.4 Energy efficiency in agriculture

There is no consideration of energy efficiency measures in the agricultural archetypes in this study. There is limited publicly quantitative and reliable information available regarding the deployment of energy efficiency processes in the agricultural sector in Ireland. Furthermore, considering the agricultural sector represents a small proportion of demand across all sectors in Ireland, we expect the relative heating and electricity demand savings due to energy efficiency measures to be small. As such, no energy efficiency measures are modelled explicitly in the agricultural sector for heating demand and electricity consumption in this work.

It should be noted, however, that SEAI recently ran an energy efficiency campaign in the agricultural sector that yielded some specific insights into the potential for energy efficiency. In the dairy subsector, SEAI notes that "for dairy farmers, a correctly-sized Plate Heat Exchanger can reduce energy costs for cooling milk by up to 50%" and the "use of water to pre-cool the milk before it enters the tank will save about 30% of milk cooling costs" [59]. This suggests significant potential for reduction in cooling demand. Additional qualitative reporting suggests other possible measures such as roof insulation for pig and poultry farms. These insights can be used in future studies to better understand the potential for energy efficiency in the agricultural sector in Ireland.

9.2.5 Energy efficiency in data centres

We have not explicitly considered energy efficiency measures for the cooling demand of data centres modelled in this study. However, an improvement in data centre energy efficiency is assumed in the energy demand projections for data centres discussed in *Section 6*. The majority of future growth of data centres is modelled in the Hyperscale data centre archetype. This archetype is the most efficient data centre archetype in this study in terms of percentage of electricity demand used for cooling. The average percentage electricity consumption for cooling across all data centres reduces from 15% of the total data centre electricity consumption in 2020 to 13.5% in 2050, equivalent to an increase in efficiency of cooling technologies across the stock.

9.3 Technical potential for heating demand and electricity consumption reduction

The sections below outline the maximum savings achievable by implementing all measures to all suitable stock across all considered sectors. These are calculated for heating demand savings, cooling demand savings and electricity consumption savings, with graphs showing the results below. The savings illustrated below in *Figure 96* and *Figure 97* account for all measures presented in *Table* 20, *Table 22*, *Table 25* and *Table 26* above. Note that the percentage values in these tables only apply to suitable buildings (or suitable industrial processes) as indicated, and so the total savings are significantly lower than if these percentage savings had been applied to the total heating and electricity demands in each sector. The savings for measures in the residential sector shown in *Table 13* also do not account for rebound, whereas the results below do include rebound for the residential sector. As discussed in *Section 9.2*, this report does not consider the efficiencies of the heating systems in the buildings, as the NEMF deals with these during the modelling stage of the study. Therefore, the energy efficiency savings presented here do not include the potential for switching to more efficient heating technologies, such as heat pumps.

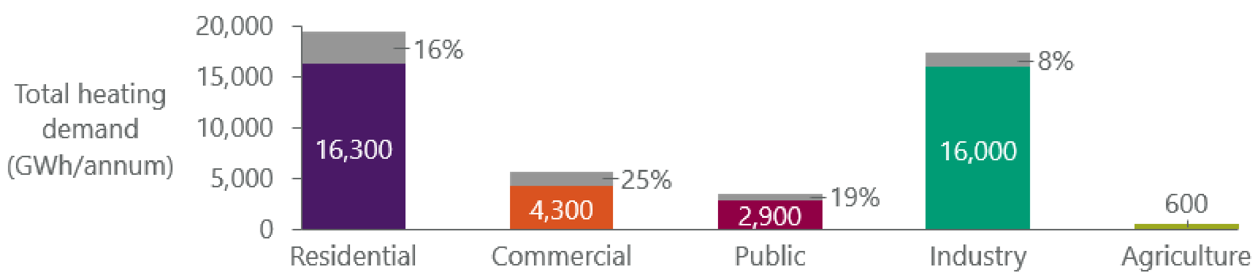
As part of the larger National Heat Study, an extensive economic analysis of the uptake of each measure in each sector is undertaken, in tandem with the uptake of renewable heating technologies. The consideration of energy efficiency improvements in cooling demand due to the uptake of more energy efficient space-cooling technologies will be considered as part of this economic analysis. This economic analysis is detailed in the final National Heat Study report, *Net Zero by 2050*[21].

9.3.1 Maximum savings in heating demand by sector

Figure 96 shows the useful heating demand, and percentage reduction, after applying building fabric and industrial process energy efficiency measures to all suitable stock. In the residential sector, the savings include the calibration to account for the rebound effect, as explained in *Section 9.2.1.1*. The heating demand savings shown here do not include the effect of an increase in heating demand in the public and commercial sectors from an improvement in the efficiency of lighting (as explained in *Section 9.2.2*), as this shows the maximum reduction in heating demand achievable with the considered measures.

