Residential Energy Use In Oman: A Scoping Study

Project Report

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Executive Summary

The Authority for Electricity Regulation (AER) Oman is addressing the nationally important issue of energy efficiency in residential premises. Reducing energy use in Oman's residential sector has the potential to reduce the cost of energy subsidies, the consumption of indigenous gas resources and the cost of constructing the infrastructure required to meet growing peak demand. Improving the efficiency of the residential stock may also create benefits for the Omani public through more comfortable living conditions and reduced energy costs.

In order to deliver these benefits, it is first necessary to measure and evaluate the current state of the built stock to understand how energy is used. This is not a simple task because energy use at the residential level is driven by the complex interaction between the household's demands for energy services, the building fabric and its systems.

In recognition of this challenge, AER contracted PassivSystems (an innovative home energy management services company) and the Energy Institute, University College London (a world-leading centre of energy research) to carry out a 9 month scoping study on residential energy use in Oman between April – December 2013.

Addressing Omani Energy Use

Designing policies that address residential energy consumption requires an understanding of the fabric performance of the building, the type and operational characteristics of building systems, as well as the drivers of energy services demand. The pilot study addressed each of these areas and delivered important insights into residential energy use such as;

- **The Omani stock is characterised by poor fabric performance**.
    - Homes have little or no thermal insulation and single glazed windows dominate.
    - There has been little discernable improvement in the thermal performance of newer housing.
    - Modelling has shown a significant opportunity to reduce residential energy consumption and therefore the cost of subsidies through a programme of building improvements and policy intervention in new building regulations.
- **The size of a household may have a stronger influence on energy consumption than the size of the property.**
    - More inhabitants occupy and cool more rooms, driving energy use higher. Although this may appear to be an obvious conclusion, in other countries the

key driver for space comfort conditioning is often building size not occupant numbers.

  - Influencing behaviour and the way people use their systems may therefore provide energy savings as well as reducing peaks in energy demand

The pilot study utilised a mix of data gathering approaches such as surveying consumers, gathering data on building fabric and systems as well as gathering dynamic data on occupant actions and building performance. This integrated approach produces insights that go beyond any single method in isolation. As an additional piece of work an initial housing stock model has been developed as a framework to help integrate these methods and has demonstrated good correlation with the gathered data. However, a larger, more sophisticated model, which would be a valuable tool in policy design and evaluation, would require more robust data on the housing stock to be representative.

Further Work

The complex nature of residential demand means that there is the potential for efficiency measures to fall short of expected performance, as well as causing unexpected consequences. In order to develop a robust understanding of energy use in the Omani residential stock and the costs and benefits of any policies to improve performance, **an integrated approach is required in future studies.**

Our scoping project has demonstrated the value of stock modelling as a tool to support policy design and help estimate the impact of a number of technical or behavioural policy driven interventions. However, **models must be based on robust, statistically valid data**, both on a national scale and the scale of an individual building.

Therefore we consider that a future project in this area should have three strands:

1. **Characterisation of the existing residential stock;** its energy systems, fabric, energy use, and occupant behaviours and comfort. This requires a large scale data gathering exercise that includes surveys together with environmental monitoring to understand the dynamics of energy use. Without a robust understanding of the existing system it is very difficult to either predict the likely impact of interventions with models or evaluate the actual impact of interventions.
2. **A programme of testing energy saving interventions** this could include both behavioural changes and technological changes to the building fabric and services or controls.
3. **The development of a stock model** that utilises this data to develop a robust tool for policy evaluation for use in the decision making process by the Omani Government.

This scoping study has broken new ground in understanding residential energy use in Oman. A larger project that builds upon this proven approach would provide the Omani Government with the tools and evidence required to address energy consumption, reduce the costs of subsidies and investment in electricity infrastructure and provide wider benefits to the Omani society as a whole.

In our view the first stage of any large scale project of this nature requires an initial planning work package to identify the hypotheses to test, determine necessary interventions to be trialled and then establish the scale necessary for each test cell to be statistically significant and scientifically robust.

