ENERGY FLAGSHIP
www.csiro.au

Inner Melbourne Energy Consumption 2011-2026

Baseline and future scenarios forecasts for the residential and commercial sectors

Seongwon Seo, Greg Foliente, Felix Lipkin, Kwok-Keung Yum, Julia Anticev, Stephen Egan and Luke Reedman

Inner Melbourne Action Plan (IMAP) Councils
30 June 2014

CSIRO Energy Flagship

Citation

Seo S., Foliente G., Lipkin F., Yum K-K., Anticev J., Egan S. and Reedman L. (2014). Inner Melbourne Energy Consumption 2011-2026: Baseline and future scenarios forecasts for the residential and commercial sectors. Report No. EP13XXXXX, CSIRO, Australia.

Copyright and disclaimer

Important disclaimer

Contents

Executive summary.....iii
1 Introduction.....1
1.1 Background.....1
1.2 Purpose.....1
1.3 Scope and limitations.....1
2 Method.....3
2.1 Overview of methodologies.....3
2.2 Datasets and mapping.....3
2.3 Energy consumption modelling.....5
3 Baseline energy and BAU forecast scenarios.....13
3.1 Introduction.....13
3.2 Baseline energy consumption 2011.....13
3.3 BAU forecast scenario to 2026.....21
4 Retrofit and New-Build Forecasts to 2026.....33
4.1 Overview.....33
4.2 Possible intervention schemes.....33
4.3 Selected scenario settings.....35
4.4 Forecast scenario results and analysis.....39
4.5 Some limitations and applications – present and future.....46
5 Conclusions and future work.....47
References.....49
Appendix A: Glossary and Abbreviations.....51
A1. Glossary.....51
A2. Abbreviations.....51
Appendix B: Classification of building stock.....53
B1. Residential building typologies.....53
B2. Commercial building typologies.....58
Appendix C: Energy Maps by Council.....61
C1. City of Melbourne.....61
C2. City of Port Phillip.....68
C3. City of Stonnington.....71
C4. City of Yarra.....74
Appendix D: Future Scenario Energy Calculation Methods.....77
D1. Residential Buildings.....77
D2. Commercial Buildings.....78
Acknowledgments.....80

< This page left intentionally blank >

Executive summary

- Understanding the spatial distribution of energy consumption in residential and commercial buildings in Inner Melbourne will allow identification of appropriate investment, policy instruments and specific actions to reduce the energy-use and the greenhouse gas (GHG) emissions footprint of the city. This report presents the energy maps for the Cities of Melbourne, Port Phillip, Stonnington and Yarra for the baseline year of 2011 and the 5-year forecast increments to 2026, based on simplified business-as-usual (BAU) and different combinations of retrofit and new-build scenarios.
- The residential and commercial building energy data are determined using a bottom-up building stock modeling approach based on a hierarchy of building typologies using CSIRO's AusZEH tool and the US Department of Energy's eQUEST tool, respectively.
- The selected baseline year of 2011 was selected to match the recent Australian Census. This was complemented by the participating council's property databases (e.g., City of Melbourne's Census of Land Use and Employment [CLUE] database and other councils' rate valuation property databases) and other related sources. The energy intensity for each residential building typology (288 building classifications in total) and commercial building typology (90 building classifications in total) in each Statistical Area Level 1 (SA1) was calculated first using the AusZEH and eQUEST tools, respectively. Results were then proportioned to all street blocks in the corresponding SA1 area according to the total floor areas and households for each building type in each block. The residential energy maps show the energy use for residential only, according to the spatial distribution of each residential building type in each block. The same was undertaken for commercial energy maps. The total energy consumption map shows the sum of the energy consumption of all relevant building types (residential and commercial) in each block.
- The building stock energy simulation results were validated with actual data from CitiPower (for macro-validation of residential and commercial energy use within its service area) and Melbourne Hospitals (for selected micro-validation at block/parcel level). In both cases, modelling and simulation results deviated less than 10% of actual energy data in the baseline year 2011. Considering the highly heterogeneous building stock and the vastly different details of building age, type, occupancy and use operating conditions, *and* the simplifications required for any building stock modelling work, this level of deviation from actual data is generally considered within an acceptable range.
- We demonstrated the capability and value of a bottom-up building stock methodology to analyse the spatial and temporal energy use in buildings at various levels that can be used to target specific analysis objectives. Without further modelling and simulation, the current results, especially the 2011 baseline set, can be used to identify intensive areas of energy use ("hot spots") by:
    - Location (specific block)
    - Building type (up to various sub-classifications within the primary residential and commercial building types; total of 288 residential and 90 commercial building types)
    - End-use category (e.g. HVAC system, lighting, hot water system, plug-in appliances and equipment, etc).
- Future scenarios capability is demonstrated by mapping the energy use forecasts on 5-year increments to 2026. The BAU growth forecasts for Melbourne are based on projected block-level development plans supplied by the City of Melbourne. The BAU forecasts for Port Phillip, Stonnington and Yarra are, however, based on highly simplified assumptions that did not consider planned or preferred growth areas, energy efficiency improvements and in what specific locations. The implications of these are that:

    (a) The change in energy demand values and spatial distribution did not change significantly because the growth was spread to every block that has properties;

(b) If there was no initial development in a block in the base year, there would be no future development growth in later years; and

(c) Spatial energy mapping for the BAU case is meaningful only for the City of Melbourne; it is not meaningful for Port Phillip, Stonnington and Yarra, and thus, excluded. Only aggregate energy consumption for the latter three councils is plotted to 2026.

This means that the three other Councils still need to develop more realistic BAU settings, as the basis for a revised BAU scenario and spatial mapping of energy use. This may include land use, development and re-zoning plans, among others.

- Future retrofit and new-build scenarios to 2026 considered minor, moderate and major levels of grid-energy reduction for both the residential and commercial buildings. The reductions can be gained by improved energy efficiency (including change of end-use behaviours) and/or installation of on-site renewable energy system such as PV panels. Two voluntary uptake and improved regulatory requirement scenarios (A and B) are considered in 2016, 2021 and 2026.

  As in the BAU cases, spatial energy mapping for the retrofit and new-build scenarios is meaningful only for the City of Melbourne; it is not meaningful for Port Phillip, Stonnington and Yarra, and thus, excluded. Only the aggregate energy consumption values of future retrofit and new-build scenarios to 2026 for the latter three councils are plotted.

- To aid the viewing of all the scenarios considered, a web-based IMAP energy map viewer is provided separately. Conversely, this report provides the background details and explanations of the data shown in the web-based viewer.

- The full capability and value of the methodology would require additional (or separate) effort but can be further demonstrated in:

  - GHG emissions mapping and analysis – with the same capability as with the energy results in the present study
  - Peak energy demand analysis – to understand and identify detailed energy demand patterns annually or by season (macro-level), and daily or by time of day (micro-level).
  - Feasibility studies of distributed renewable energy options (what, how and where – including specific and context-based assessment of the economics and effectiveness of different GHG abatement options)
  - Planning and/or assessment of policy and other intervention schemes alone or in cooperation with other stakeholders (e.g. federal, state and local governments; utility companies; service companies; and clients/customers/public).

- To maximise the value and applications of energy-relevant data sets, their collection and management need to be made compatible with other protocols and platforms across jurisdictions and database systems. In the near term, it would be ideal to:

  - Harmonise the differences of terms and interpretations of building classification among Councils and ABS datasets. Modelling will be better served if these differences can be ironed out in the years to come.
  - Establish a database of building energy certificates and disclosure information.
  - Obtain detailed and higher resolution data about energy consumption patterns, including plug-in appliances and equipment, fuel types and mix (if any), time/hours of operation, etc., for some residential and commercial building types to help in optimising energy efficiency and GHG emission reduction options.

1 Introduction

1.1 Background

The Inner Melbourne Action Plan (IMAP) is a collaborative partnership between the Cities of Melbourne, Port Phillip, Stonnington, Yarra and Maribyrnong (IMAP 2013). Analysis in this project has only been conducted for the four foundation IMAP Councils: Melbourne, Port Phillip, Stonnington and Yarra. IMAP aims to ‘make Melbourne more liveable' within the next five to ten years by implementing a series of strategies and actions. It guides a collective and consistent approach to the future growth and development of inner Melbourne.

IMAP has developed eleven strategies to achieve this goal. Under Strategy 9 (Sustainability Improves the Environmental Performance of the Inner Melbourne Region), there is a Green Demonstration Project entitled “Distributed Energy Project” that aims to identify opportunities for matching the local energy demand and supply, including the distributed power generation. Results are intended to inform property owners, developers and energy companies where the electricity demand is consumed most and what appropriate technology could be used to pursue energy efficiency and distributed generation projects to take advantage of network constraints and opportunities, and also to reduce the associated greenhouse gas (GHG) emissions. A potential development will be incorporating distributed generation (DG) technologies (e.g. solar power, wind power and co- and tri-generation) into the current centralised power supply. Locally generated power may offset the cost of power transmission. The challenge is to analyse spatially distributed information of energy consumption and identify hot spots for potential DG deployment or other non-network solutions. For this, the Councils need a spatially distributed energy model for the analysis of energy efficient mixes of supply and demand of energy sources.

1.2 Purpose

To achieve the above, the present study seeks to:

a) Understand and map the current distribution and type of end-use energy consumption in residential and commercial buildings within the four Councils in the IMAP region that were studied (‘the study area’). An important first step, this will be established as the 2011 baseline case.

b) Investigate the changes in end-use energy consumption and their spatial distribution considering different future scenario settings on 5-year increments to 2026. The scenarios include:

   - Business-as-usual (BAU), based on population growth, development plans (when available), business and other trend projections; and
   - Retrofit and new-build scenarios, based on different levels of grid-energy reduction for both the residential and commercial buildings, and voluntary uptake or adoption by consumers.

Spatial mapping will be at the street block level across the study area.

A glossary of common terms and abbreviations are given in Appendix A.

1.3 Scope and limitations

The modelling and analysis does not cover the industrial sector, which is heterogeneous and only accounts for about 4% of the total load (according to the data from CitiPower, the key electricity provider in the IMAP study area) and is not amenable to the typology style modelling approach used herein.

The BAU scenarios to 2026 are based on general trends (using easily accessible information or datasets) and various simplifications although the models used can take into account more realistic input datasets for a range of scenarios. With the detailed anticipated development plan to 2026 supplied by the City of Melbourne, we have been able to present the spatial distribution of estimated changes in energy consumption within the council at block-level. When the future development information and data are partial or incomplete, we are unable to distribute local energy demand. In such a circumstance – as it was for Port Phillip, Yarra and Stonnington in this report – energy demand trends for these three councils were conducted per council geographic aggregate only.

Since the same constraints as above apply when evaluating the impacts of various retrofit and new-build case scenarios, the resulting energy demand was spatially mapped for the City of Melbourne only. The changes in energy consumption for all the retrofit and new-build scenarios for Port Phillip, Yarra and Stonnington were conducted per council geographic aggregate only.

The energy map representation at the block level is constrained by the quality and accuracy of the supplied GIS layer representing blocks (especially capturing the boundaries of nature reserves, water bodies and other non-building related areas).

Furthermore, in choosing energy mapping at block-level in order to protect individual building privacy parcel data, various local factors and details including the irregularity in shape and size of a cadastral parcel makes it difficult to find a common geographic boundary to derive an aggregate representation for an area as large as IMAP or each individual council. This challenging problem has not been overcome in the present study. The practical implication is that when one tries to identify high energy intensity users, one that is actually sitting on a small block (or area) will be appear to be a lower intensity user compared to a large block (or area) with many small intensity users. Setting aside privacy concerns, for scientific data analysis and modelling, the most ideal representation would be at the parcel level.

This analysis and report does not include any intervention options or optimal cost mixed options. We have not considered herein peak energy demand modelling and analysis, and impacts of changing energy supply system and mix. Later stages of the study can take these into account, for example, also considering the economics of implementing various technologies and options such as installing localised DG power systems compared to purchasing grid-delivered electricity.

2 Method

2.1 Overview of methodologies

In order to identify and assess the feasibility and desirability of specific decision and/or investment options to reduce the energy consumption and the associated GHG emissions in the building sector, the end-use energy estimation methodology needs to:

- Be more specific, i.e. based on current status and context (e.g. age or condition and type of building), and quantitative than general energy efficiency measures such as “residential/commercial new builds”, “residential/commercial appliances”, “commercial retrofit HVAC”, etc.
- Account for the spatial distribution of energy consumption (what, by whom, where, etc).

In other words, the analysis needs to go deeper and more detailed than what has been commonly assumed or undertaken to date (e.g. Petchey 2010, Climateworks Australia 2010).

Building stock energy use modelling approaches have been reviewed extensively and critically by Swan and Ugursal (2009), Kavgic et al. (2010), Higgins et al. (2011), Foliente and Seo (2012), Ren et al. (2012) and Boulaire et al. (2013). These can be generally classified as either top-down or bottom-up approaches.

The top-down modelling approach works at an aggregated level, typically national, and is primarily focused on broad econometric or technological impacts. But these are neither designed nor useful for investigating the impacts and effectiveness of a specific action or policy. The bottom-up modelling approach works at a disaggregated level, providing flexibility and the powerful capability to investigate the impact of a specific action, measure or intervention at various levels of aggregation (i.e. building stock at the city, regional or state level). However, this approach is highly dependent on the availability, reliability and quality of data at the starting point of analysis (or level of disaggregation) and the nature and capability of the model used at the lowest level of analysis. The modelling technique may be based on building physics, statistical models or a hybrid of the two (Kavgic et al., 2010).

Using a statistical approach – and given highly granular and comprehensive energy consumption and building stock data sets – Howard et al. (2012) mapped end-use energy intensity (KWh/m^2 floor area) for space heating, domestic hot water, electricity for space cooling and electricity for non-space cooling applications for each tax lot in New York City. However, their model assumed that such end use is primarily dependent on building function (e.g. residential, educational or office) and not on construction type or the age of the building.

CSIRO’s structured cross-typology approach is a novel contribution to bottom-up modelling approaches because it enables different stakeholders (e.g. policy makers, property portfolio owners, utility companies and building tenants) to assess the impacts of their specific actions or decisions, considering a range of typologies of buildings (by type, age and function), appliances, lighting system, heating and cooling systems, and occupancy patterns. This is achieved using physics-based building energy simulation models for residential and commercial buildings (Foliente and Seo 2012, Ren et al. 2012 and Grozev et al. 2013). Residential and commercial end-use energy intensities are then mapped for each block within the study area.

2.2 Datasets and mapping

The modelling, presentation and analysis of energy consumption can be done at various spatial levels of detail, depending on data availability and objectives of the stakeholder. As our modelling data were largely

from 2011 Census data, which were aggregated to the Statistical Area Level 1 (SA1) (ABS 2011), we modelled energy consumption at the SA1 level.

Figure 1 gives the relative sizes of spatial levels of SA1, block and cadastre (land parcel).

Figure 1: Spatial levels of detail in the context of the study area (Cities of Melbourne, Port Phillip, Stonnington and Yarra)

The Councils carry out a property census for the purpose of rate evaluation once every two years. Their data are collected at the cadastral level, which relates data to the boundary of the associated land parcel. In order to preserve privacy and commercially sensitive information we selected the street block level for the spatial presentation of energy end-use consumption. Each council provided the GIS layer representing blocks within its boundary.

For the present study, we obtained input data from the following datasets:

- Census data for the study area at the SA1 level
- CLUE dataset for the City of Melbourne, and
- Valuer-General's property evaluation dataset for the cities of Port Phillip, Stonnington and Yarra.

Our main input data for residential modelling came from Australian Bureau of Statistics (ABS) *Census of Population and Housing*. The Australian Census has been held at five-year intervals since 1961. The 2011 Census was the most recent census. These data were extracted at SA1 level using the ABS TableBuilder tool (ABS 2011b). TableBuilder provides flexibility in selecting and combining any variables contained in the Census output record file and does not limit data selection to predefined table structures.

Our main input data for commercial property modelling came from the CLUE dataset or council's property valuation dataset. These data are surveyed and assessed once every two years by each council.

In addition to data that characterize the building, the City of Melbourne's CLUE database also recorded the following for every property in the census area within its jurisdiction:

1. Cadastral ID for the building that the property is located in
2. Construction/refurbishment date of the building (from which the age is derived)
3. Floor number
4. Australian and New Zealand Standard Industrial Classification (ANZSIC) of the main type of business in the property
5. Space (in square metres) used by key building type (retail, wholesale, manufacturing, transport, storage, education, hospital, entertainment, sport & recreation, residential, parking, common area, unoccupied, performance, etc.)
6. Total number of employees and related employment status.

From the CLUE dataset, we can estimate, for each commercial building, the floor space for various building types. For each building type, we can then simulate the energy consumption intensity (MWh per m^2).

Finally, we note below the following limitations when mapping Census Data to the parcel level:

- There were inconsistencies in the accuracy of census data *vs* Council datasets
- The building structure classification differs between those used in the census and those use by the Councils
- There was a mismatch between council property and parcel layer (i.e., property record contains no parcel information), and
- Rates extraction was from 2012-2013 yet census data is from 2011.

2.3 Energy consumption modelling

2.3.1 GENERAL

The CSIRO's cross-typology bottom-up approach was used for both residential and commercial buildings' energy use calculations. The building stock energy modelling process is similar but since different factors and operating conditions determine the energy consumption in residential and commercial buildings, different building modeling tools were used for each building typology under each type of building.

The residential building typologies were modeled using AusZEH (Ren *et al.* 2011; 2013), which uses the same computational engine for the residential building thermal performance modeling software known as AccuRate (Delsante 2004; 2005).

The commercial building typologies were modeled using eQUEST (eQUEST 2013) following the method outlined in Foliente and Seo (2012).

2.3.2 RESIDENTIAL BUILDINGS

Figure 2 shows the residential building stock energy modelling process. As noted earlier, the primary geospatial boundary selected for analysis is the SA1 level to match the census data set. The following classification attributes, defined mostly by the census definitions[1], were used:

- Dwelling structure (high rise, detached, semi-detached, low rise) (classification from Structure of Residential Dwellings (ABS 2011b); count data from ABS census 2011)
- Dwelling age (pre 1991, 1992-2006, 2007-2011) (Building age counts from CLUE or Property Valuation databases[2])

[1] The only two exceptions are: property age data (taken from council property data) and electricity/gas dominance ratio (Ren *et al.* 2011)).

- Occupancy type (couple with no child, couple with child, single parent with child, other) (classification from Family Household Composition (ABS 2011b); count data from ABS census data 2011)
- Operation hours (half day, all day, evening) (from Labour Force LFSP (ABS 2011))
- Electricity/gas supply ratio (70%:30%) (from Ren *et al.* 2011)

The classification resulted in a table of classified residential building stock at SA1 level (

Table 1).

Table 1: Examples of residential building stock types in an SA1

SA1	Dwelling Structure	Dwelling age (CLUE database)			Occupancy, etc.	Dwelling number in 2011 Census
		Pre 1991	**1992 - 2006**	**2007 -2011**		
Dwelling type 1	Detached	0.265957	0.56383	0.170213	Etc.	38
Dwelling type 2	Semi-detached	0.265957	0.56383	0.170213		46
Dwelling type 3	Low	0.085223	0.827863	0.086914		0
Dwelling type 4	High	0.085223	0.827863	0.086914		29

[2] CLUE database was used in the modelling for City of Melbourne, whereas Property Valuation databases were used in the modeling for other three IMAP councils that were studied.