The commercial sector has the greatest potential for reducing energy demand through energy efficiency, with a maximum potential reduction of 25% relative to the 2019 base year. The residential sector has the potential to reduce current energy demand by 16% through energy efficiency, including the direct rebound effect. The public sector has the potential to achieve a 19% reduction, and the industrial sector to achieve a 9% reduction. We did not examine the potential for energy efficiency measures in the agriculture sector for this study as it has a small share of overall heating demand, as discussed in *Section 9.2.4*. It is worth noting that the energy efficiency measures considered here only affect space heating demand, with no change to hot water demand; however, the reductions due to energy efficiency shown in *Figure 96* below represent the percentage reduction in total heating demand (including space heating and hot water demand) in each sector.

Figure 96: The remaining heating demand in each sector after applying energy efficiency measures to all suitable stock



Note:

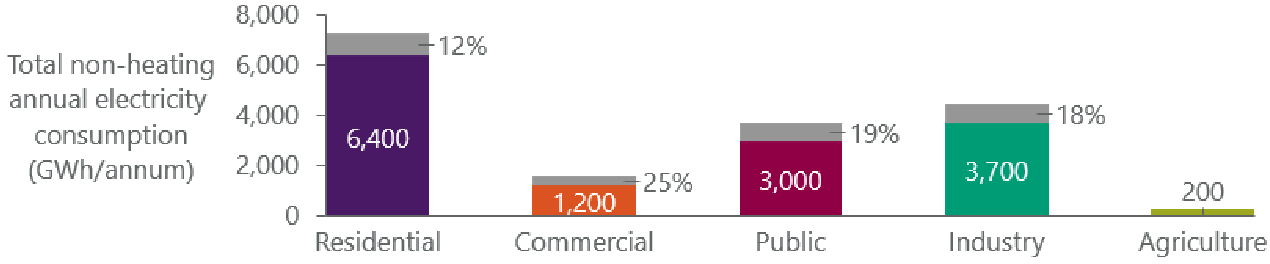
- *The grey area of each chart represents the heating demand saved by the implemented energy efficiency measures.*

9.3.2 Maximum savings in electricity consumption by sector

Figure 97 below shows the remaining non-heating electricity consumption in each sector following the full implementation of energy efficiency measures which reduce electricity consumption in these sectors. The commercial sector again has the potential to achieve the greatest percentage reduction in electrical consumption, with 25% of its demand reduced by these measures. The residential sector has the potential to achieve a 12% reduction in electricity consumption, the public sector has the potential to achieve a 19% reduction and industry has the potential to achieve an 18% reduction.

[21] Available from www.seai.ie/NationalHeatStudy/

Figure 97: The remaining non-heating electricity consumption in each sector after applying energy efficiency measures to all suitable stock



Note:

- *The grey area of each chart represents the electricity consumption saved by the implemented energy efficiency measures.*

10 Suggestions for further work

The following section highlights some of the main limitations of the methods described in this report for profiling heating and cooling demand in Ireland. Suggestions for improvements are also listed. Whilst this section highlights limitations, this should not detract from the quality of this work, which presents a comprehensive, detailed profiling of heating and cooling demand for all buildings in Ireland, across sectors. It also includes several significant improvements on previous attempts, as detailed in previous sections.

Due to the nature of the archetyping process and the final archetypes chosen, all the low-level granularity that describes the difference between individual buildings cannot be captured. Some examples of potential limitations are in *Table 27* below. Further refinement in future work would be possible, but would lead to a larger, more complex model.

Table 27: List of examples of archetype model limitations

Sector	Limitation/simplification
Domestic	Archetypes only specify the main heating fuel, whereas BER records often include main and secondary heating systems, which sometimes use different fuels and have different efficiencies. Archetypes combine fuel use of the main and secondary heating systems and use a demand-weighted heating efficiency to calculate heating demand from fuel consumption data reported in BER ratings. Only the primary fuel is considered when defining the 'existing heating system' in the archetypes.
Commercial & public	BER data provided area-weighted, rather than demand-weighted, heating, and cooling system efficiency. In the absence of an alternative, this was used to derive heating and cooling demand. Area-weighted system efficiency may introduce inaccuracies in some cases, for instance, where a large area (such as a storeroom) relies on a heating system that is rarely used in practice.
Commercial & public	Non-domestic BER data only specifies the main heating fuel for each data record, whereas commercial and public properties sometimes utilise several different heating systems and fuels, each with different efficiencies. Archetypes therefore assume all fuel use (reported in aggregate form by end use in the data) is attributable to the main heating fuel, in the absence of more detailed data. This may introduce inaccuracies in cases where many different heating systems are used in one building, with the main heating system possibly contributing only a minority of total demand. However, such instances are likely rare.
Commercial & public	Fuel used to power equipment is not specified in the non-domestic BER data (only total fuel consumption is recorded). Equipment fuel use is assumed to be all-electric, given the majority of equipment, from IT equipment in offices to coffee machines in retail outlets, is likely to be powered by electricity. This may over-estimate the total electricity consumption for the commercial and public sectors, if a share of equipment is powered by fuels other than electricity, for instance, forklifts in warehouses.
Industry	The split of fuel use/heating demand by equipment type within sectors is not based upon site specific data, and hence the uncertainty could be significant. The best estimates used here are based on ETS permits, EU BREFs (best available technology reference documents) and external industrial stakeholder engagement.
Industry	The number of pieces of equipment on non-ETS sites is uncertain, and as such it is assumed that each site contains one of each piece of equipment relevant to the sector. This could lead to a greater number of pieces of equipment on non-ETS sites in the modelling compared to a true representation (as some sites might only have a subset of the equipment types).