Detailed design of the sampling strategy would be carried out at the initial stages of the project however we estimate that a survey sample in the range of 2,000 – 4,000 homes would be required with approximately a quarter of these forming a monitored control group and at least a quarter forming a number of test cells for energy efficiency measures. The number of test cells will be dependent on the range of interventions to be tested, which will be determined in consultation with the Omani Government.

Based upon our experience of UK Government expenditure on similar sized initiatives, we estimate that a project necessary to deliver statistically robust evidence and a tool to develop national residential energy efficiency policies would start at 2m Omani Rial. The actual cost estimate will depend on the precise scope of the follow on project which will be informed by the recommendations presented here and reflect the priorities of the Omani Government.

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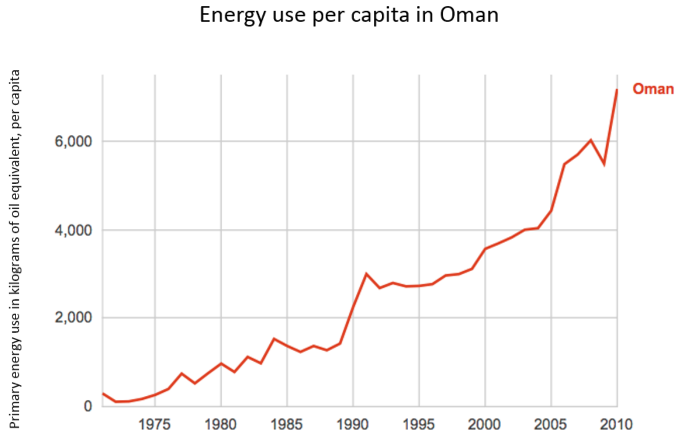
1 Introduction

1.1 Energy Use in Oman

Since the 1970's, Oman has taken huge steps towards achieving a strong and sustainable economy. These changes in the economy have led to significant population growth and an influx of foreign workers particularly in the main urban centres[1].



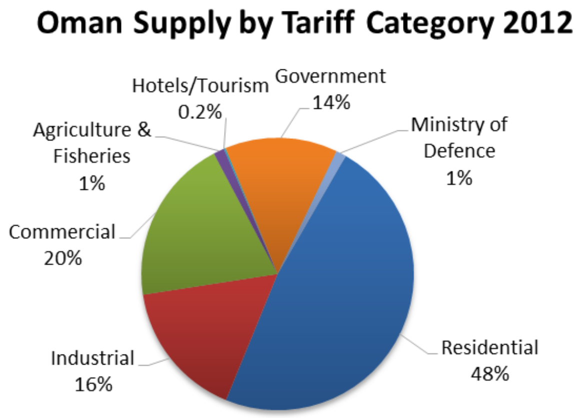


Figure 1: Energy Use Per Capita & Use by Sector (Sources: Word Bank Public Data, 2011, Provided by AER)

As illustrated by, Figure 1, Energy consumption per capita in Oman has risen significantly since the 1970's to a per capita energy consumption similar to the USA. The importance of the residential sector as a driver for total energy demand is also highlighted, with residential demand accounting for almost 50% of the total for the Main Interconnected System[2].

Understanding the drivers in residential energy demand and forming strategies for demand reduction is crucial, if Oman is to reduce its consumption of indigenous gas resources. Figure 2 shows Omani residential energy consumption along with that of its neighbours and that

[1] Al Badi, A. H., Malik, A., & Gastli, A. (2009) *Assessment of renewable energy resources potential in Oman and identification of barriers to their significant utilization* in *Renewable and Sustainable Energy Reviews* 13(9), pp 2734-2739. doi: 10.1016/j.rser.2009.06.010

[2] Authority for Electricity Regulation *(2012) Annual Report 2012* From: www.aer-oman.org/images/aer320.pdf

consumption is close to average for its peers.