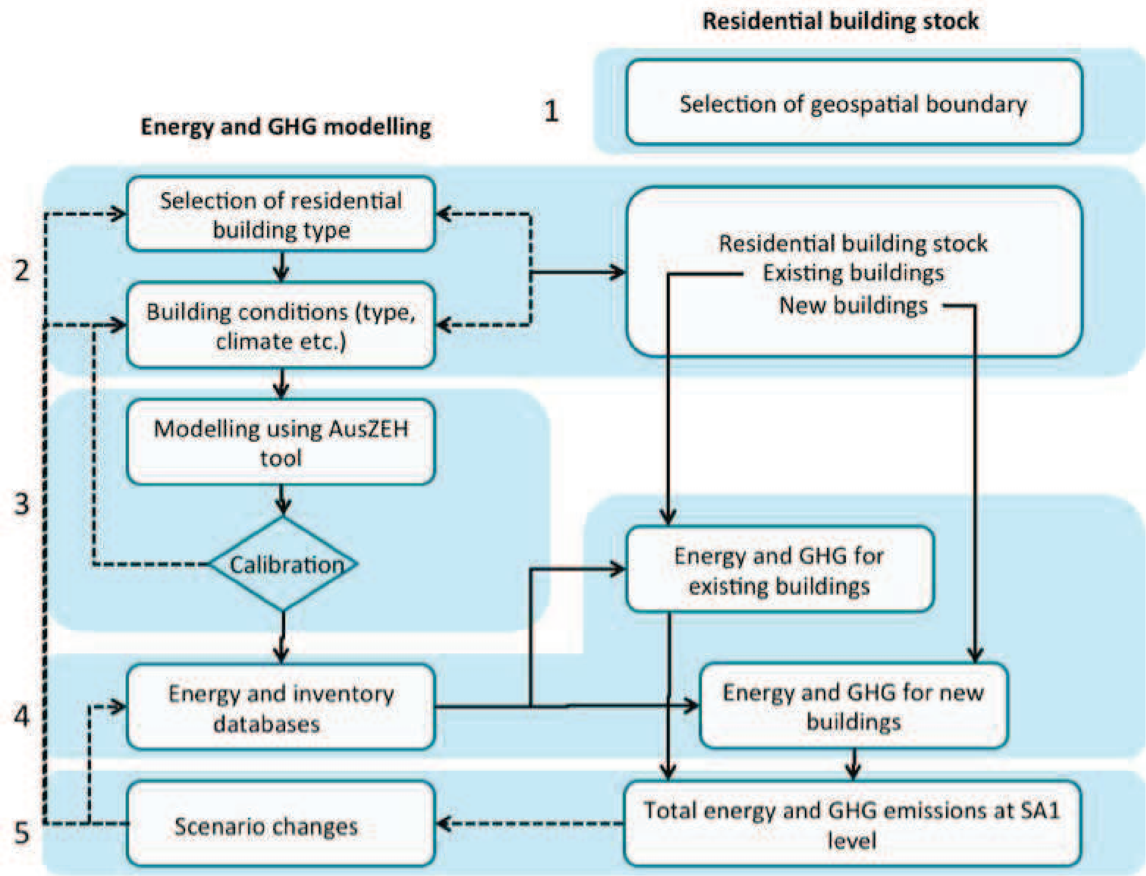


Figure 2: Residential building stock energy consumption modelling process

For each SA1 area, there are 4 (dwelling structure) x 3 (dwelling age) x 4 (occupancy types) x 3 (operation hours) x 2 (electricity/gas ratios) = 288 property stock types (see Appendix B for complete details).

Figure 3 shows the simulation process for each building type in SA1. Then, we aggregated the total energy to the corresponding SA1 area proportionally by total property number or by total floor space for each building type in that area (Equation 1):

Total energy consumption in SA1 = (1)

$$\sum_{Building\ types\ in\ SA1} \text{Pro rata factor for building type in SA1 X Energy intensity for building type in SA1}$$

Aggregated simulation results were validated against the electricity consumption data in SA1 areas serviced by CitiPower, the main electricity distribution network service provider in the IMAP area (see Section 3.2.1 for details).

Although not undertaken in this study, GHG emissions due to energy use can be estimated using a conversion factor for consumed electricity and the proportion of gas in the residential sector.

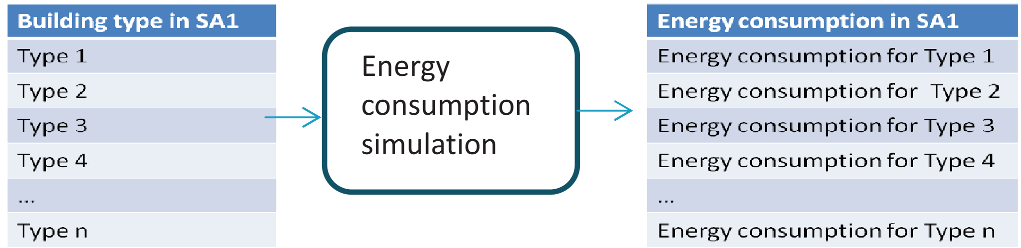


Figure 3: Energy consumption simulation by building type and SA1 area

2.3.3 COMMERCIAL BUILDINGS

For each SA1 area, the selected office building prototypes follow the low-rise (LR), medium-rise (MR) and high-rise (HR) classifications of Cordell Costing Solutions (2003). For streamlined modeling, the structural frame – whether concrete or steel – is assumed not to affect energy performance, and 2-storey, 6-storey and 20-storey building models are assumed sufficient to proxy LR, MR and HR buildings, respectively. Thus, the baseline specifications of the office building prototypes are shown in

Table 2. Details for each commercial type, such as floor area and activity profiles for occupancy, lighting, power, equipment and HVAC systems are shown In Table 3.

A summary of the Councils' commercial property stock for the purpose of building stock modeling is as follows:

- Building structure (3 types: LR, MR and HR) (classification from Cordell Costing Solutions (2003); count data from CLUE or from CLUE or Property valuation databases)
  - LR: concrete construction with 1-3 storeys
  - MR: concrete construction with 4-7 storeys and lifts
  - HR: concrete construction with more than 8 storeys and lifts
- Business type (structure and count data from CLUE or Property valuation databases):
  - Commercial accommodation
  - Community use
  - Educational/research
  - Entertainment/recreation-indoor
  - Hospital/clinic
  - Office
  - Retail
  - Storage
  - Wholesale
  - Workshop/studio
- Age of building: Ideally a different set of prototypes would be defined for each size of building, stratified by age of building shell and age of HVAC (the latter is significant due to improvements in efficiency of HVAC). For the building age, Geoscience Australia (2010) classified two types: Pre and post 1980. This study extends this into three classifications:
  - Pre 1980,
  - Post 1980 and
  - Less than 5 years.

  The first two cases are based on the Geoscience Australia data and new construction is allocated in the 'Less than 5 years' category.

Thus, for each SA1 area, there are 3 (building structure) x 10 (business type) x 3 (building age) = 90 property stock types (see Appendix B for complete details).

Climatic differences affect HVAC loads applied to the various prototypes. This study considered only one single climate zone in the IMAP region. In addition, different fuel mix types in the commercial building stock are not considered in the present study; energy estimates have been assumed to be supplied by electricity only (for simplicity and to limit the total number of commercial building typologies).

The specific procedure follows the concept shown as Steps 2, 3 and 4 in Figure 4. Each prototype building is modelled using eQUEST 3.64 for each SA1 (this tool runs DOE-2.2 as its simulation engine and performs an hourly simulation of a building for a year (Zhu, 2006)). That is, for each prototype *t* in a given SA1 *s*, the model parameters are established for an average building of type *p* in SA1 *s*; the building model is then run; and the results from this run (energy usage and GHG) are scaled up by a factor of A/a, where A is the total floor space of buildings of type *p* in *s*, and a is the average floor space of each such building.

The individual building's energy performance is expressed in terms of energy intensity, and the associated GHG emissions are expressed in terms of carbon intensity.

Table 2: Specification of commercial building prototypes by size

	Building type		
	Low	Medium	High
Total floor area (m2)	Depending on the commercial type		
Floor (storeys)	2	6	20
Wall	Brick	150mmHW	Metal framed glass
Floor	6 in. concrete		
Glazing	20% single colour tinted	Double glazing	
Building operation	Depending on the commercial type (Benchmarked ABCB energy profile)		
HVAC system	DX		VAV with reheat (Chilled water)
Temp. Cooling	23		
Temp. Heating	22		
Lift	N/A	One of 7 kW of electrical power load	Three of 7 kW of electrical power load

Table 3: Floor area activity profiles for occupancy, lighting, equipment, HVAC system

Commercial types	Floor area (m2)	Occupancy, lighting, power, HVAC profiles etc
Com. Accommodation	930 for low No considered for Medium 16,720 for high	Benchmarked energy activity profiles of class 3 (Hotel/motel) by ABCB*
Community use	930 for all types (low, medium and high rise)	Assumed to be similar to low rise building energy profile.
Educational/research	23,220 for all types	Benchmarked energy activity profiles of Green Star Education**
Entertainment/recreation	6,050 for all types	Benchmarked ABCB's energy profile of class 9b (Theatre) by ABCB*
Hospital/clinic	1,850 for low 23,220 for medium No considered high rise	Benchmarked ABCB's energy profile of class 9a (Healthcare) by ABCB*
Office	2,450 for low 9,600 for medium 32,000 for high	Benchmarked ABCB's energy profile of class 5 (Office) by ABCB*
Retail	300 for low 600 for medium 1200 for high	Benchmarked ABCB's energy profile of class 6 (Retail) by ABCB*
Storage	18,580 for all types	Benchmarked ABCB's energy profile of class 7 (Warehouse) by ABCB*
Wholesale	13,900 for low only	Benchmarked ABCB's energy profile of class 7 (Warehouse) by ABCB*
Workshop/studio	2,000 for all types	Benchmarked ABCB's energy profile of class 8 (Workshop) by ABCB*

*ABCB (2002) Activity Profiles for Class 1, 2,3,5,6,7,8,9a ,9b building energy use, ABCB

**Green Star (2010) Green Star Education v1: Energy calculator guide, Green Building Council Australia.

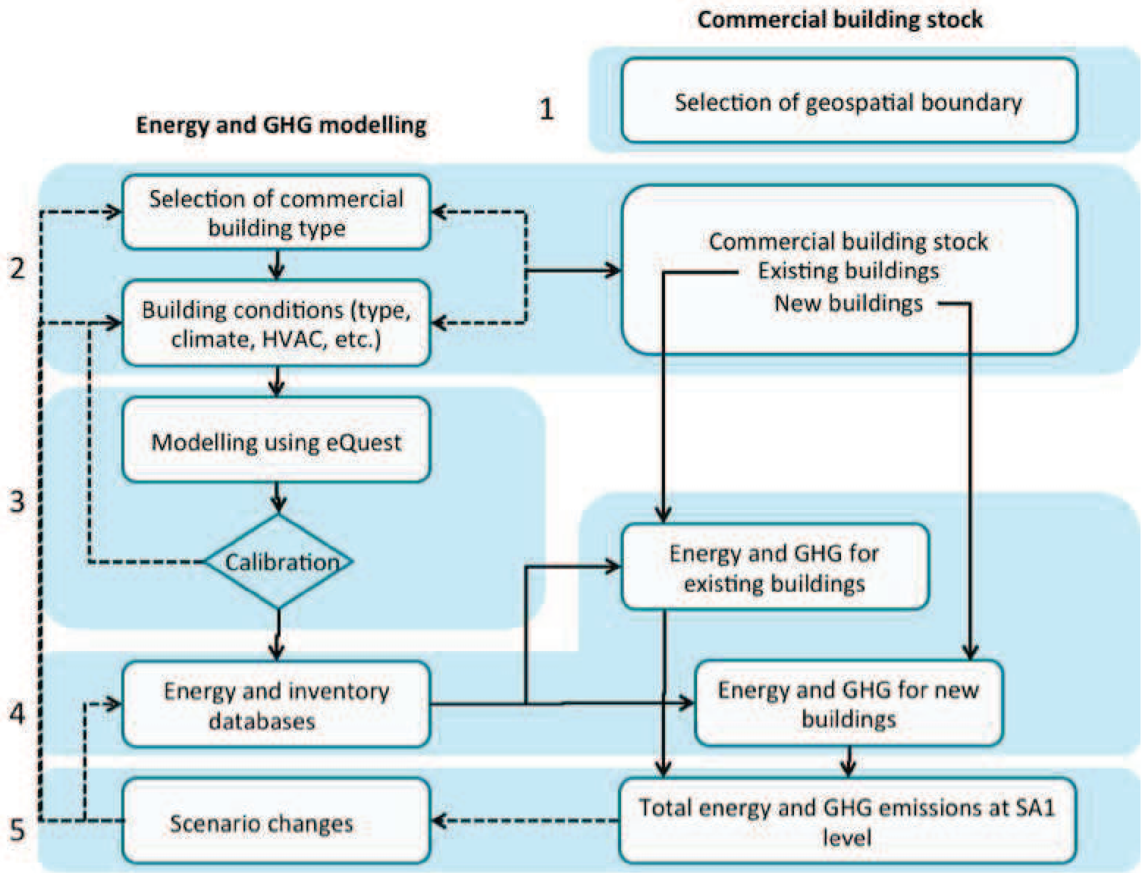


Figure 4: Commercial building stock energy consumption and GHG emissions modelling process (from Foliente & Seo 2012)

2.3.4 GROWTH FORECAST FOR BUSINESS-AS-USUAL SCENARIO TO 2026

The BAU forecasts for the City of Port Phillip, Stonnington and Yarra are based on general property growth projections as described below. Because of incomplete information, we did not consider planned or preferred growth areas, energy efficiency improvements and in what specific locations.

For residential property growth, we used the population and household number projections taken for each Council area from the website http://forecast.id.com.au. These data are used to calculate the percentage increases over the study snapshot years (2016, 2021, 2026). These percentages are then applied to the detailed population and household numbers taken from ABS for 2011 to produce projections for each SA1 within the Council areas.

For commercial property growth, we used the following assumptions:

- The Australian Construction Industry Forum (ACIF 2013) forecasting data is used, which considered future population, economic (wage, GDP) and social (unemployment, etc) at a macroeconomic level
- Current market value of each commercial type (Rawlinsons 2013) to convert future commercial building stock into building floor area
- Refurbishment or retrofit of existing building stock is not considered
- Assumed 1% of existing commercial building demolished every year.

The BAU growth forecasts for the City Melbourne are based on projected block-level development plans to 2026 supplied by the council. Data and assumptions from the sources cited above are used only as needed to fill-in or verify specific information from the council's projected development plans.

2.3.5 MAPPING OF RESULTS

From the SA1 area results, which were validated with CitiPower energy consumption data where relevant (see Section 3.2.1), we then distributed the end-use energy to each block as expressed in Equation (2). This is very similar to Equation (1), except that in Equation (2), we summed up the energy of building types in any block, rather than in any SA1 area, based on the distribution of floor area for each building type in the whole block:

Total energy consumption in a block = (2)

$$\sum_{Building\ types\ in\ the\ block} \text{Floor area for a building type in the block X Energy intensity (per m2) for the building type}$$

Results were then mapped based on a GIS block layer, which we simply derived by performing GIS intersection of all paved roads within the study area. As noted earlier, this approach missed some of the important boundaries such as those for nature reserves, water bodies and other non-building related areas. A more accurate GIS block layer is needed. (See Section 2.2 for other mapping notes).

3 Baseline energy and BAU forecast scenarios

3.1 Introduction

In this Section we present the baseline energy consumption for the residential and commercial sectors in the four IMAP councils that were studied. The baseline year of 2011 matches the most recent ABS Census data set, supplemented with local Council data sets, and validated with electricity consumption data from CitiPower.

The 15-year BAU forecasts to 2026 from the 2011 baseline energy results are based on either: (a) council-wide development plans to 2026, or (b) highly simplified projections of building population growth, as described in Section 2.3.4. The City of Melbourne's BAU forecasts are based on the former, while those for the Cities of Port Phillip, Stonnington and Yarra are based on the latter.

The main mapping results presented herein are:

- the four IMAP councils' 2011 baseline energy consumption values and distribution
- the City of Melbourne's projected development plans and BAU forecasts of energy consumption to 2016, 2021 and 2026.

Spatial energy mapping for the BAU case is meaningful only for the City of Melbourne; it is not meaningful for Port Phillip, Stonnington and Yarra because we did not have their council-wide development plans to 2026, and thus, excluded. Only aggregate energy consumption values for the latter three councils are plotted to 2026. Supplementary maps are given in Appendix C.

3.2 Baseline energy consumption 2011

3.2.1 VALIDATION

The electricity supply in the study area is provided by a number of distribution network service providers, but the primary supplier is CitiPower (Figure 5).

We developed a method for validating modelled energy demand against the electricity supply data in matching locations, as provided by CitiPower. This included a map outlining the boundaries relating to the geographical coverage of each zone substation (see Figure 6) and a corresponding database detailing half-hourly energy consumption for a given year.

The total electricity supplied by Citipower into the areas identified in Figures 5 and 6 in 2011 was 4,524 GWh via 21 zone substations (note that this does not constitute the whole study area). However, a breakdown of energy consumed by commercial, residential and industrial customers on a per substation level is not available. However, CitiPower indicated that about 4% of the total usage in its service territory is for industrial consumption. This leaves a total of 4,343 GWh for commercial and residential customers. Compared to the sum of simulated energy consumption (3,912 GWh as shown in Table 3), the modelling results under-estimated CitiPower's actual data by 9.93% (calculated as: [model – actual]/[actual] x 100%). Generally, a deviation of +/- 10% is considered very satisfactory for studies of this kind.