Sector	Limitation/simplification
Industry	Efficiencies of equipment used to estimate the 'heating demand' are challenging to assign within industry. For example, the 'thermodynamic' heating demand for a process could be lower than the realistic most efficient process; the process equipment used might mean that the heat needed is larger (e.g. steam leakage out of pipework). The efficiencies used represent the efficiencies of the combustion/heating equipment, and do not account for later impacts where the heat is transported/used.
Industry	The prominent limitation of this work concerns the demand of heat and cooling consumption for the industrial sector. The industrial data used did not clearly pair demand with site location, and so additional steps have had to be made in order to assign heating and cooling consumption to high consuming Irish sites.
Agricultural	Data for farm energy use is limited; bottom-up modelling is based on the latest available public data provided by the CSO and Teagasc.
Data centres	No future improvements in efficiencies of data centres have been modelled. All PUE values are assumed constant until 2050 for all archetypes. This could result in the cooling demand given here being an over-estimate of the actual cooling demand, if there is a significant increase in data centre cooling efficiency in Ireland by 2050.
Data centres	There is a lack of granularity in modelling different cooling technologies in individual data centres. Instead, only an average cooling demand per archetype has been assumed. No costs have been modelled for different cooling technologies. This means that the approach to data centres taken here is not as detailed as the approach taken for other sectors.
Spatial mapping	This work required the utilisation of multiple data sources, with multiple archetypes within residential and various subsectors within commercial, public and industrial, with some variances between the datasets. Calculating the load factors for each archetype per sector, per dataset and then apportioning all combinations per small area combined with building footprint was not attempted and the units remain the same as the existing heat map.
Spatial mapping	As part of this project, future work will be undertaken to validate the existing mapping and develop spatial mapping of future thermal demand scenarios.

Glossary

Term	Description
Archetype	A simplified representation of a normally large number of real-world items, such as buildings.
BER	Building Energy Rating
Direct fired heating equipment	Industrial heating equipment where combustion gases come into direct contact with the product being heated), such as in furnaces or kilns.
Energy-related emissions	Greenhouse gas emissions resulting from the combustion of fossil fuels for energy use, either from direct use of fossil fuels for energy, or indirectly from electricity use. It excludes emissions not from the combustion of fossil fuels, such as biogenic greenhouse gas emissions from agriculture or industrial process emissions.
ETS	Emissions Trading Scheme (regarding the EU's emissions trading scheme)
Final energy	The actual amount of energy used to meet a demand (i.e. actual fuel used). These data are reported in aggregated form in the *National Energy Balance*. Also known as final energy. Corresponds to the energy consumption that normally appears on energy bills.
High Grade Heat	Industrial heat of temperature >500°C
Indirect heating	Industrial heating equipment where heat is supplied through a medium such as steam/hot water.
Low Grade Heat	Industrial heat of temperature <100°C
Medium Grade Heat	Industrial heat of temperature <150°C and >500°C
Medium/Low Grade Heat	Industrial heat of temperature <100°C and >150°C
ND-BER	Non-domestic Building Energy Rating
Non-ETS	This refers to industrial sites or other greenhouse gas emitters which are not part of the EU's emission trading scheme.
PUE	Power Usage Effectiveness – the sum of all data centre electricity loads (including for lighting, cooling and other non-IT electricity loads), divided by the sum of the electricity loads for IT (information technology) purposes only. By definition, this value cannot be greater than one; a value closer to one implies a more efficient data centre.
Stock	Represents either one building or one piece of equipment, depending on the building sector being discussed.

Technology efficiency	The conversion efficiency of a technology, which links useful and final energy.
Useful energy demand	The amount of energy required to fulfil a demand. Does not take any losses into account (for example, due to technology conversion efficiency).
Small Area (SA)	Smallest administrative land area in Ireland, over which Census data are published, typically containing 80 to 120 dwellings
CSO	Central Statistics Office
NEMF	National Energy Modelling Framework
Macro	A sequence of instructions applied to a dataset
GIS	Geographic Information System (GIS) - A spatial system that creates, manages, analyzes, and maps all types of data

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