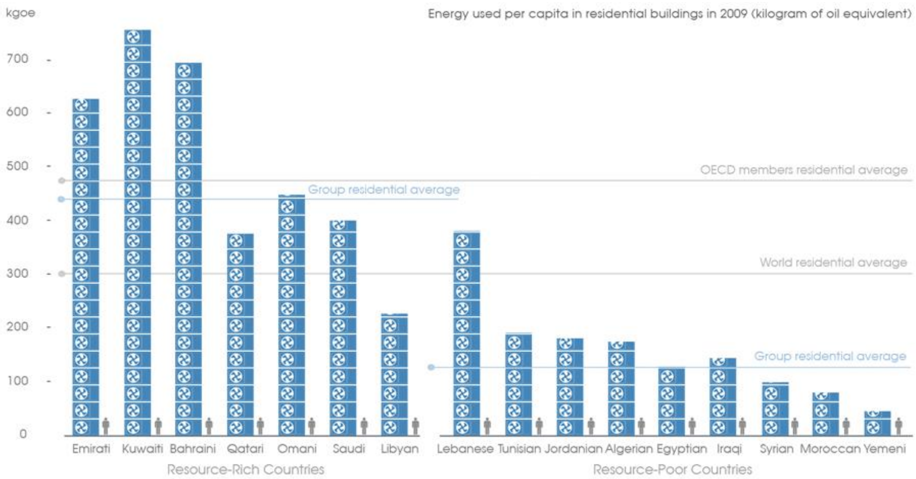


Figure 2: Residential Energy Consumption *(Source: www.carboun.com)*

1.2 The Project

This report is the culmination of a 9 month long scoping project which has broken new ground in terms of understanding energy use in Omani homes and laying the foundations for future work, which will further explain and address residential energy use in Oman.

The project was conceived with four main aims:

- Understand the key issues in relation to energy use in the residential housing stock;
- Define the information needed to understand and address these issues;
- Understand how this information could be gathered and develop a framework for understanding and analysing it;

The approach taken to address these aims was to:

- Analyse policy design, measurement and verification approaches in the field of residential energy efficiency elsewhere;
- Review the currently available data that may help understand energy demand at the national level;
- Pilot a survey and monitoring approach to provide a deeper understanding of demand at the household level;
- Utilise the data to form and test hypotheses on the drivers of energy use in residential homes in Oman and evaluate how these might be addressed.

The results of this process and the lessons learnt from the data gathering exercise form the basis for recommendations for further work to understand and reduce residential energy use. This report begins by discussing the role of evidence in developing energy efficiency policies, the methodology and results of each of the data gathering activities carried out as part of this scoping project, focusing on the value of evidence in understanding energy use, and on the lessons learnt from the process of data gathering. These items are further discussed in the context of a future project in the area of residential energy use, and our recommendations for a full scale project which builds upon this scoping study.

2 Evidence Based Policy for Residential Energy Efficiency

2.1 The Value of Evidence

Gathering and appraising high quality evidence is a crucial aspect of effective policy making[3]. Evidence helps to understand the policy environment and its dynamics; appraise and quantify the likely effects of policy changes to guide decision making; verify the success of policy interventions; and identify improvements.

The need for evidence is particularly acute in the residential sector, where the complexity of energy use at the dwelling level (which is a function of the performance of the building fabric and building systems as well as the way occupants use those systems) means that the performance of energy efficiency improvements can be subject to significant uncertainty. It is important to understand (and where possible minimise) this uncertainty in order to quantify the benefits of energy efficiency policies. This means that energy efficiency policies have to be designed for a complex system. In addition, these policies often have several different and sometime competing aims, for example, improving the health and comfort of building occupants, saving money for occupants, saving infrastructure costs, reducing carbon emissions and, improving energy security.

Research[4] has shown repeatedly that the in-use performance of energy saving technologies frequently falls short of manufacturer or design team predictions, or as tested under controlled laboratory conditions. This installed underperformance is often the result of multiple confounding factors, such as quality of installation, interactions between different components in the energy system, occupant behaviour, climate and unintended consequences. These factors mean that it is not possible to assume that a given technology either tested in a laboratory or in the field in another country will deliver the same benefits when installed into a different complex people – building - climate system. The acquisition of monitored data, as well as an understanding of the building and its systems and how the building occupants interact with these systems, can provide insights into the mechanisms behind the performance gap.