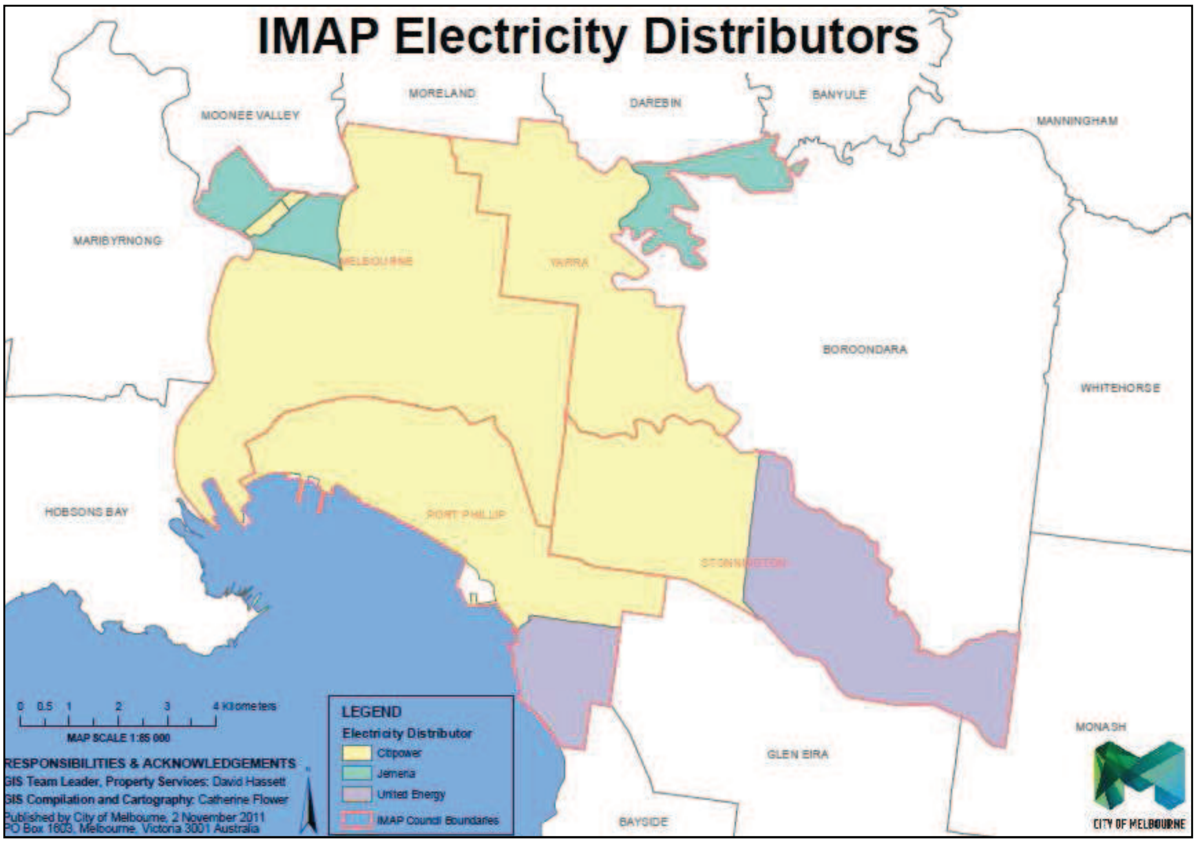


Figure 5: Electricity distributors of IMAP councils (Courtesy of City of Melbourne)

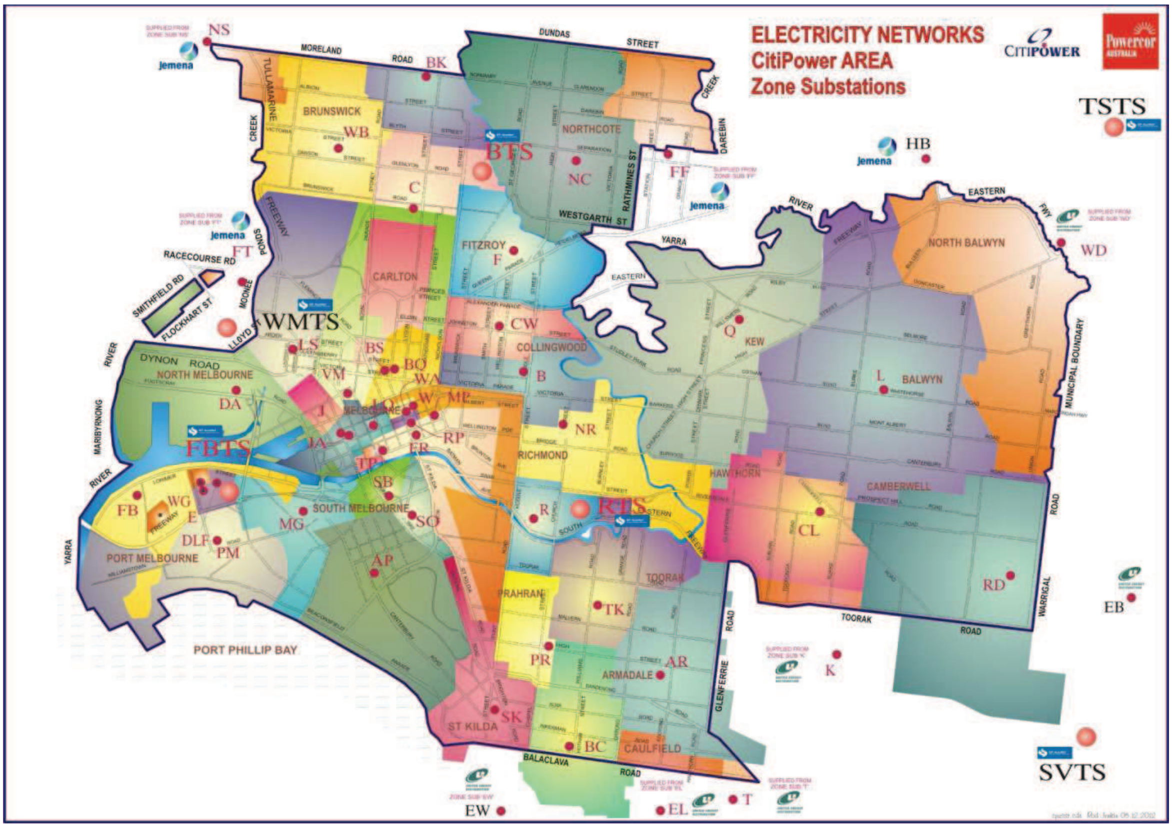


Figure 6: CitiPower zone sub-station approximate geographical coverage area (Courtesy CitiPower)

Table 4: Modelled electricity consumption Data in CitiPower's electricity supply area within the study area

	Modeled electricity consumption (GWh)	CitiPower supplied (actual) (GWh)	Error % of modeled consumption against actual
Commercial building energy demand (modelled) in CitiPower supply area	3,579		
Residential building electricity demand (modelled) in CitiPower supply area	333		
Total	3,912	4,343	-9.93%

It should be noted that the notion of geographical boundaries representing the coverage of zone substations was only an approximation. Any zone substation could be feeding to an adjacent area dependent on the increase in load over time (e.g., cross-feeders). The best example is the 'DLF' zone substation in Fishermans Bend. This zone substation also supplies electricity to Federation Square and Crown Casino, among others. In these instances, it is difficult to determine the extent of cross-feeding and apportion the load to a particular zone substation. Accordingly, it was not possible to accurately assess the accuracy of the modeled electricity consumption against the electricity supply data provided at a zone substation level.

In order to gain confidence over the finer scale of the modelling, a limited parcel level validation was undertaken using actual electricity and natural gas consumption data in the baseline year 2011 at the Royal Woman's Hospital, the Royal Melbourne Hospital and the Royal Children's Hospital (collectively called herein the "Melbourne Hospitals"). These hospitals have some of the highest intensity energy consumption within the City of Melbourne. Together, their total energy consumption in 2011 was 138,056 MWh.

Figure 7 shows the location and energy modelling results for these three hospitals. The simulation modelling results shown have been calculated based on the energy intensity data for the hospital typology in Table 2 from modelling (Section 2.3.3); thus, in this case, the differences in the three hospitals' modelled results are based only on different floor areas. The sum of 124,361 MWh for the three hospitals is compared to the combined actual 2011 consumption of 138,056 MWh sourced from the appropriate authority.

In this micro-validation case, the modelling results for the three hospitals under-estimated the actual data by 9.9% (calculated as: [model – actual]/[actual] x 100%). Considering the general modelling approach described earlier in Section 2.3.3, this deviation at the building/parcel level may be considered very good. Even if these results came from very detailed building energy modelling of these hospitals, which can be undertaken selectively for any "hot spot" area or location in the study area, this level of deviation from actual data can be considered acceptable. But specific or individual building energy modelling requires more detailed input data and more effort in constructing specific building models and usage scenarios.

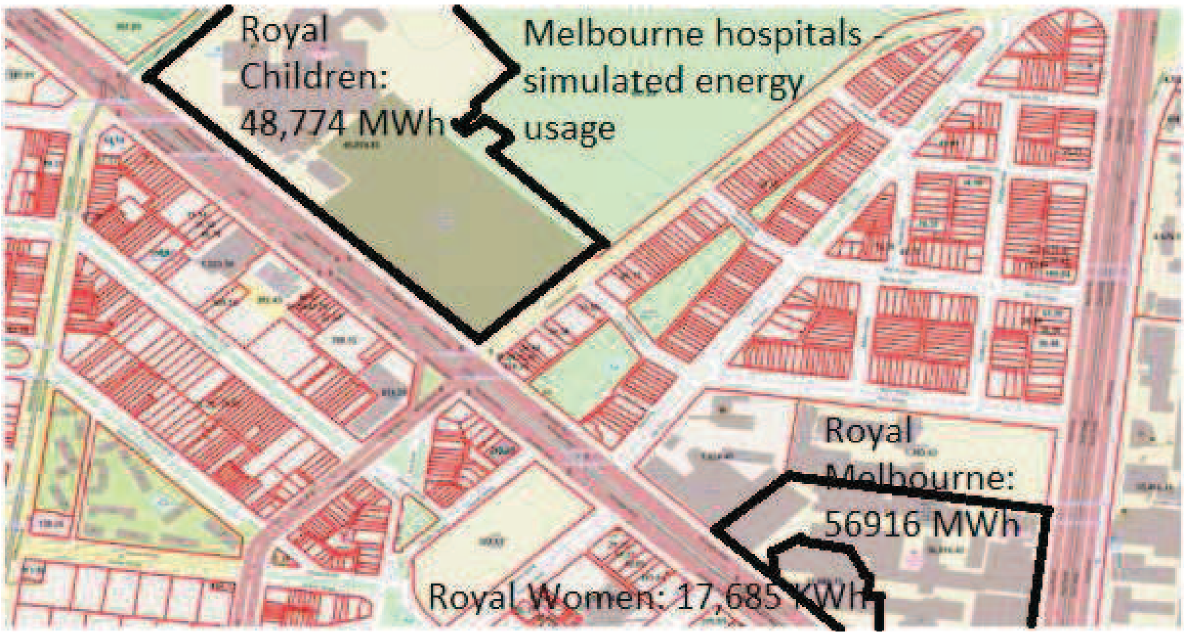


Figure 7: Micro-validation of building energy consumption in three hospitals in the City of Melbourne: modelling results total for the three hospitals is 124, 361 MWh while actual energy consumed in 2011 is 138,056 MWh

3.2.2 ENERGY CONSUMPTION RANGE AND DISTRIBUTION

To facilitate comparison across maps for different years and energy uses, the total energy consumption for a block is presented following the same or consistent concept of visualising energy demand changes over the lower and higher bands of a percentile-based classification (also known as the tails of a frequency distribution). This is illustrated in Figure 8, with a higher resolution 5-percentile increment at the highest and the lowest bands of the full range of energy consumption values (i.e. the lower and the upper 30th percentile) and a 10-percentile increment in the middle band, around the median (which is the 50th percentile).

Here's a description behind each map's classification:

- The City of Melbourne's total energy demand, retrofit and new-build options and commercial classifications are based on applying the percentiles presented on the right column in Fig. 8 over the Council's 2011 Baseline Energy Demand total (the values on the left being the resulting range).
- The City of Melbourne's residential energy demand is based on applying the percentile ranges on the right column of Fig. 8 over the Council's 2011 residential energy demand (thus, resulting on different ranges of energy consumption bands on the left).
- The total IMAP residential, commercial and combined energy demand classification are based on applying the percentiles presented in Fig. 8 over the IMAP areas' 2011 baseline total estimates (thus, also resulting on different ranges of energy consumption bands on the left).

There are alternative ways of visualising the spatial distribution of energy consumption of baseline and different future scenario cases. The final choice will depend on the primary questions that need to be addressed. To serve different purposes, the main sets of data resulting from building stock modelling may need further processing before any GIS mapping.

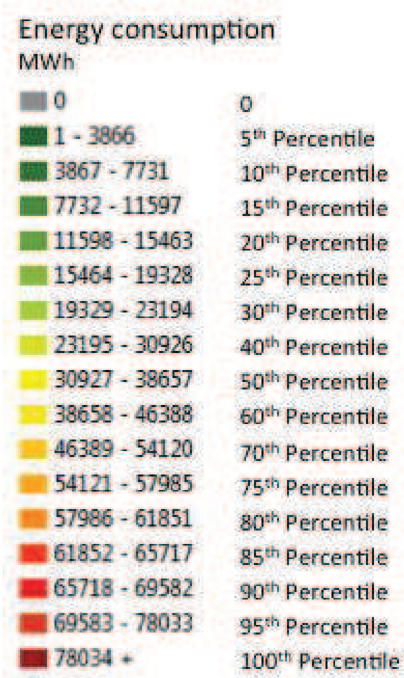


Figure 8: Example of an energy consumption band classification for spatial energy use mapping at block level, based on percentiles (right column) with a higher resolution at the tails of the distribution (i.e. 5-percentile increments at the highest and the lowest bands)

3.2.3 BASELINE ENERGY MAPS (2011)

In this section, we present the 2011 baseline energy maps for all the studied Councils: Residential (Figure 9), Commercial (Figure 10) and Total (Residential and Commercial) (Figure 11 and Figure 12).

The comparative totals and proportions of residential vs. commercial are shown in Figure 12.

Separate Council maps of 2011 baseline energy consumption are presented in Appendix C.

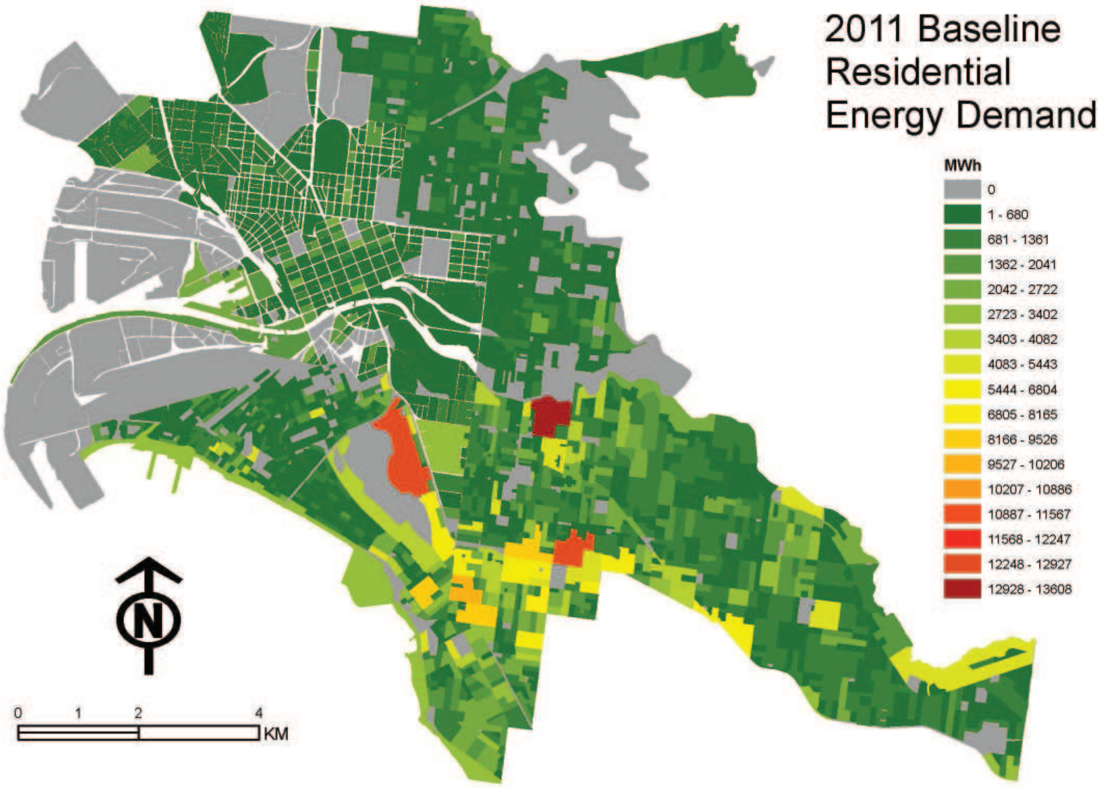


Figure 9: Residential energy consumption by block in the baseline year 2011

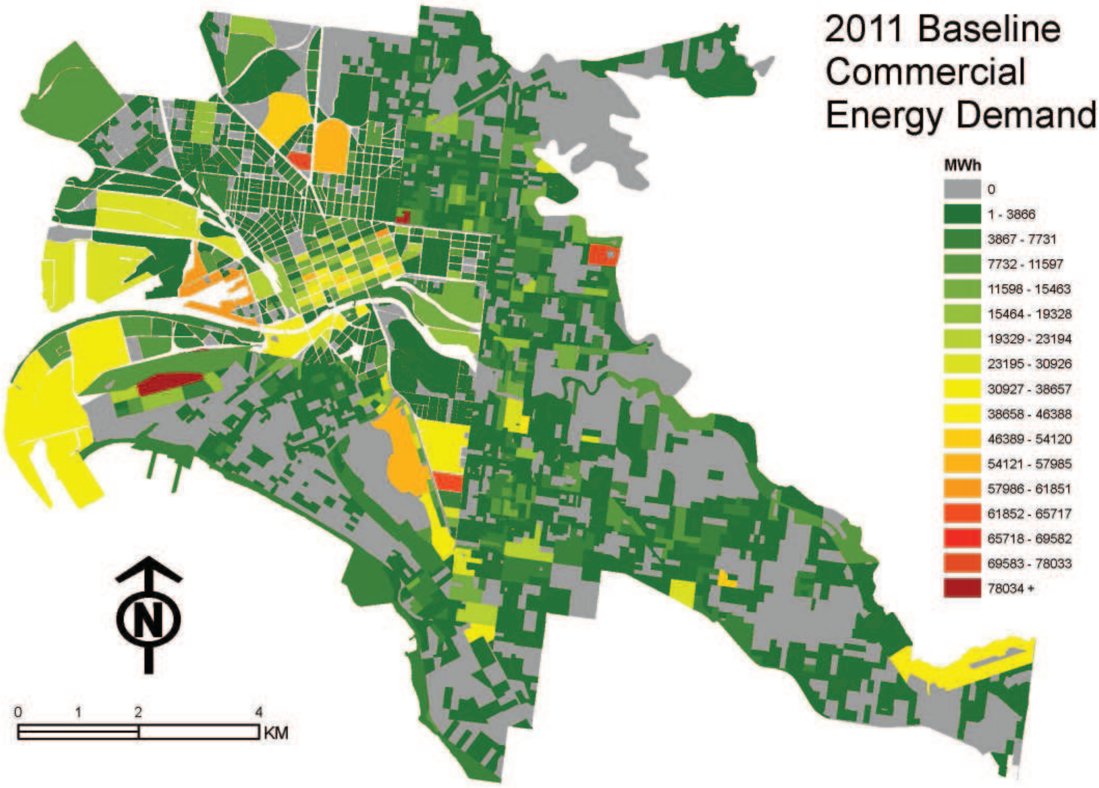


Figure 10: Commercial energy consumption by block in the baseline year 2011

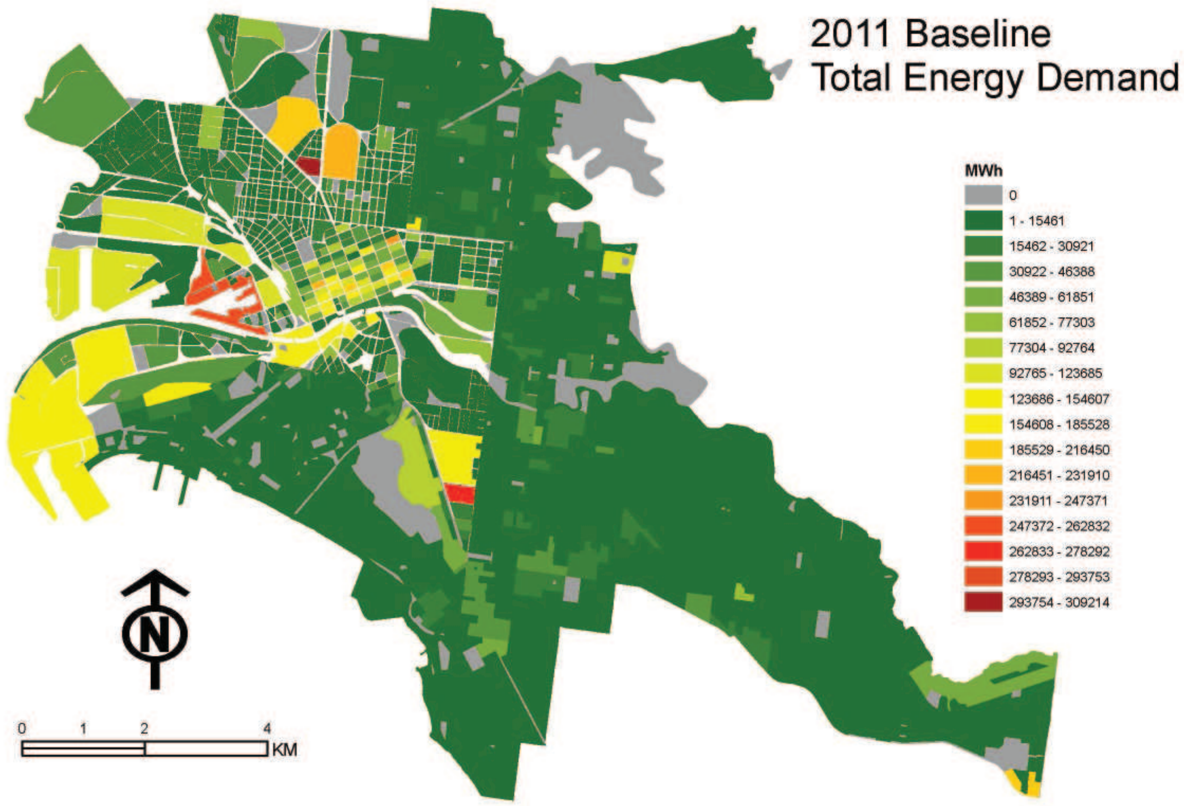


Figure 11: Total (Residential + Commercial) energy consumption by block in the baseline year 2011

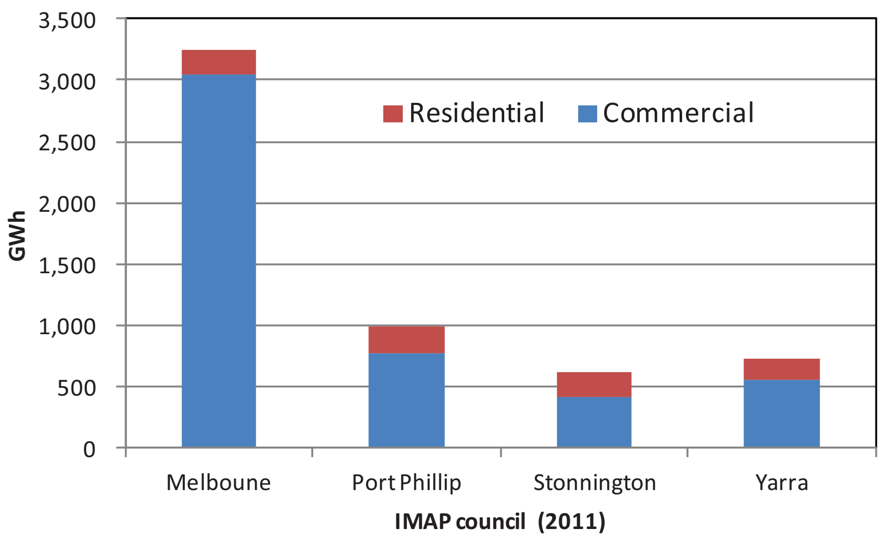


Figure 12: Total (Residential + Commercial) energy consumption by council in the baseline year 2011

3.2.4 ILLUSTRATIVE ANALYSIS OF RESULTS

The current results, especially the 2011 baseline set, can be used to identify hotspots for energy use by:

- Location
- Building type
- End-use category

For example, the 2011 baseline energy use distribution by end-use categories for commercial buildings can be mapped as shown in Figure 13. Modelling and simulation results using our approach and the eQUEST tool already provide these data sets at SA1 level and so they are mapped in Figure 13 at block level using the same approach as in the previous sub-sections. Individual Councils can then undertake more detailed geographic information analysis energy end-use categories for specific building types (Appendix B).

For another example, the 2011 baseline energy daily usage profiles for residential buildings are plotted as shown in Figure 14 for each Council. This is possible because the AusZEH tool's analysis output is available at set intervals (i.e. hourly). Detailed analysis of these patterns is not part of the present study.

These two examples demonstrate new ways of analysing the spatial and temporal energy use at various levels to meet specific objectives.

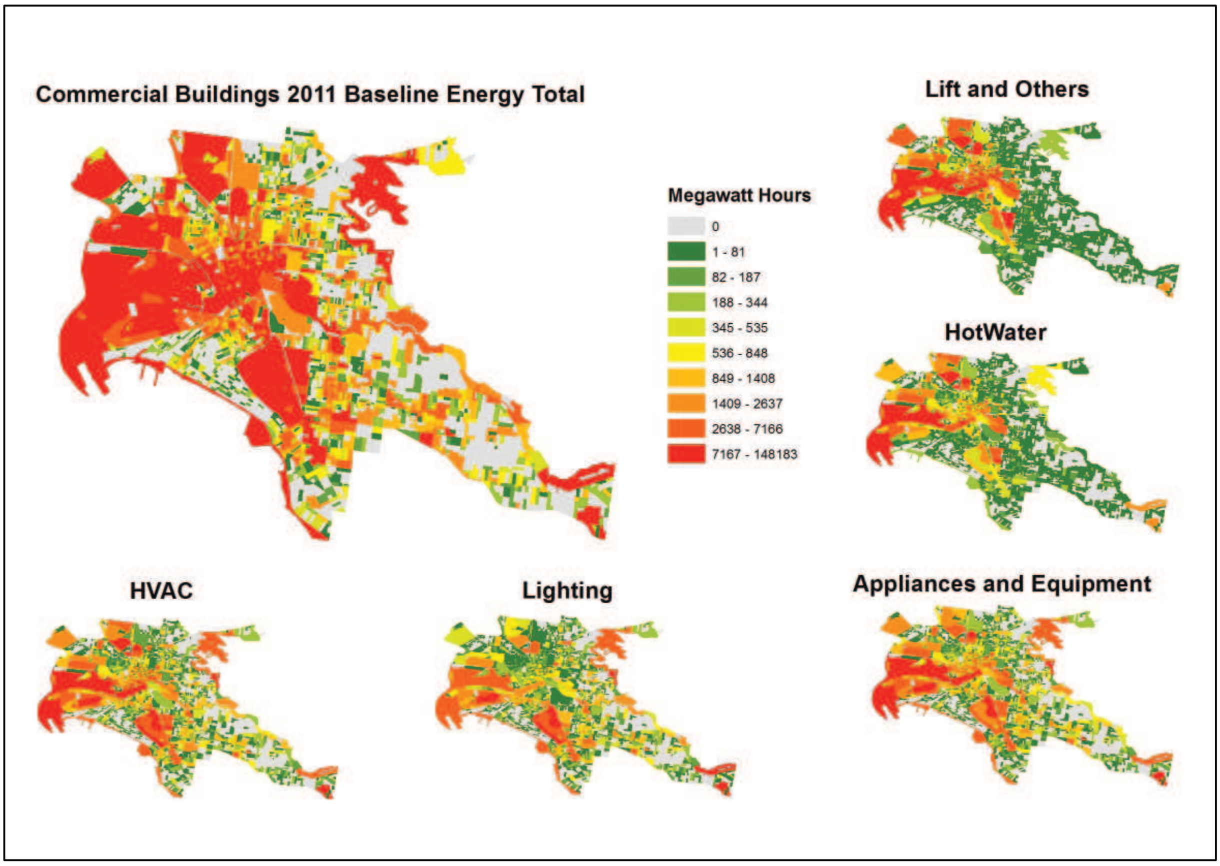


Figure 13: Total commercial building energy consumption in the IMAP area by end-use category in 2011

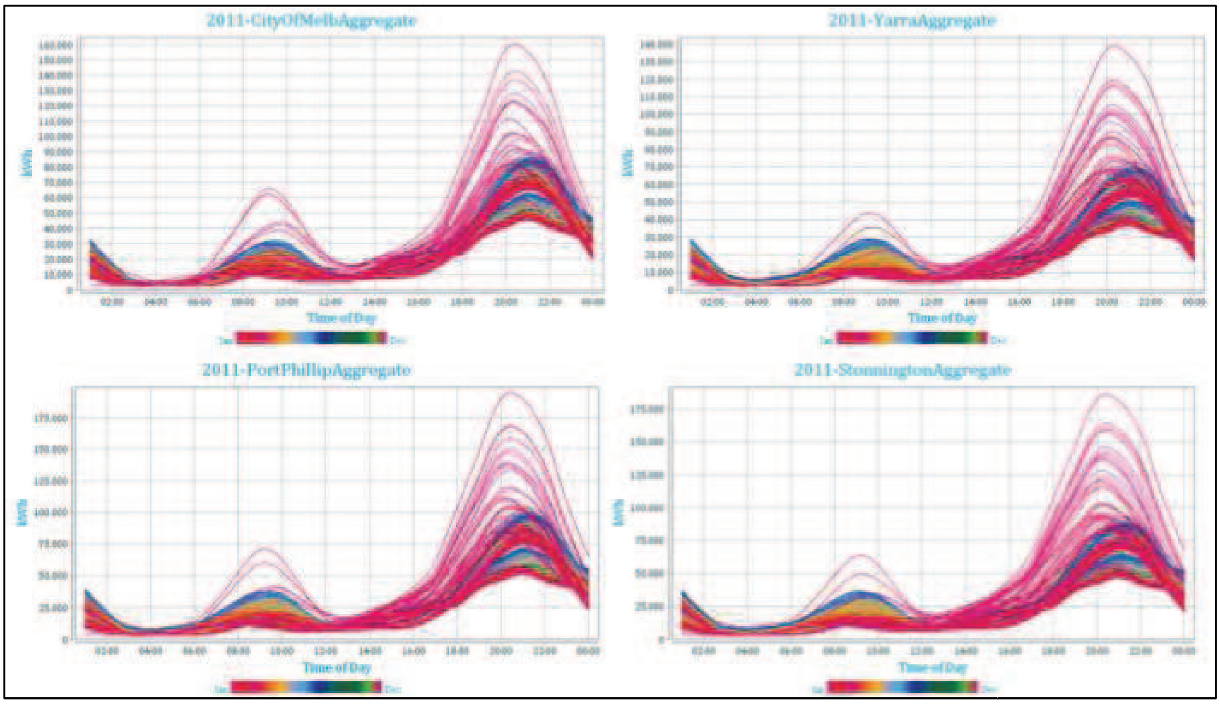


Figure 14: Residential building energy 24-hour consumption profile by Council in 2011

3.3 BAU forecast scenario to 2026

The following tables, figures and charts present the 15-year BAU forecasts to 2026 from the 2011 baseline energy results based on council-wide development plans to 2026 for the City of Melbourne, as shown in Figure 15, and on simplified and evenly distributed projections of building population growth, as described in Section 2.3.4, for the Cities of Port Phillip, Stonnington and Yarra. This means that spatial energy mapping for the BAU case is meaningful only for the City of Melbourne.

The BAU approach with the three other Councils, in the absence of council-wide development plans to 2026, means that the change in energy demand values and spatial distribution would not change significantly because the growth is spread to every block that has properties. And If there was no initial development in a block in the base year, there would be no future development growth in later years. Thus, spatial mapping of energy consumption is not meaningful. Only aggregate energy consumption values are plotted and compared to 2026 for the other three councils.

In all cases, the BAU forecasts did not include potential energy efficiency improvements; these are explicitly considered in the retrofit and new-build forecasts (Section 4).

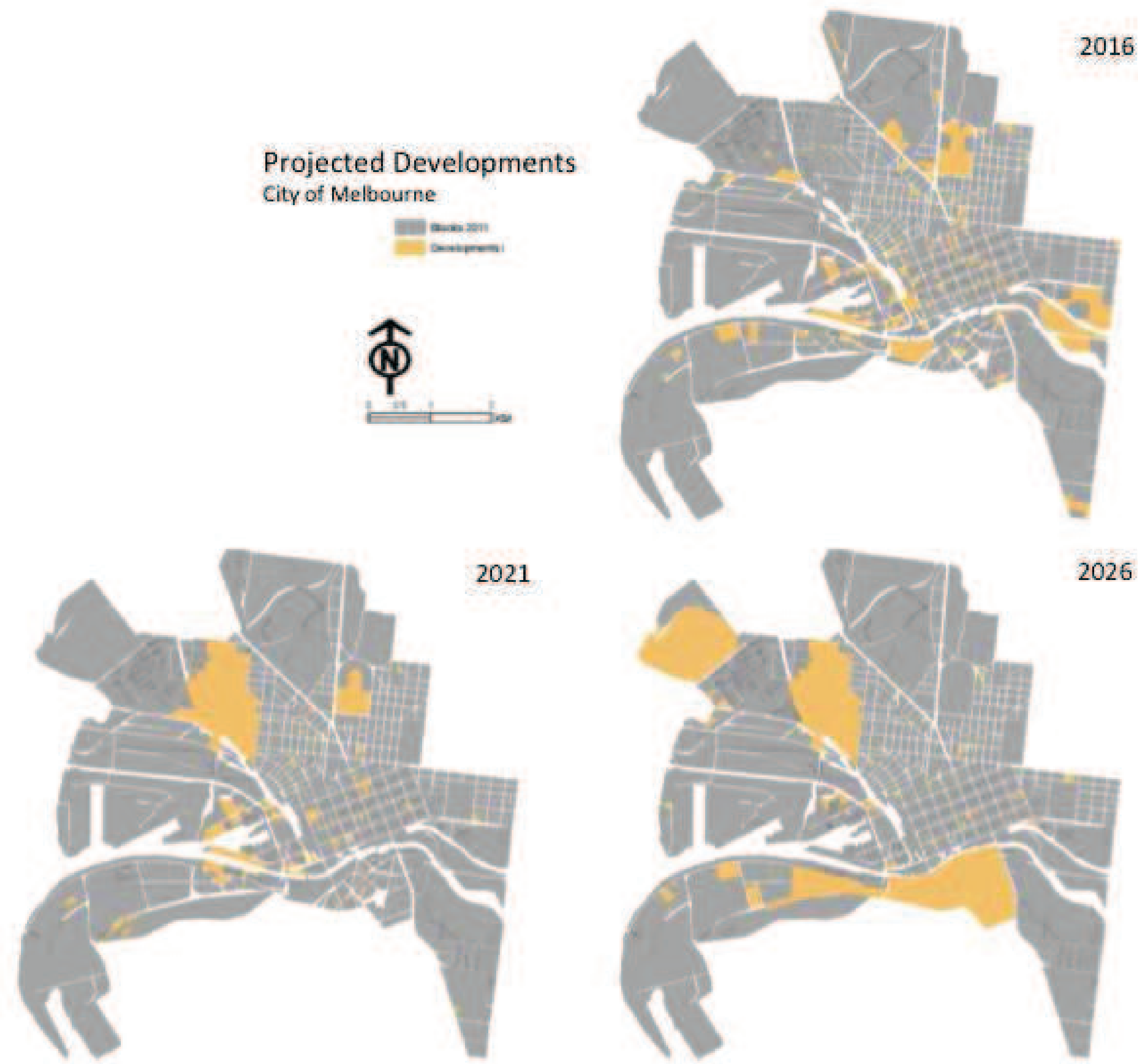


Figure 15: Projected development areas in the City of Melbourne in 2016 (top right), 2021 (bottom left) and 2026 (bottom right)

3.3.1 RESIDENTIAL BUILDINGS

Considering the BAU case for the City of Melbourne, the starting point is the 2011 baseline residential energy demand shown in Figure 16 (and extracted from Figure 9, noting the change in the energy consumption band values between the two figures because the of the percentile-based classification as discussed in Section 3.2.2).

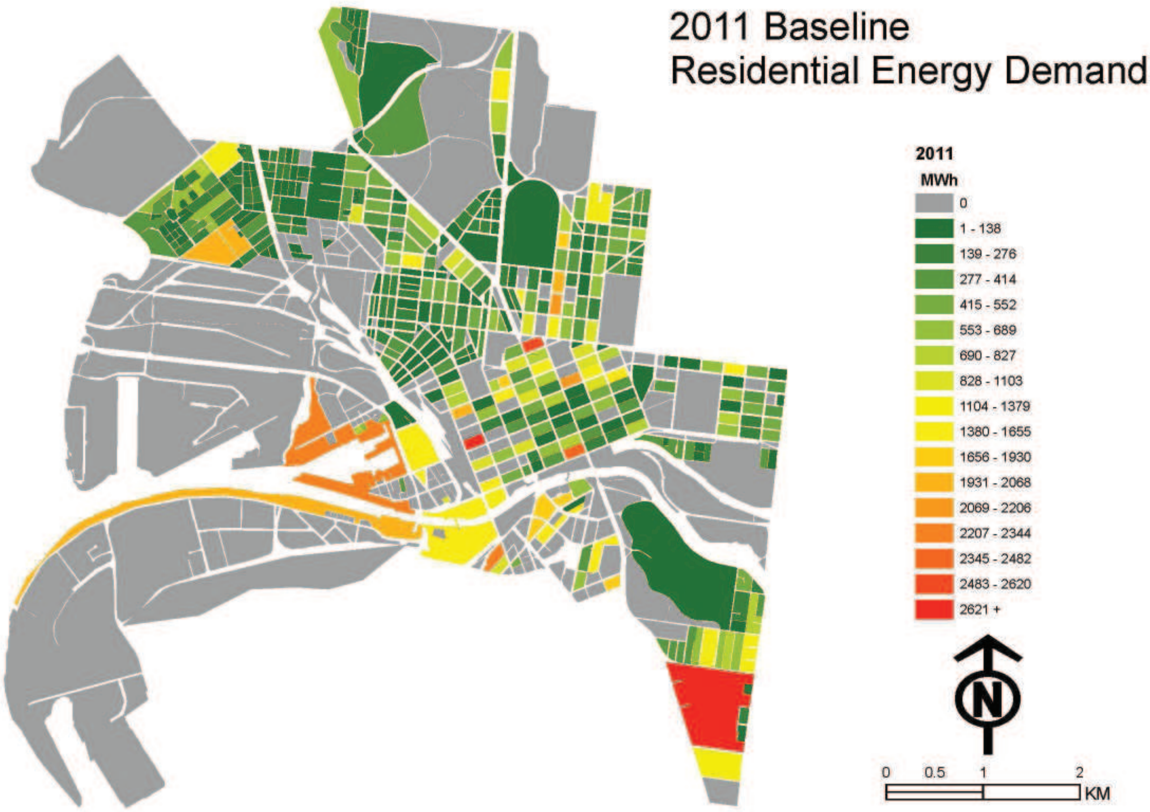


Figure 16: Spatial distribution of 2011 baseline residential energy consumption by block in the City of Melbourne

On the basis of the projected development plans in Figure 15, and with further details and consideration of likely dwelling types and residential household trends in these development areas, we calculated the BAU forecasts to 2026, as shown in Figure 17. Note that Figures 16 and 17 have the same energy band classification (and colour) schemes; thus, with this series of maps the evolution of residential energy consumption in the City of Melbourne from 2011 to 2026 can be easily gleaned.

Then Table 5 and Figure 18 how the BAU residential forecasts in the combined study area (all four Councils) to 2026. The bar charts are further broken down to reveal the relative distribution of growth by dwelling type.