Policies aimed at saving energy often have unintended consequences that result in higher

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[3] Sutcliffe, S. and Court, J. (2005) *Evidence-Based Policymaking: What is it? How does it work? What relevance for developing countries.* Overseas Development Institute

[4] See for example:

Dunbabin, P. and Wickins, C. *(2012) Detailed analysis from the first phase of the Energy Saving Trust's heat pump field trial* (www.gov.uk/government/uploads/system/uploads/attachment_data/file/48327/5045-heat-pump-field-trials.pdf) for a discussion of heat pump underperformance.

energy use. An example from the UK context is the encouragement of households to retrofit conservatories as a passive solar measure. This intervention is shown to increase energy consumption when those conservatories are heated by fossil fuels. Anticipating and understanding the potential for these unintended consequences is the key to managing them.

2.2 Building an Evidence Base – Experience in the UK

It is useful to show how other countries have addressed these complex and challenging issues using evidence. Figure 3 is a high-level illustration of the process of designing and evaluating a successful residential energy efficiency policy in the UK. The process involves data gathering, modelling, both as a tool to estimate the performance of the stock as a whole and evaluate policy options, and a process of evaluating policy success.

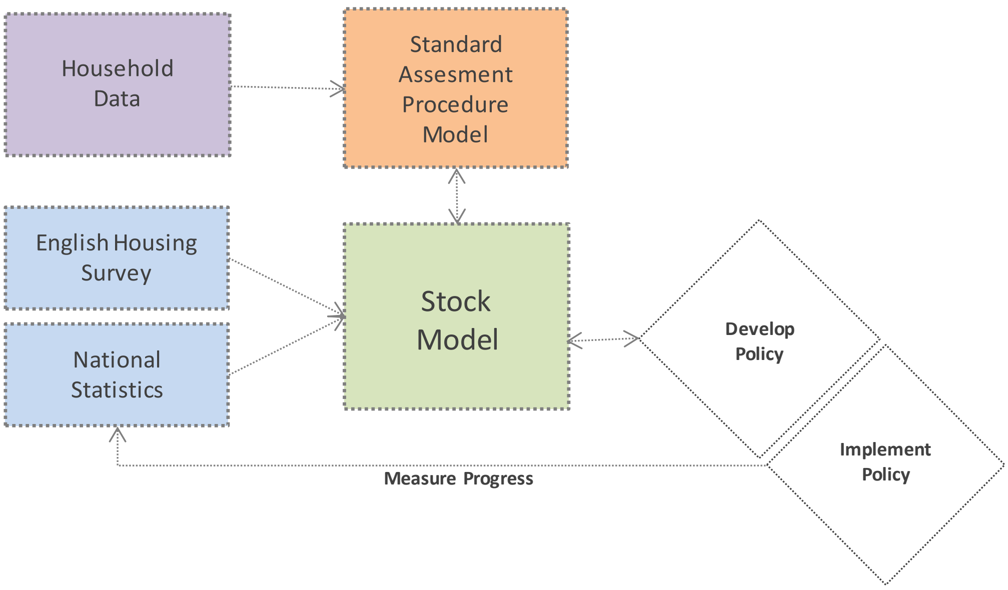

Figure 3: UK Policy Development

Data Gathering

The English Housing Survey (EHS)[5] gathers data on the housing stock using household interviews covering approximately 13,500 homes per year, of which 6,000 homes per year are subject to a physical survey by a qualified surveyor. The households who participate in the survey are chosen at random from a database of all private addresses.

The survey originated as a means of understanding the general condition of the UK housing stock and although gathering data on the energy performance of the home is now one of the central goals, a wide variety of information is still collected.