Table 5: Residential energy consumption by Council in years 2011, 2016, 2021 and 2026

	Residential energy consumption (GWh)				**Growth rate base year 2011=100%**			
	2011	2016	2021	2026	2011	2016	2021	2026
Melbourne	**194.8**	**311.4**	**391.0**	**511.4**	100.00%	160%	201%	262%
Port Phillip	**225.0**	239.9	253.5	265.2	100.00%	107%	113%	118%
Stonnington	**209.8**	239.8	251.5	264.0	100.00%	114%	120%	126%
Yarra	**163.6**	189.3	207.7	224.8	100.00%	116%	127%	137%

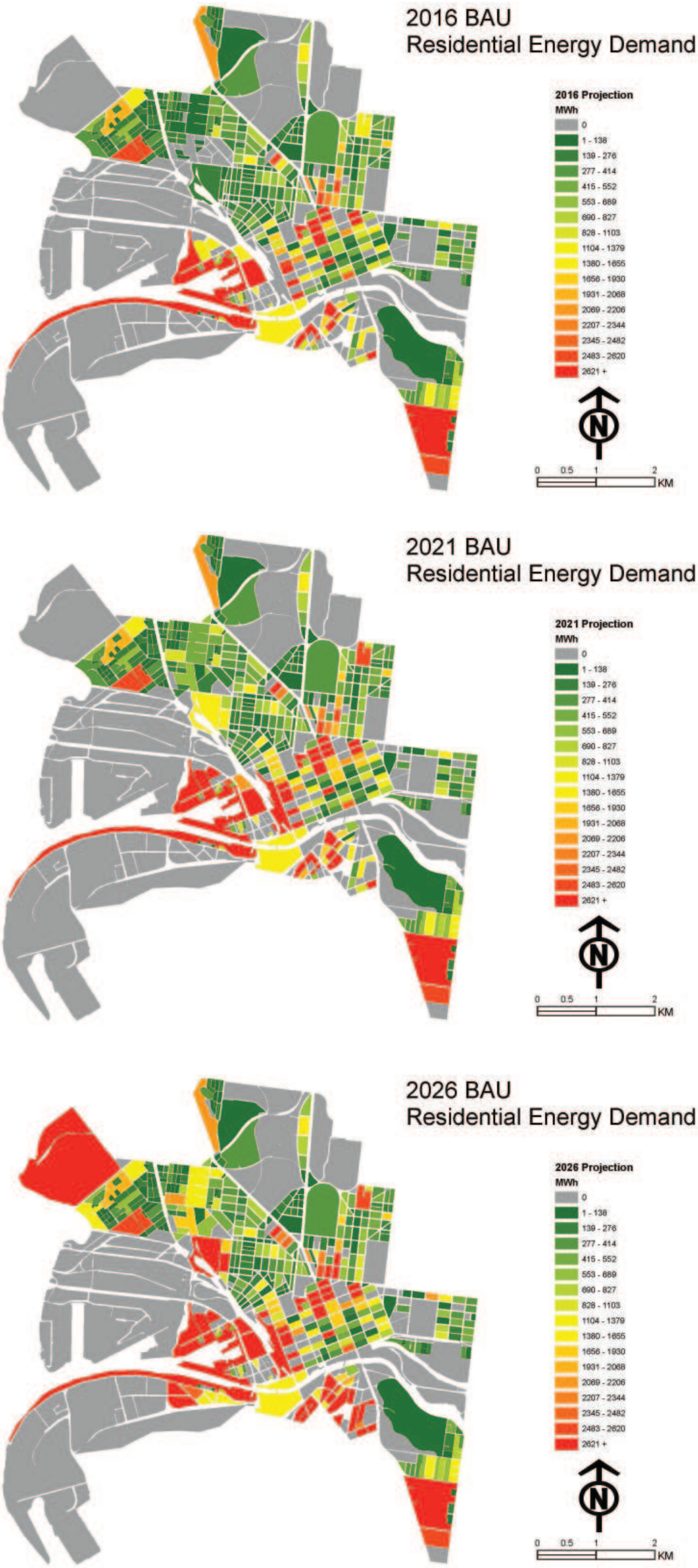


Figure 17: Projected BAU residential energy consumption by block in the years 2016, 2021 and 2026 in the City of Melbourne

Figure 18: Residential energy consumption forecast based on the BAU case by dwelling type in each Council to 2026

3.3.2 COMMERCIAL BUILDINGS

In a similar fashion, the starting point for the BAU commercial energy demand forecast is the 2011 baseline commercial energy demand shown in Figure 19 (and extracted from Figure 10, noting the change in the energy consumption band values between the two figures because of the percentile-based classification as discussed in Section 3.2.2).

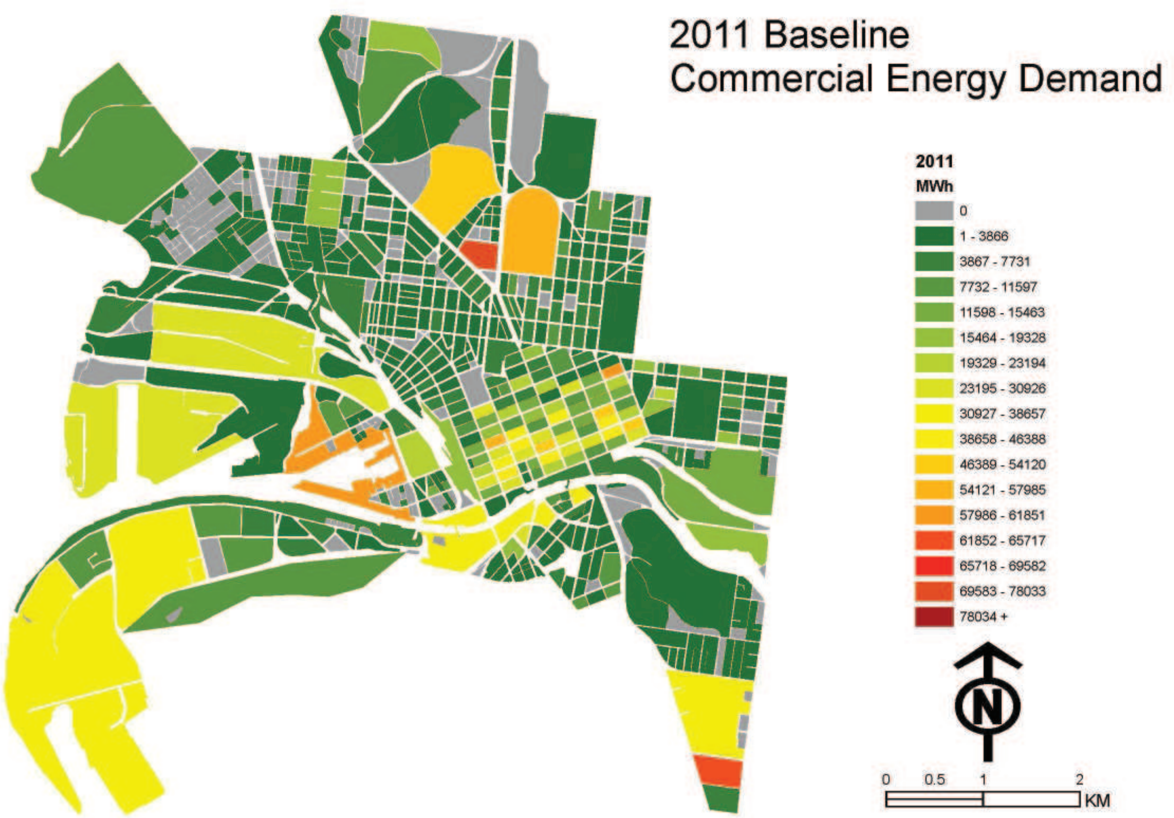
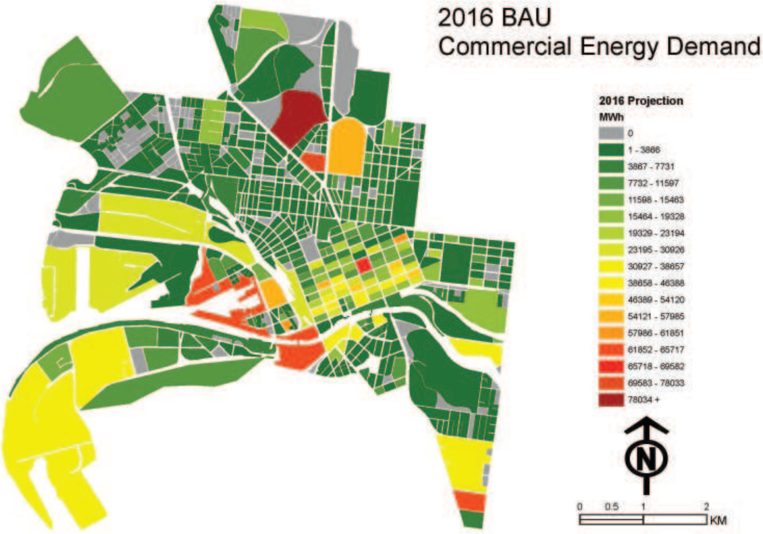
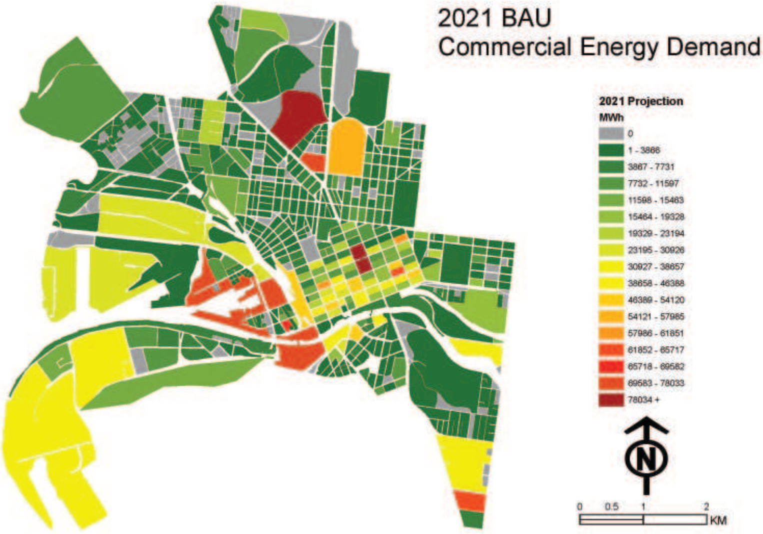


Figure 19: Spatial distribution of 2011 baseline commercial energy consumption by block in the City of Melbourne

On the basis of the projected development plans in Figure 15, and with further details and consideration of likely commercial building types and related trends in these development areas, we calculated the BAU forecasts to 2026, as shown in Figure 20. Note that Figures 19 and 20 have the same energy band classification (and colour) schemes; thus, with this series of maps the evolution of commercial energy consumption from 2011 to 2026 in the City of Melbourne can be easily gleaned.

Then Table 6 and Figure 21 show the BAU commercial forecasts in the combined study area (all four Councils) to 2026. The bar charts are further broken down to reveal the relative distribution of growth by commercial building type in each Council.





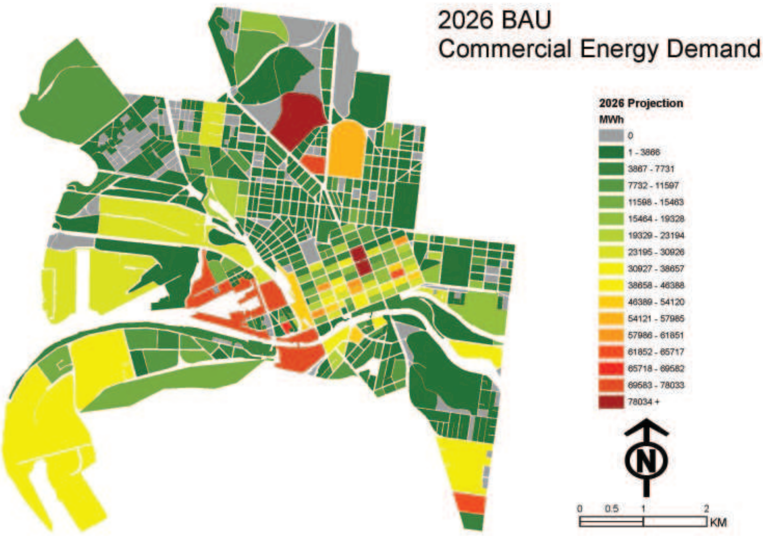
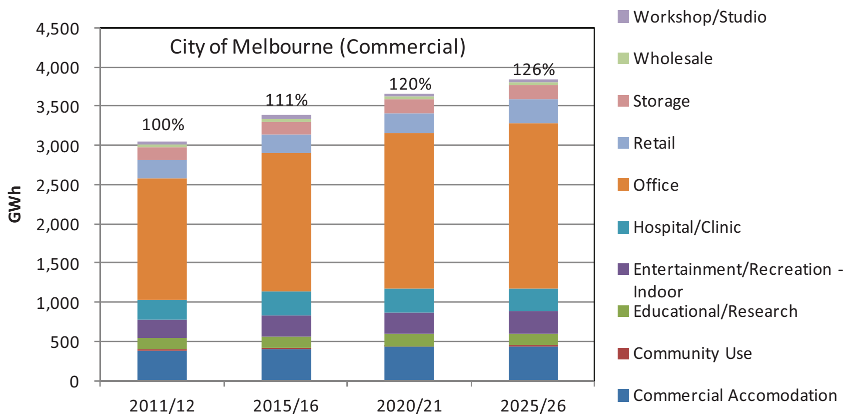
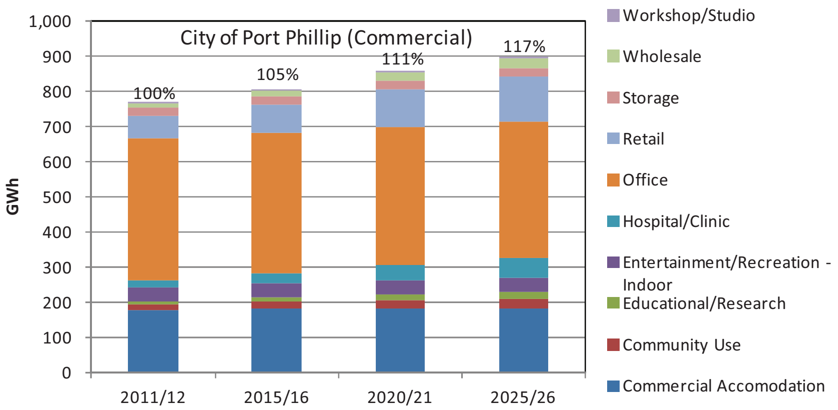


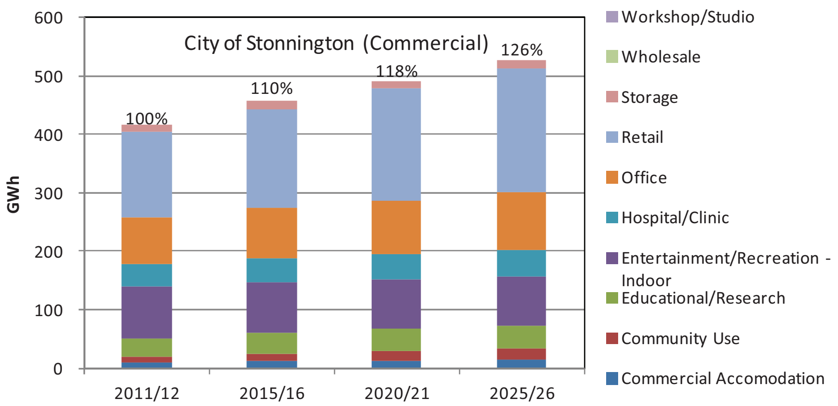
Figure 20: Projected BAU commercial energy consumption by block in the years 2016, 2021 and 2026 in the City of Melbourne

Table 6: Commercial energy consumption by Council in years 2011, 2016, 2021 and 2026

	Commercial energy consumption (GWh)				Growth rate 2011/12=100%			
	2011/12	2015/16	2020/21	2025/26	2011/12	2015/16	2020/21	2025/26
Melbourne	3047.5	3382.3	3661.0	3846.0	100%	111%	120%	126%
Port Phillip	770.4	807.4	858.0	897.7	100%	105%	111%	117%
Stonnington	416.1	455.8	491.6	525.7	100%	110%	118%	126%
Yarra	564.5	639.7	705.8	769.0	100%	113%	125%	136%
Total	4798	5351	5882	6340	100%	112%	123%	132%







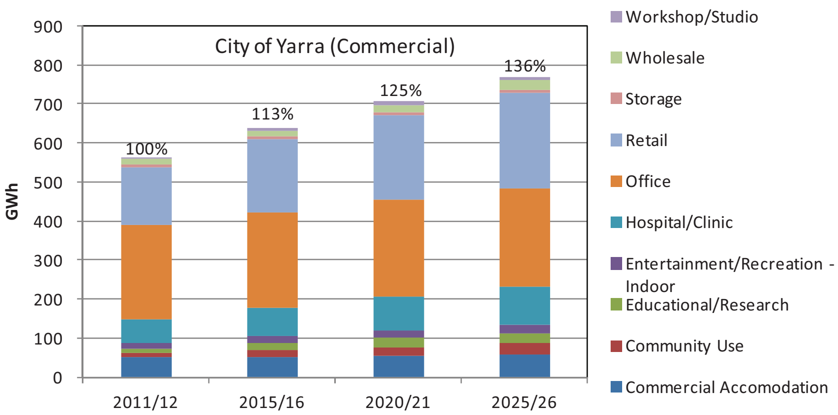


Figure 21: Commercial energy consumption forecast based on BAU trends by commercial building type in each Council to 2026

3.3.3 COMBINED BUILDING STOCK

Combining the energy consumption in residential and commercial building stock within the City of Melbourne, given the projected council-wide development plans in Figure 15, the BAU forecasts to 2026 from the 2011 baseline (Figure 22) are shown in Figure 23.

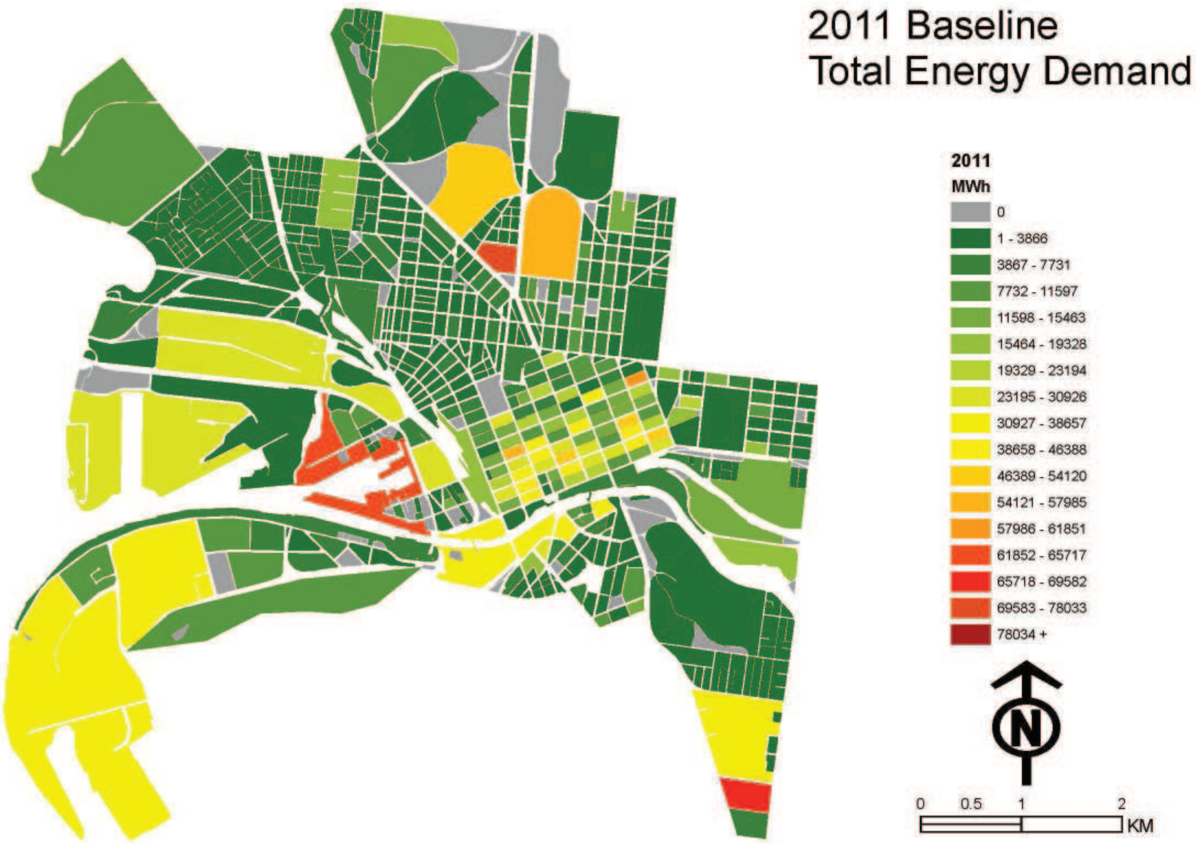


Figure 22: Spatial distribution of 2011 baseline energy consumption in commercial and residential buildings, mapped by block, in the City of Melbourne

Then Table 6 and Figure 24 show the BAU commercial forecasts in the combined study area (all four Councils) to 2026. The bar charts are further broken down to reveal the relative distribution of growth by building type in each Council.

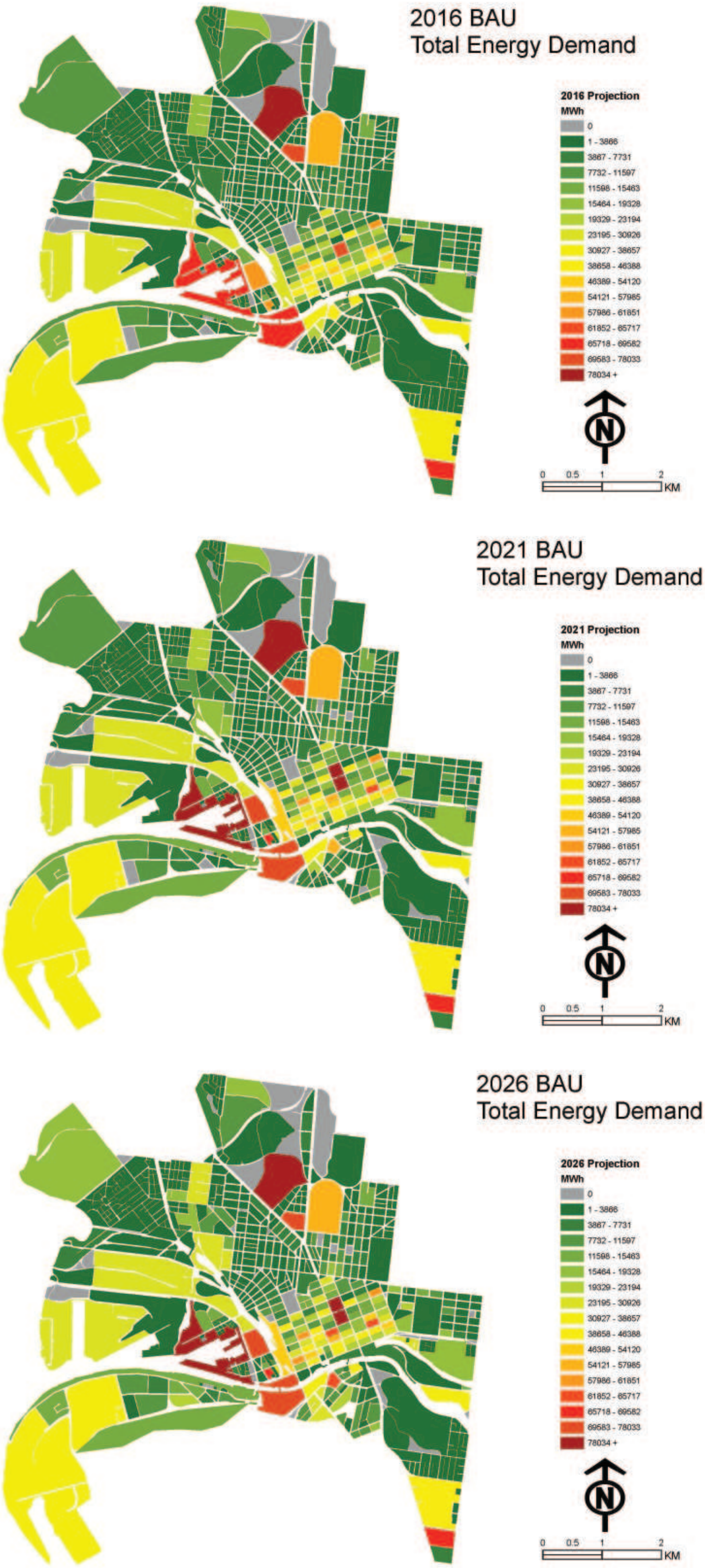
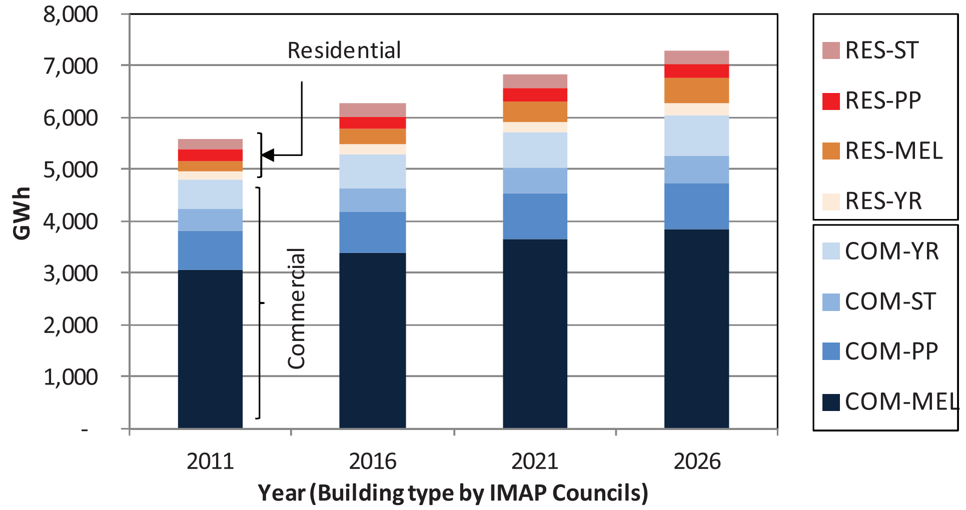


Figure 23: Projected BAU commercial and residential building energy consumption, mapped by block, in the years 2016, 2021 and 2026 in the City of Melbourne

Table 7: Total residential and commercial energy consumption by Council in years 2011, 2016, 2021 and 2026

	Total (residential + commercial) energy consumption (GWh)				Growth rate base year 2011=100%			
	2011/12	**2015/16**	**2020/21**	**2025/26**	**2011/12**	**2015/16**	**2020/21**	**2025/26**
Melbourne	3,242.3	3693.7	4052.0	4357.5	100%	114%	131%	134%
Port Phillip	995.3	1,047.3	1,111.5	1,162.9	100%	105%	112%	117%
Stonnington	625.9	695.7	743.1	789.7	100%	111%	119%	126%
Yarra	728.2	828.9	913.5	993.8	100%	114%	125%	136%
Total	5,591.7	6,269.8	6,885.6	7,428.7	100%	112%	123%	133%



Notes: Type- RES: Residential, COM: Commercial
Council- ST: Stonington, PP: Port Phillip, MEL: Melbourne, YR: Yarra

Figure 24: Total building energy consumption forecast based on BAU trends by building type and by Council to 2026

4 Retrofit and New-Build Forecasts to 2026

4.1 Overview

Many factors can influence and impact the energy consumption landscape in IMAP to 2026. The demand for grid-supplied energy will be affected by:

- The range and effectiveness of various energy efficiency measures (**demand-side** factors);
- The incorporation and effectiveness of on-site renewable energy generation systems (**supply-side** factors); and
- The **adoption** or **uptake** rate by residential and by commercial building stakeholders of one or both of these types of measures.

These measures can be implemented through:

- voluntary, or
- regulatory/mandatory means,

and applied to:

- the **existing** building stock, through various levels of retrofit measures; and/or
- **new** buildings and developments.

This section presents the types and combinations of the above-mentioned factors that have been considered in forecasting the future energy consumption patterns in the IMAP study area to 2026. The five-yearly forecast estimates from the 2011 baseline to 2026 parallel the analysis undertaken for the BAU case that has been presented in the previous section.

As in the previous section, since we did not have the council-wide development plans to 2026 for the Cities of Port Phillip, Stonnington and Yarra, only the trends in aggregate energy consumption values are presented along with those from the City of Melbourne. The spatial distribution of energy consumption for selected combinations of future retrofit and new-build scenarios in Melbourne is also presented.

To aid the viewing of all the scenarios considered, a web-based IMAP energy map viewer is provided separately. Conversely, this report, and this section in particular, provides the background details and explanations of the data shown in the web-based viewer.

4.2 Possible intervention schemes

The variety and range of possible alternative interventions and scenarios settings for analyses are reproduced from Foliente and Seo (2012), and given in Table 8 and Table 9. A council's or a single agency/stakeholder's action can be analysed alone or in combination with cooperative actions or policy instruments by others (see the bottom row in Table 8 and Table 9).

Table 8: A typology of policy instruments and intervention schemes for GHG emission reductions in buildings (from Foliente and Seo [2012], adapted from the concept in UNEP [2007]).

Simplified type	**Sticks**	**Carrots**	**Tambourines**
Brief description	Mandatory, legal or regulatory schemes, including mandatory	Benefits-based schemes, whether financial or non-	Advocacy, awareness and education, including any programs that influence

	financial schemes[1]	financial (not mandatory[2])	behaviours (not mandatory[2])
Examples	• Building codes • Planning regulations • Procurement regulations • Appliance and equipment standards • Mandatory certification and disclosure programs • Taxation and levies • Banned product(s)	• Rebates and incentives • Tax exemptions or reductions • Capital subsidies and grants, loan subsidies • Energy efficiency certificate schemes	• Energy efficiency information campaigns • Voluntary certification and labelling • Voluntary disclosure programs • Professional and trades education and training programs
Stakeholders (primary actors)	• Government	• Government • Financial institutions • Utility industry • Building and property industry • Investors	• Government • Industry • Individual firms • Education and training institutions • NGOs • Consumers and community organizations

[1]Mandatory financial schemes are included in this type because failure to comply is subject to specific legal or other formal consequences from relevant government authorities.
[2]In non-mandatory or voluntary schemes, failure to follow or adopt has no legal consequences.

Table 9: A typology of energy demand/consumption and supply systems that determine associated GHG emissions in a building (from Foliente and Seo [2012])

	Energy demand			
Typology classes	**Physical building**	**Energy 'load'**	**Occupancy or use profile**	**Energy supply**
Description	• Location and climate zone • Age or year built (and year of last major renovation or refurbishment) • Physical characteristics and properties of building (main construction type, features of building envelope, etc.) • Energy efficiency rating	• Heating, ventilation & air-conditioning (HVAC) system • Hot water system • Lighting • All 'built-in' and 'plug-in' or 'pluggable' appliances and equipment; energy rating • Other equipment (e.g. lifts)	• Type of use or occupancy • Occupancy and operating pattern (e.g. hours of operation) • Number of occupants • Socio-demographic profile of occupants	• Energy supply mix by type (electricity, gas, diesel, renewables, etc.) and source (grid, district or 'near-site' or on-site etc.) • Nature/type, size and age of low- or zero-emission energy source(s)
Stakeholders (primary actors)	• Government • Industry • Professionals • Clients/owners • Investors	• Government • Utility firms • Building and property industry • Clients or owners • Facility managers • Tenants	• Owners • Facility managers • Tenants	• Clients or owners • Investors • Utility firms

As noted earlier, CSIRO has developed a structured cross-typology approach that enables different stakeholders (e.g. policy makers, property portfolio owners, utility companies and building tenants) to assess the impacts of their specific actions or decisions (Table 8), considering a range of typologies of buildings (by type, age and function), appliances, lighting system, heating and cooling systems, occupancy patterns and energy supply systems (Table 9). This is achieved using physics-based building energy simulation models for residential and commercial buildings (Foliente and Seo 2012, Ren et al. 2012 and Grozev et al. 2013) and a novel integration of spatial diffusion and choice modelling with multi-criteria analysis (Higgins et al. 2011, Higgins and Foliente 2013, Higgins et al. 2013 and Higgins et al. 2014). With this cross-typology approach, it would be possible to investigate the impacts of a wide range of combination of factors and actions in Tables 8 and 9, alone or in combination.

In the present study, however, we are employing a simpler approach of projecting the future impact of a selected combination of factors and settings on the energy consumption in the IMAP study area. The efficiency or grid-energy reduction effects of demand-side and supply-side factors are applied directly to the BAU forecasts presented in the previous section. The selected measures discussed and agreed with IMAP stakeholders are described next.

4.3 Selected scenario settings

4.3.1 RETROFIT

The range of "retrofit" options in the present study includes both demand-side and supply-side options of reducing grid-supplied energy, termed herein as "energy efficiency" and "on-site generation", respectively.

Energy efficiency intervention schemes are classified into three: "Minor", "Moderate" and "Major". A minor intervention scheme is one that is relatively easy to implement for residential and commercial buildings such as "tuning" of the building performance and/or replacing lighting systems with more energy efficient alternatives. A major intervention scheme is one that requires major effort and thus, more cost such as chiller replacement, upgrade of lifts, water heating system replacement, etc, in addition to the other measures already included in the moderate and minor schemes. A moderate scheme sits between the minor and major schemes. Depending on the level of intervention scheme, various solar energy uptake rates are also considered.

Table 10 shows the specific energy efficiency measures that describe each intervention level for commercial and residential buildings. The major and moderate levels for residential buildings are further classified to common dwellings (e.g. single-detached, units and other medium-density-type housing) and apartments.

Table 10: Minor, moderate and major energy efficiency settings for commercial and residential retrofit scenarios

	Level of grid-energy reduction		Description of interventions included
Commercial	Minor		Minor interventions such as - Re-commissioning, management system etc; Examples: - Tuning-up, - Installation of lighting control; - Replacing CFL into LEDs and/or T12 into T5
	Moderate		Upgrade central plant, replace elevator & electric appliances & hot water heating + all the 'Minor' interventions above Examples: - HVAC chiller replacement; - Elevators & appliances; - Water heating
	Major		Upgrade central plant, waste energy reduction + 'Minor' & 'Moderate' interventions - Energy waste reduction
Residential	Minor		Metering Behavior change - Eliminating standby power - Water efficient showerheads - Less use cloth dryer etc Replacement of energy efficient appliances
	Moderate	Common Dwellings	Water heating Thermal insulation Replacing CFL into LEDs and/or T12 into T5 + all the 'Minor' interventions above
		Apartments	Water heating Car park lighting Replacing CFL into LEDs and/or T12 into T5 + all the 'Minor' interventions above
	Major	Common Dwellings	HVAC retrofit (New A/C, High efficient gas/electric heater etc) + all the 'Minor' & 'Moderate' interventions above
		Apartments	HVAC retrofit Common area elevators + all the 'Minor' & 'Moderate' interventions above

4.3.2 NEW-BUILD

For new residential buildings, future changes are based on improvements to current regulations. For example, the Building Code of Australia (BCA) energy performance requirement for new housing is a minimum of 6 stars (NatHERS) since 2010. This means that in the IMAP service area (i.e. in the Tullamarine climate zone), a new residential building's thermal envelope should meet an energy performance target of around 138 MJ/m^2/year (based on heating and cooling demand). A plausible future scenario is a further energy efficiency requirement like a 12.5% to 20% further reduction (uptake scenario A), or even a 15% to 50% further energy reduction (uptake scenario B) for new residential buildings.

For new commercial buildings, in the absence of a BCA minimum requirement, we use the local government's current requirements as the starting point. In many councils, a new office building is required

to have a NABERS Energy rating of 4 or 4.5 stars (NABERS, 2014[3]). The City of Melbourne requires at least a 5-star NABERS Rating for new office development having more than 2,000 square metres of gross floor area (Melbourne Planning Scheme Clause 22.19). Thus, in this case, we assume a 5-star requirement for all new commercial office buildings as the base case (current). As before, two future scenarios are considered: scenario A will require a moderate energy reduction from the current case (a 12.5% to 20% further energy reduction), and scenario B will have a higher energy reduction (a 15% to 50% further energy reduction).

The selected energy reduction requirements for new buildings (residential and commercial) are summarised in Table 11. Table 12 presents a summary of energy efficiency measures based on the City of Melbourne's planning scheme. .

Table 11: Projected minimum energy performance requirement for new residential & commercial building

	Scenario	2013	2016	2021	2026
Residential	A*	138 MJ (6 star)	121	117	110
	B**	138 MJ (6 star)	117	97	69
Commercial	A*	271 MJ (5 star)[4]	237	230	217
	B**	271 MJ (5 star)	230	190	136

*A: Moderate regulation (further energy reduction with 12.5% to 20% during 2016 to 2026 for current building code)
**B: Tough regulation (further energy reduction with 15% to 50% during 2016 to 2026 for current building code)

Table 12: Energy efficiency measures based on Melbourne's planning scheme[5]

		Current Energy efficiency measures	Note
Residential	House	Minimum 5 star (NaTHERS)	
	Semi-Detached	Stringency increased	Assumed the same as House
	APT	Stringency increased	
Commercial	Office	5 NABERS star	
	Retail	N/A	Assumed similar to Office
	Educational	5 points for Ene-1 credit under the GBCA's Green Star- Education.	
	Accommodation	5 star rating for Green Star – Multi Unit residential rating.	
	Others	N/A	

[3] NABERS (2014) Fact Sheet 2: How is NABERS being used?, retrieved from website (www.nabers.gov.au) on 22 May, 2014.
[4] Obtained from NABERS Energy for Office Reverse Calculator (v.10.0) with 50 hrs a week for 5 stars to achieve.
[5] CoM (2014) Melbourne Planning Scheme: 22.19-5 Performance Measures, retrieved from the website (http://www.melbourne.vic.gov.au/BuildingandPlanning/Planning/planningschemeamendments/Documents/AmendmentC187/C187_22_19_Local_Policy_Adopted.doc) on 22 May, 2014.

4.3.3 ON-SITE ENERGY GENERATION

In order to reduce grid-supplied energy, and in addition to energy efficiency measures, we considered the potential for widespread adoption of solar photo voltaic (PV) panels in both existing and new buildings. The general assumptions for the forecasts are as follows:

- No solar PV installation in high-rise buildings.
- No solar PV in Retail shop, Warehouse, Storage and big Hospitals.
- Each solar panel produces 185.04 watt of power.
- Solar PV systems can be effectively installed and used at 10% of a building's roof area.

Specific details considered in applying solar PV energy systems in the scenario forecast analysis are presented in Table 13.

Table 13. On-site solar PV energy generation assumptions

	Type	Roof size of prototype (m^2)	Potential Solar PV	Note
Residential	House	240*	1.8 kWp	See note (A)
	Semi-Detached	140*	1.2 kWp	
	APT	-	-	Not considered
Commercial	Office	1600	8.8 kWp	Only considered low & medium rise with the same roof size. See note (B)
	Retail	-	-	Not considered
	Warehouse	-	-	Not considered
	Educational	3000	14.5 kWp	See note (A)
	Hospital	-	-	Not considered
	Healthcare	1000	4.5 kWp	See note (A)
	Entertainment	-	-	Not considered
	Hotel	-	-	Not considered
	Motel	1600	8.8 kWp	See note (A)
	Community	1600	8.8 kWp	See note (A)
	Storage	-	-	Not considered

* ABS (2014) Building approvals, Australia, Australian Bureau of Statistics.
(A): Obtained PV panel size (1.3mx1.9m) with PV array considering available roof size (10% of total roof area) multiplying PV panel power generation (185watt a panel).
(B): Consider an office building with 40m x 40m of roof area, for example, with a marginal space 32m in length available. Twenty four PV panels can be installed (32m/1.3m per panel = 24.6 panels). Since this study assumed that only 10% of roof size is available for PV installation, the other side length available would be 5m at maximum (160m, 10% of roof area). Thus, a maximum of 2 arrays can be installed in this office building (5m/2.26m). Then total solar PV power can be calculated as 24 (panels) x 0.185 (kW/panel) x 2 (array) = 8.8 kWp.