[5] Department for Communities and Local Government *(2013) – English Housing Survey – Technical Advice Note – Survey Overview and Methodology*

In addition to EHS data, other national data such as total gas and electricity demand, data from large retrofit programmes and the results of detailed monitoring studies, contribute to the overall understanding of energy use in the residential sector.

Modelling

Historically, the BRE Residential Energy Model (BREDEM)[6] or its variants such as the Government's Standard Assessment Procedure (SAP) have been a central element of residential stock models in the UK. BREDEM is a steady-state physics-based model that estimates the energy consumption of a home for a given set of parameters. BREDEM was developed and has been maintained using a mixture of theoretical calculations and monitored data.

Various statistical approaches have been developed that allow the model to be run with a very basic set of input data (i.e. Reduced Data SAP) and therefore estimate energy consumption using nationally representative data within residential stock models such as the Cambridge Housing Model (CHM)[7].

There are a number of criticisms of this approach, including shortcomings with the BREDEM model itself[8]. Therefore, it is not suggested that this is the ideal approach, merely a useful example. Indeed the UK Government is currently in the process of implementing a new 'National Household Model' for policy evaluation.

Policy Design & Evaluation

Models such as the Cambridge Housing Model and the new National Household Model play an important role in policy development, impact assessment and cost/benefit analysis. Policy evaluation through measurement and verification schemes are also important and provide valuable insights on the success of policy measures and the performance of energy efficiency interventions.

Successful energy efficiency policies must not only provide the right incentives for consumers to improve energy efficiency but also need to support the markets and supply chains required to deliver these improvements. UK experience in this area indicates that market certainty facilitated by long term planning is crucial to avoid the formation of a boom and bust cycle in young energy efficiency industries.

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[6] Henderson, J. and Hart, J. *(2013) BREDEM 2012 – A technical description of the BRE Domestic Energy Model* From: www.bre.co.uk/filelibrary/bredem/BREDEM-2012-specification.pdf

[7] Department of Energy and Climate Change (2010) *Cambridge Housing Model and User Guide* From: www.gov.uk/government/publications/cambridge-housing-model-and-user-guide

[8] The Scottish Government *(2009) Critique of BREDEM 12 Energy Model* From: www.scotland.gov.uk/Publications/2009/10/08143041/3

Summary

Evidence based policy making in the UK utilises a combination of data gathering, stock modelling and ongoing measurement and verification. The development of models such as those used in the UK requires both nationally representative data and data that can be used to model energy use at the individual level. These approaches are equally relevant to Oman.

3 Scoping Study Approach

3.1 Data Gathering

The data gathering and analysis carried out during this study were aimed at providing dataset for exploratory analysis and a means of piloting a data gathering approach to inform future studies.

The data gathering process was led by the Authority for Electricity Regulation (AER) with support from PassivSystems, who supplied monitoring equipment and advised on the design of the household surveys along with the Energy Institute at University College London (UCL). The data gathering exercise was carried out in three phases, described below.