4.3.4 SUMMARY SETTINGS FOR RETROFIT AND NEW-BUILD SCENARIOS

The summary details of alternative scenarios with different retrofit and new-build settings are given in Table 14. The included measures for minor, moderate and major reduction scenarios have previously been presented in Table 10.

For existing buildings, only the Energy Efficiency (demand-side) and On-Site Generation (supply-side) apply.

For new buildings, in addition to the Energy Efficiency and On-Site Generation, potential increases in minimum building energy performance through regulation (or Building Code requirements) are also considered.

Two uptake scenarios (A or B) are considered for each energy reduction scenario relating to Energy Efficiency and On-Site Generation. Two mandatory levels of minimum performance requirement for new buildings (also labelled A or B) are taken into account.

Energy consumption calculations based on the above scenario settings are shown in Appendix D.

4.4 Forecast scenario results and analysis

4.4.1 AGGREGATE RESULTS – ALL COUNCILS

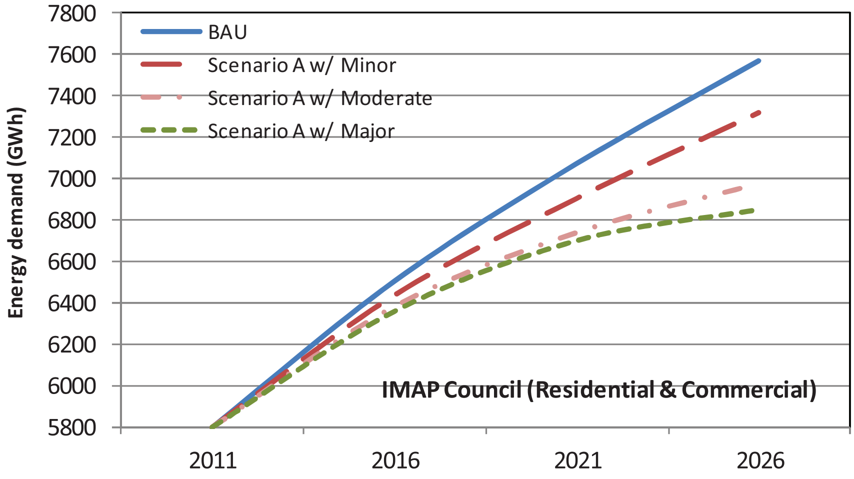
Starting with the aggregate results and trends for all councils, Figure 25 shows the energy reduction effects for different intervention schemes under two different uptake and regulation scenarios (A & B). In this figure, the BAU scenario shows energy demand in IMAP councils having 117.8 GWh per year of annual energy increase and thus reaching 7,568 GWh in 2026. This is 30% more than the 2011 baseline year.

With different intervention schemes, the future energy demand decreases compared to the BAU. The reductions are 1% to 4% for ‘Minor’, 2% to 10% for ‘Moderate’ and 3% to 12% for ‘Major’ intervention schemes over the 2016 to 2026 period in the Scenario A (moderate uptake and regulation). But in Scenario B (higher uptake and tougher regulation for new buildings), the energy reduction effects are much higher as shown in Figure 22b. With ‘Minor’ intervention under scenario B, the energy reduction effect shows 2% in 2016 but it continuously increases to 8% less than the BAU in 2026. The ‘Moderate’ intervention scheme shows 4% to 17% less energy demand than the BAU case from 2016 to 2026. This is almost twice the energy reduction effect for the ‘Minor’ intervention scheme. With the ‘Major’ intervention scheme, the energy reduction is 5% in 2016, which is similar to that in the ‘Moderate’ case (4% less than BAU). In 2021,the energy demand shows 6,562 GWh in the IMAP councils under the ‘Major’ intervention case, which is a 9% energy reduction comparied to the BAU (7,072 GWh). This is 2% less than that for the ‘Moderate’ intervention, which has 6 424 GWh (11% less than BAU). This is because the uptake rate for ‘Major’ intervention scheme is lower compared to the ‘Moderate’ case as shown in Table 14. However, when both uptake rates are similar like in 2026 (50% for both), the energy reduction effect of ‘Major’ intervention scheme represents much higher: 21% less (1,243 GWh) than BAU (7,568 GWh), or 4% higher energy reduction effect than that for the ‘Moderate’ case in Figure 22b.

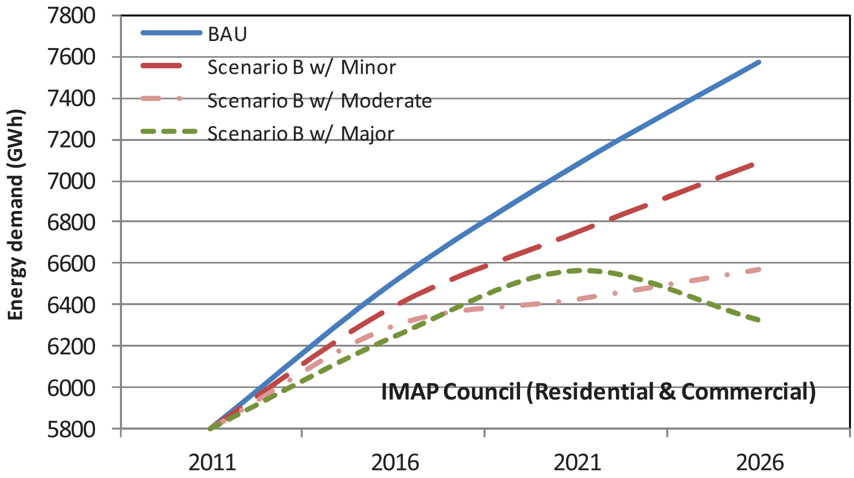
Figure 26 presents the energy reduction effect of the different intervention scheme under two different uptake and regulation scenarios for each council.

Table 14. On-site solar PV energy generation assumptions

			Grid-Energy Reductions Applied to All New Buildings																	
			Per Cent Uptake Applied to Existing Buildings in the BAU Case																	
	Scenarios of different levels of grid-energy reduction		Due to Energy Efficiency*						Due to On-site Generation**						Through (New) Building Code Requirements***					
			2016		2021		2026		2016		2021		2026		2016		2021		2026	
			A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Commercial	Minor		5	10	30	60	40	80	1	5	5	10	12.5	20	237MJ/m2/yr (+12.5)	230 MJ/m2/yr (+15)	230 MJ/m2/yr (+15)	190 MJ/m2/yr (+30)	217MJ/m2/yr (+20)	136 MJ/m2/yr (+50)
Commercial	Moderate		5	10	20	40	30	50	1	5	5	10	12.5	20	237MJ/m2/yr (+12.5)	230 MJ/m2/yr (+15)	230 MJ/m2/yr (+15)	190 MJ/m2/yr (+30)	217MJ/m2/yr (+20)	136 MJ/m2/yr (+50)
Commercial	Major		5	10	10	20	30	50	1	5	5	10	12.5	20	237MJ/m2/yr (+12.5)	230 MJ/m2/yr (+15)	230 MJ/m2/yr (+15)	190 MJ/m2/yr (+30)	217MJ/m2/yr (+20)	136 MJ/m2/yr (+50)
Residential	Minor		5	10	30	40	50	80	1	5	5	10	12.5	20	121MJ/m2/yr (+12.5)	117 MJ/m2/yr (+15)	117 MJ/m2/yr (+15)	97MJ/m2/yr (+30)	110MJ/m2/yr (+20)	69MJ/m2/yr (+50)
Residential	Mod.	Common Dwellings	5	10	30	40	50	75	3	5	5	10	30	50	121MJ/m2/yr (+12.5)	117 MJ/m2/yr (+15)	117 MJ/m2/yr (+15)	97MJ/m2/yr (+30)	110MJ/m2/yr (+20)	69MJ/m2/yr (+50)
Residential	Mod.	Apts.	5	10	10	20	30	50	1	2.5	5	10	12.5	20	121MJ/m2/yr (+12.5)	117 MJ/m2/yr (+15)	117 MJ/m2/yr (+15)	97MJ/m2/yr (+30)	110MJ/m2/yr (+20)	69MJ/m2/yr (+50)
Residential	Major	Common Dwellings	5	10	10	20	25	50	3	5	5	10	30	50	121MJ/m2/yr (+12.5)	117 MJ/m2/yr (+15)	117 MJ/m2/yr (+15)	97MJ/m2/yr (+30)	110MJ/m2/yr (+20)	69MJ/m2/yr (+50)
Residential	Major	Apts.	5	10	10	20	15	30	1	2.5	5	10	12.5	20	121MJ/m2/yr (+12.5)	117 MJ/m2/yr (+15)	117 MJ/m2/yr (+15)	97MJ/m2/yr (+30)	110MJ/m2/yr (+20)	69MJ/m2/yr (+50)

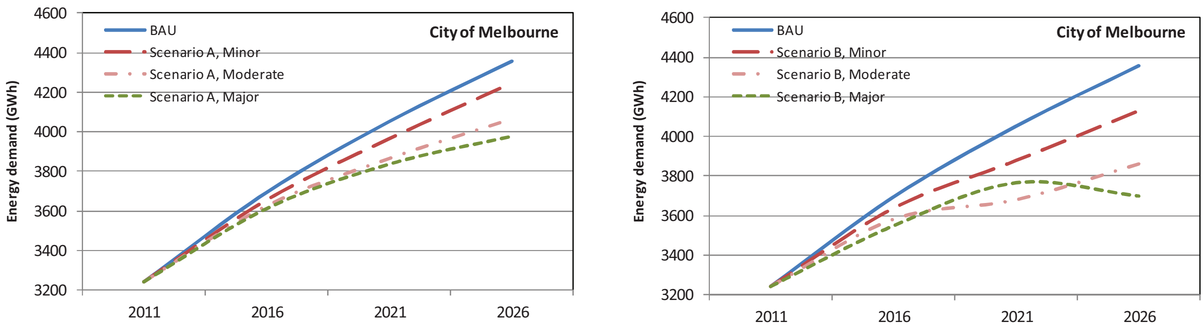


(a) Scenario A for IMAP councils

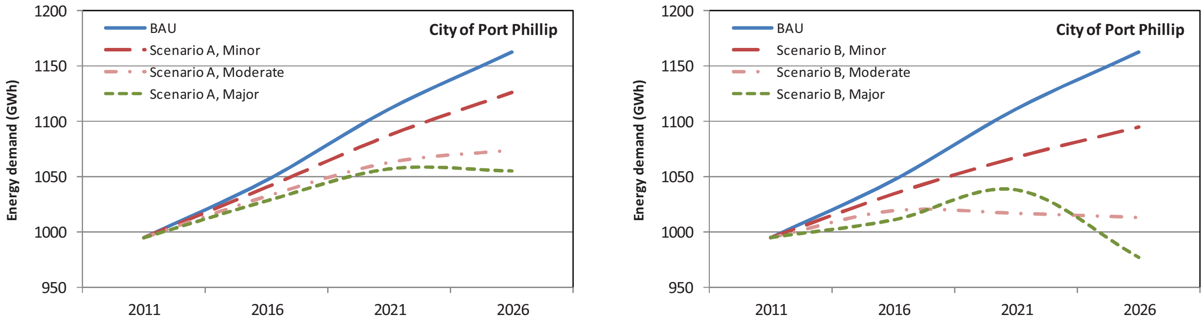


(b) Scenario B for IMAP councils

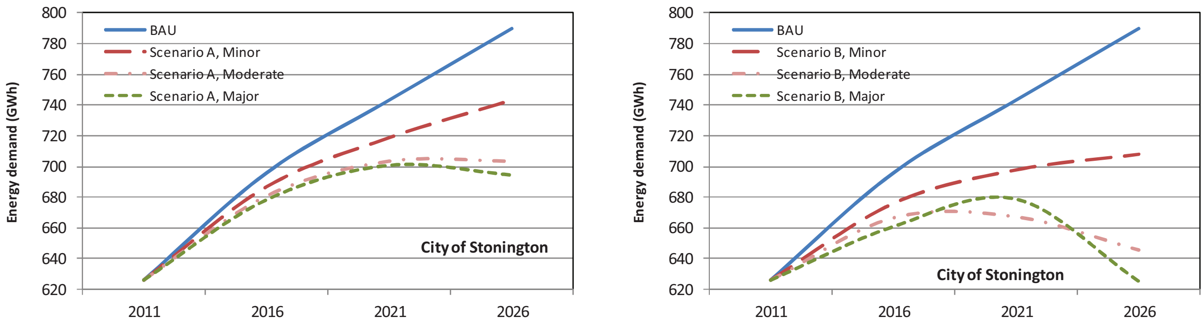
Figure 25: Total Energy demand for IMAP councils with uptake and regulation Scenarios A and B



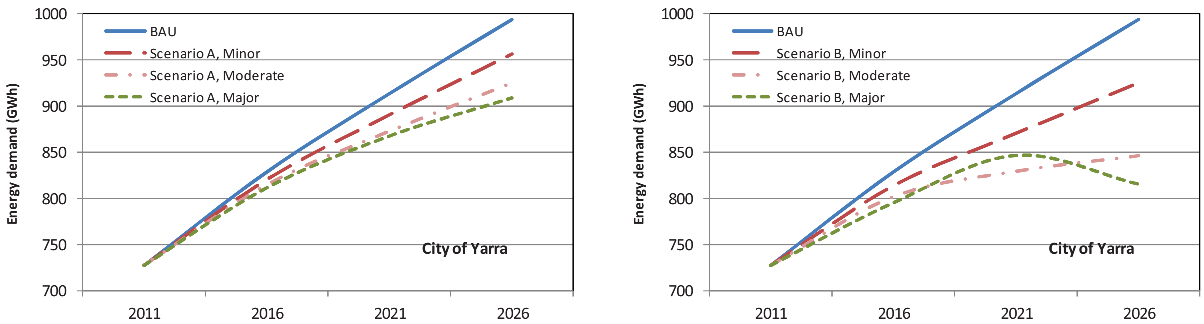
(a) Energy demand of different scenarios in City of Melbourne



(b) Energy demand of different scenarios in City of Port Phillip



(c) Energy demand of different scenarios in City of Port Stonnington



(d) Energy demand of different scenarios in City of Yarra

Figure 26. Energy demand of different intervention scenarios for IMAP councils

4.4.2 SPATIAL ENERGY DISTRIBUTION – CITY OF MELBOURNE

The projected energy demand in the City of Melbourne in 2016, 2021 and 2026, based on three different intervention and grid-energy reduction measures (Minor, Moderate and Major) and different uptake and new regulation settings (Scenario A and B) is spatially mapped in Figures 27, 28 and 29, respectively.

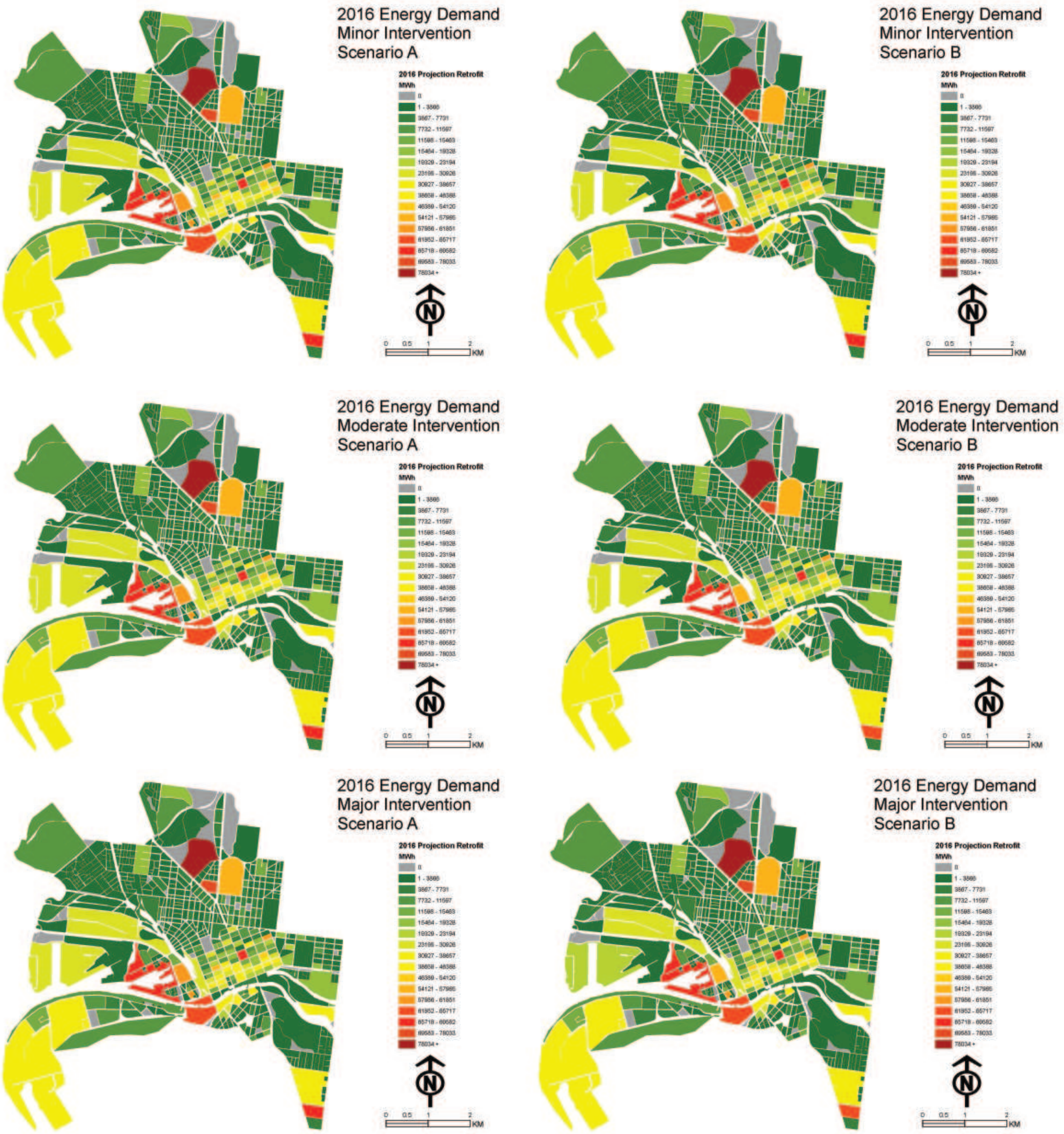


Figure 27. Projected spatial energy demand distribution within the City of Melbourne in 2016 under different intervention scenarios ('Minor' at the top, 'Moderate' in the middle and 'Major' in the bottom) and different scenarios for uptake rate and new regulations (Scenario A on the left and Scenario B on the right)

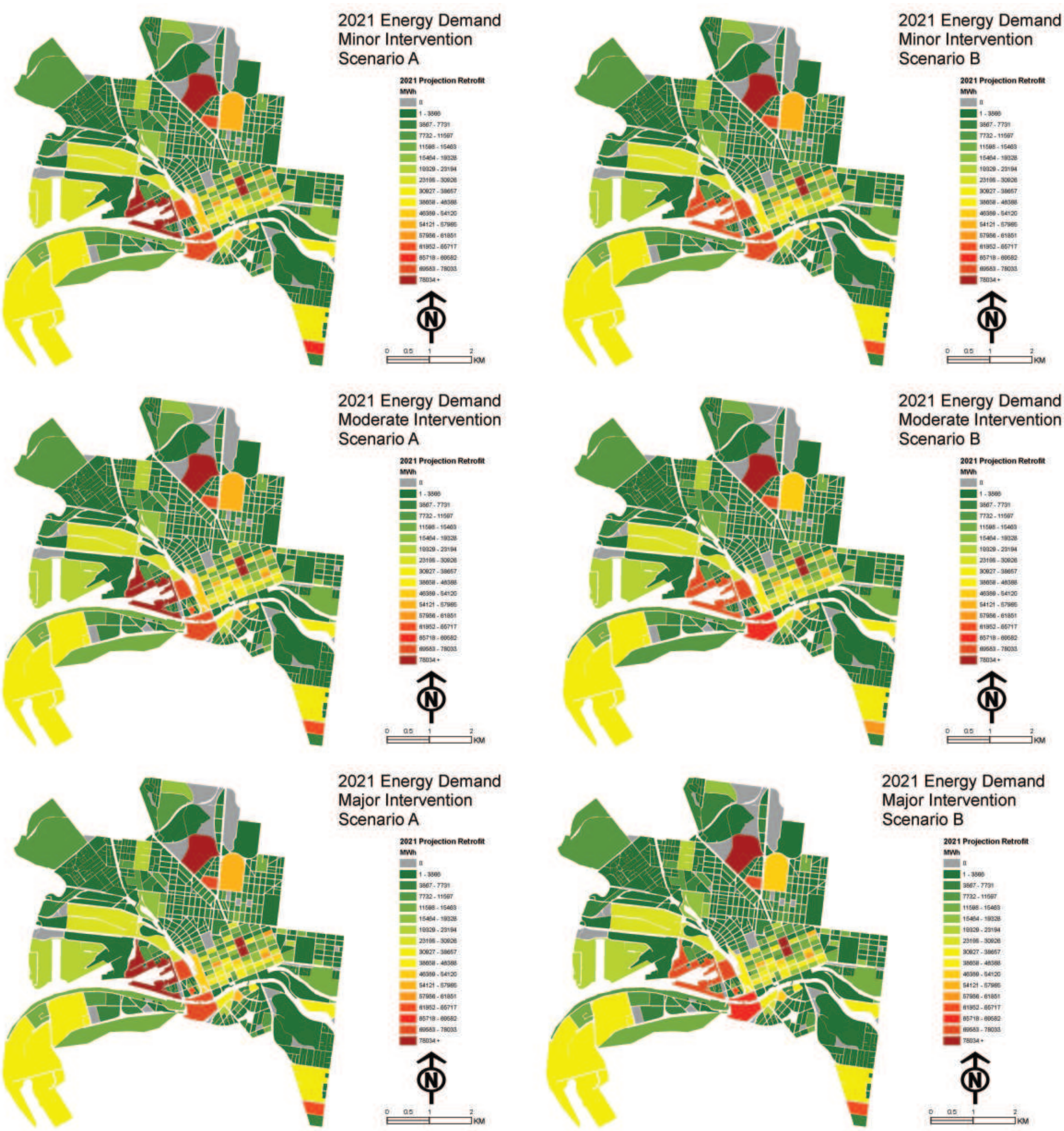


Figure 28. Projected spatial energy demand distribution within the City of Melbourne in 2021 under different intervention scenarios ('Minor' at the top, 'Moderate' in the middle and 'Major' in the bottom) and different scenarios for uptake rate and new regulations (Scenario A on the left and Scenario B on the right)

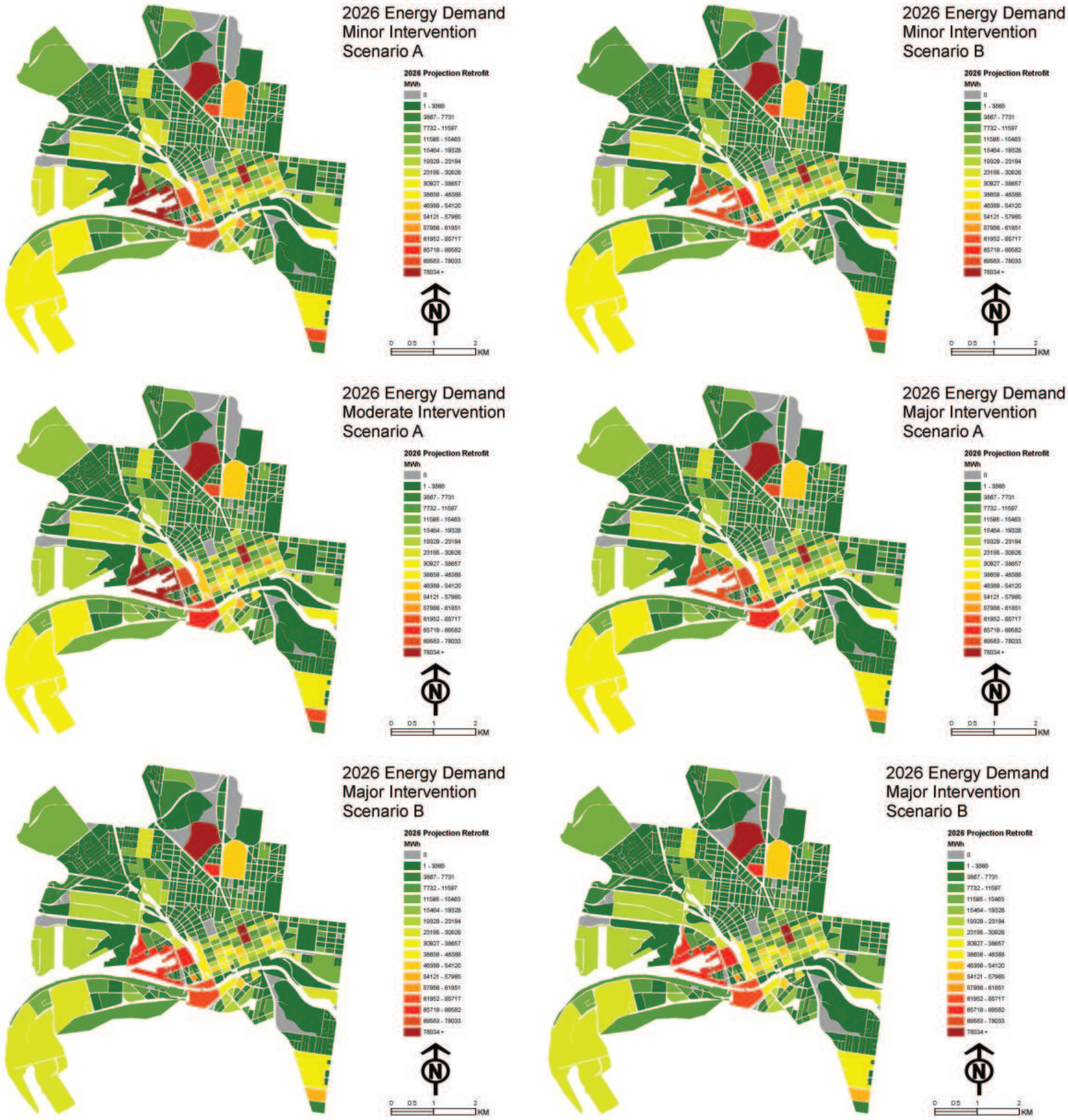


Figure 29. Projected spatial energy demand distribution within the City of Melbourne in 2026 under different intervention scenarios ('Minor' at the top, 'Moderate' in the middle and 'Major' in the bottom) and different scenarios for uptake rate and new regulations (Scenario A on the left and Scenario B on the right)

The preceding maps and figures provide a static way of viewing the future energy demand results. A dynamic way of viewing the calculated estimates of energy-use in three-dimensions and from different perspectives is possible with the web-based IMAP energy map viewer that comes with this report.

4.5 Some limitations and applications – present and future

4.5.1 GENERAL

Combining the building stock energy modelling and simulation with the visualisation and mapping capability demonstrated herein, provides a number of immediate and prospective applications. These will be bounded (or constrained) by:

- The way the building typologies and sub-typologies have been classified and modelled (and thus, the type and number of unique models analysed; in the present case, 288 residential types and 90 commercial types)
- The capability and level of detail included in the building energy modelling tools used in the study (i.e. AusZEH for residential energy and eQUEST for commercial building energy, the extent fuel mix is considered and modelled, etc)
- The data type, level of detail and alignment available for modeling, calibration and validation
- The assumptions and data types and sources for future forecasts and scenarios.
- The completeness, level of detail and reliability of future development plans council-wide.

In other words, the modelling and visualisation capability are

4.5.2 EXTENSIONS AND FUTURE APPLICATIONS

In the same manner the energy maps have been presented here, the associated GHG emissions from energy use in 2011 in the study area can also be mapped and analysed. The residential building modelling approach already incorporates a simple electricity/gas sub-typology, thus the results can be converted to equivalent GHG emissions in a fairly straightforward manner. The commercial building modelling assumed only electricity supply for all end-uses (i.e. no natural gas) for simplicity and lack of readily available data across many different commercial building types that meet the modelling requirements. Thus, a sub-typology for different fuel mix needs to be introduced here to obtain the equivalent GHG emissions for commercial buildings. In either or both cases, if the actual fuel-mix data/information are also available for validation (i.e. from relevant utility companies or building owners), then the building emissions maps can also be generated. The GHG emission hotspots can be identified and different types of actions (energy efficiency, distributed generation or demand response options) can be assessed technically and economically.

Other potential application include:

- Peak energy demand analysis – to understand and identify detailed energy demand patterns annually or by season (macro-level), and daily or by time of day (micro-level).
- Feasibility studies of distributed renewable energy options (what, how and where – including specific and context-based assessment of the economics and effectiveness of different GHG abatement options)
- Policy and other intervention schemes – optimised with others (e.g. federal, state and local governments; utility companies; service companies; and clients/customers/public).

5 Conclusions and future work

The spatial distribution of energy consumption in residential and commercial buildings in four IMAP Councils, together and by individual Councils, were presented at block level for:

- The baseline year of 2011
- The Business-As-Usual (BAU) case in 2016, 2021 and 2026
- A range of retrofit and new regulation scenarios in 2016, 2021 and 2026.

To aid the viewing of all the scenarios considered, a web-based IMAP energy map viewer is provided separately. Conversely, this report provides the background details and explanations of the data shown in the web-based viewer.

The energy use estimates were determined using a bottom-up building stock modelling approach based on a hierarchy of building typologies and using CSIRO's AusZEH tool for residential buildings and the US Department of Energy's eQUEST tool for commercial buildings.

The baseline year was 2011 to match data from the most recent Australian Census. These were complemented by the participating Council's property databases (City of Melbourne's CLUE database and other Councils' rate valuation property databases) and other related sources). The energy intensity for each residential building typology (288 building types in total) and commercial building typology (90 building types in total) in each statistical area SA1 was calculated and validated with actual data from CitiPower (for macro-validation) and Melbourne Hospitals (for micro-validation) then proportioned to all street blocks in the corresponding SA1 area according to their total floor areas for each building type in each block. The sum of the energy consumption of all building types in each block was then the calculated as the energy consumption (residential and commercial, respectively) in the block. In both cases, modelling and simulation results deviated less than 10% from the actual energy data in the baseline year 2011. Considering the highly heterogeneous building stock and the vastly different details of building age, type, occupancy and use operating conditions, *and* the simplifications required for any building stock modelling work, this level of deviation from actual data may be considered within an acceptable range.

We have demonstrated new ways of analysing the spatial and temporal energy use at various levels and that can be used to target specific analysis objectives. Without further modelling and analysis, the current results, especially the 2011 baseline set, can be used to identify hotspots for energy use by:

- Location (specific block)
- Building type (up to various sub-classifications within the primary residential and commercial building types; total of 288 residential types and 90 commercial types)
- End-use category (e.g. HVAC system, lighting, hot water system, plug-in appliances and equipment, etc)

The modelling and mapping capabilities were further demonstrated in calculating and visualising energy use forecasts on 5-year increments to 2026.

The BAU growth forecasts for Melbourne are based on projected block-level development plans supplied by the City of Melbourne. The BAU forecasts for Port Phillip, Stonnington and Yarra are, however, based on highly simplified assumptions that did not consider planned or preferred growth areas, energy efficiency improvements and in what specific locations. Thus, the spatial energy mapping for the BAU case is meaningful only for the City of Melbourne; it is not meaningful for Port Phillip, Stonnington and Yarra, and thus, excluded. Only aggregate energy consumption for the latter three councils is plotted to 2026.

Projected council-wide development plans, with details of size and type of development in designated areas, are needed for revised scenario analysis and spatial mapping of energy use in both the BAU case and the set of retrofit and new regulation scenarios. This may include land use, development and re-zoning plans, among others.

Other prospective applications, but requiring further work, include:

- GHG emissions mapping and analysis – with the same capability as with the energy results in the present study
- Peak energy demand analysis – to understand and identify detailed energy demand patterns annually or by season (macro-level), and daily or by time of day (micro-level).
- Feasibility studies of distributed renewable energy options (what, how and where – including specific and context-based assessment of the economics and effectiveness of different GHG abatement options)
- Policy and other intervention schemes – optimised with others (e.g. federal, state and local governments; utility companies; service companies; and clients/customers/public).

The building stock energy analysis and map representations depend heavily on the quality, completeness and nature of energy performance-related datasets and block/parcel representation (GIS) datasets. To maximise the value and applications of energy-relevant data sets, their collection and management need to be made compatible with the protocols and platforms across jurisdictions and database systems – for example, harmonising with the protocols of the Australian Urban Research Infrastructure Network (AURIN; http://www.aurin.unimelb.edu.au). Either way, in the near term, it would be ideal to:

- Harmonise the differences of terms and interpretations of building classification among councils and ABS datasets. Modelling will be better served if these differences can be ironed out in the years to come.
- Establish a database of building energy certificates and disclosure information.
- Obtain or research additional data about energy consumption patterns, including plug-in appliances and equipment, fuel types and mix (if any), time/hours of operation, etc., to help in optimising energy efficiency and GHG emission reduction options.

References

1. ABCB (2002) Activity Profiles for Class 1, 2,3,5,6,7,8,9a ,9b building energy use. Aiustralian Building Codes Board, Canberra.
2. ABS (2011a). 2901.0 - Census Dictionary. Australian Bureau of Statistics, Canberra.
3. ABS (2011b). Census of Population and Housing: Outcomes from the 2011 Census Output Geography Discussion Paper, cat. no. 2911.0.55.002, Australian Bureau of Statistics, Canberra.
4. ACIF (2013), “Non-residential (office) building forecast in NSW”, Australian Construction Industry Forum, available at: from http://www.acif.com.au/forecasts/forecast-search (accessed 10 April, 2013).
5. Boulaire F, Higgins A and Foliente (2013) Statistical modeling of district-level residential electricity use in NSW, Australia. Sustainability Science , March 2013.
6. CitiPower (2013) http://www.powercor.com.au/
7. ClimateWorks Australia (2010). Australian Carbon Trust Report: Commercial buildings emissions reduction opportunities. Melbourne, Australia. (Report available for download at http://www.climateworksaustralia.org/)
8. Cordell Costing Solutions (2003). Commercial/Industrial Cost Guide, NSW, Australia, available at: http://www.cordellestimating.com.au/main/costguidehousingcommercialindustrial.aspx (accessed 11 May 2012).
9. DCCEE (2012) Baseline Energy Consumption and Greenhouse Gas Emissions in Commercial Buildings in Australia – Part 1 – Report. Commonwealth of Australia.
10. Delsante, A. (2004). A validation of the AccuRate simulation engine using BESTEST. Report for the Australian Greenhouse Office, CMIT -2004-152.
11. Delsante, A. (2005). “Is the new generation of building energy rating software up to the task? – A review of AccuRate.” Paper presented at the ABCB Conference ‘Building Australia’s Future, Surfers Paradise.
12. DSE (2014). 2014 Valuation Best Practice, Specifications Guidelines. Department of Sustainability and Environment, Victorian Government.
13. CoM (2012) CLUE 2012 definition, glossary of terms. City of Melbourne Council.
14. CoM (2013) Population and household forecast, city of Melbourne. http://forecast2.id.com.au/Default.aspx?id=128&pg=5110
15. eQUEST (2013) http://www.doe2.com/equest/ accessed in June 2013.
16. Foliente G and Seo S (2012) Modelling building stock energy use and carbon emission scenarios. Smart and Sustainable Built Environment 1(2) 2012 118-138.
17. Geoscience Australia (2010). NEXIS database, Geoscience Australia, Canberra, information available at http://www.ga.gov.au/hazards/our-techniques/data-collection/databases/nexis-database.html (accessed 11 May 2012).
18. Green Star (2010) Green Star Education v1: Energy calculator guide, Green Building Council Australia.
19. Grozev GV, Paevere P, Higgins AJ, Egan S, Ren Z, Horn MET, Anticev J, Garner S, Bloom W (2013). Modelling of electric vehicle charging patterns and impacts on peak electrical demand in Townsville, Queensland. CSIRO, Australia.
20. Howard B., Parshall, L., Thompson, J., Hammer, S., Dickinson, J. and Modi, V. (2012) “Spatial distribution of urban building energy consumption by end use”, Energy and Buildings, Vol. 45, pp. 141–151.
21. Higgins, A. and Foliente, G. (2013) “Evaluating intervention options to achieve environmental benefits in the residential sector”, Sustainability Science 8(1): 25–36, http://dx.doi.org/10.1007/s11625-012-0160-x.
22. Higgins, A, Foliente, G. and McNamara, C. (2011) “Modelling intervention options to reduce GHG emissions in housing stock — A diffusion approach”, Technological Forecasting and Social Change 78(4): 621-634, http://dx.doi.org/10.1016/j.techfore.2010.12.003.

23. Higgins et al. (2013). Forecasting uptake of retrofit packages in office building stock under government incentives. Energy Policy. http://dx.doi.org/10.1016/j.enpol.2013.10.041

24. Higgins, A., McNamara, C. and Foliente, G. (2014) “Modelling future uptake of solar photo-voltaics and water heaters under different government incentives”, Technological Forecasting and Social Change 83: 142–155, http://dx.doi.org/10.1016/j.techfore.2013.07.006.

25. Swan LG and Ugursal VI (2009) Modeling of end-use energy consumption in the residential sector: a review of modeling techniques. Renewable and Sustainable Energy Reviews 13 (8) 2009.

26. IMAP (2013) Inner Melbourne Action Plan. http://imap.vic.gov.au/

27. Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z., Diurrovic-Petrovic, M. (2010), “A review of bottom-up building stock models for energy consumption in the residential sector”, Building and Environment, Vol. 45, pp. 1683–1697

28. NatHERS (2013) http://nathers.gov.au/software/index.php accessed in June 2013.

29. Petchey, R (2010). End use energy intensity in the Australian economy, ABARE–BRS research report 10.08, Canberra, September

30. Rawlinsons (2013) Australian Construction Handbook, Edition 31

31. Ren Z, Foliente G, Chan, W-Y and Syme M (2011) AusZEH Design: Software for low-emission and zero-emission house design in Australia. Proceedings of Building Simulation 2011, 12th Conference of International Building Performance Simulation Association, Sydney, 14-16 November.

32. Ren, Z., Foliente, G., Chan, W.-Y., Chen, D., Ambrose, M. and Paevere, P. (2013) A model for predicting household end-use energy consumption and greenhouse gas emissions in Australia, International Journal of Sustainable Building Technology and Urban Development, 4:3, 210-228, DOI: 10.1080/2093761X.2013.801801

33. Ren Z, Paevere P and McNamara C (2012) A local-community-level, physically-based model of end-use energy consumption by Australia housing stock. Energy Policy 49 (2012) 586-596.

34. Zhu, Y. (2006) Applying computer based simulation to energy auditing, Energy and Building, Vol.38, No.5,.421-428