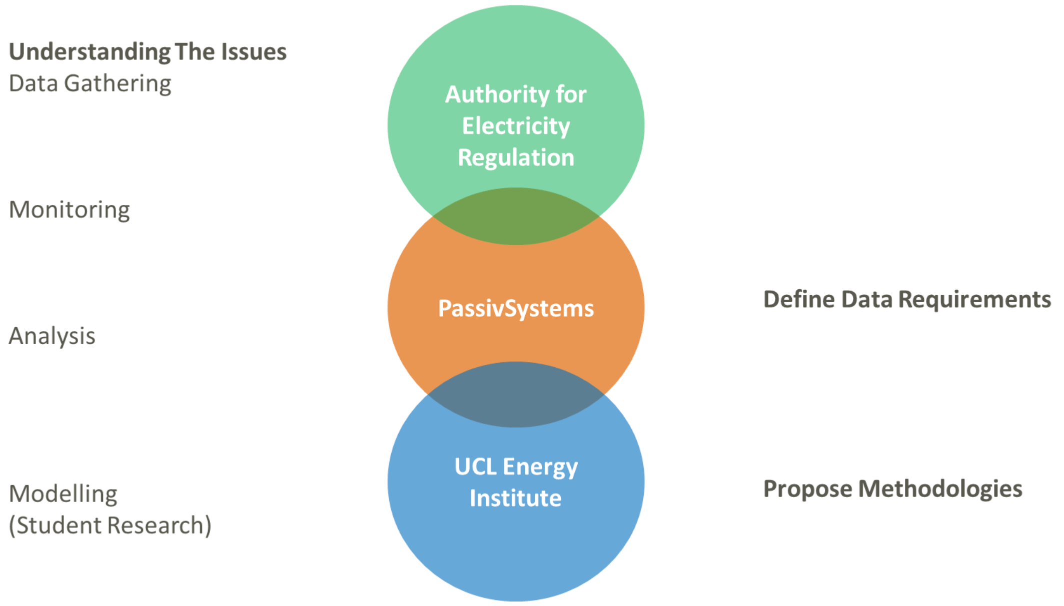


Figure 4: Partner Roles

Reviewing Existing Data

AER conducted a survey of available data that may be valuable in understanding residential energy use at the national level, generalising findings from a sample of homes to the country as a whole and designing a sampling procedure. National statistics are also important in developing and validating models of energy use.

This review uncovered data about the housing stock (dwelling types, plot sizes, tenure, the number of bedrooms, appliances, and occupants e.g. income and expenditure). The results of the data review have been compiled in a separate report.

Household Surveys

Survey Design

The survey was designed to gather data on the characteristics of the home (form, fabric and building services) and its occupants (their use of space conditioning, appliances and attitudes to comfort and energy use). In many cases the surveyors also captured pictures of the homes and cooling equipment as well as sketching floor plans.

Sample Selection & Data Collection

The survey was administered by a number of survey teams managed by AER. The aim in sample selection was to address a wide range of house types and households from the available population. Participants were contacted either through the electricity distribution company or through AER contacts.

Data were collected using an online form and then exported subsequently to Microsoft Excel for post processing. Each householder was assigned a reference, allowing data to be linked anonymously.

Household Monitoring

Sample Selection

Of the 50 households surveyed, those that were willing to participate and had a broadband internet connection with sufficient bandwidth to support PassivSystems' equipment or where AER could provide a connection were deemed eligible to participate in the monitoring phase. A 20 home sample was chosen from the eligible population with the aim of addressing the widest possible range of dwelling and household types. To facilitate the participation of a low income family AER met the cost of providing a broadband internet service.

Equipment & Installation

PassivSystems web-connected monitoring system was installed in all 20 homes and captured:

- Air temperature in 5 occupied rooms (main living space, dining room, kitchen, hall and main bedroom).
- Relative humidity in the main living space.
- Motion (via PIR sensors) in the 5 rooms with temperature monitoring.
- Electricity consumption for a selection of appliances.

In addition, smart metering was installed in the homes capturing total electricity consumption at half hourly intervals, and local weather data were made available.

3.2 Data Analysis

The data analysis phase of the project was exploratory, aimed at understanding the drivers of residential energy use in the Omani residential stock by developing hypotheses and using the data to test them. The data gathering and analysis work carried out in this project was not designed to provide statistically robust results, rather to uncover potential areas for further research and inform future data gathering strategies.

In order to prepare the data for analysis, a data framework was created whereby a unique reference related the survey, monitored and smart meter data for each of the homes. The analytical approach which was applied to the data is illustrated in Figure 5. The first stage (1) was to summarise the dataset in order to understand the characteristics of the sample, how the sample under consideration related to the wider population and to build confidence in the reliability of the data. The process of considering the summary statistics lead to the formation of a range of hypotheses (2) which were tested with more detailed analyses of the data. The methodology and results of these analyses are described in the following sections. Finally, the data were used as input to a model (3) which provided a further means of testing hypotheses, exploring future strategies and developing research questions and data requirements for future work.

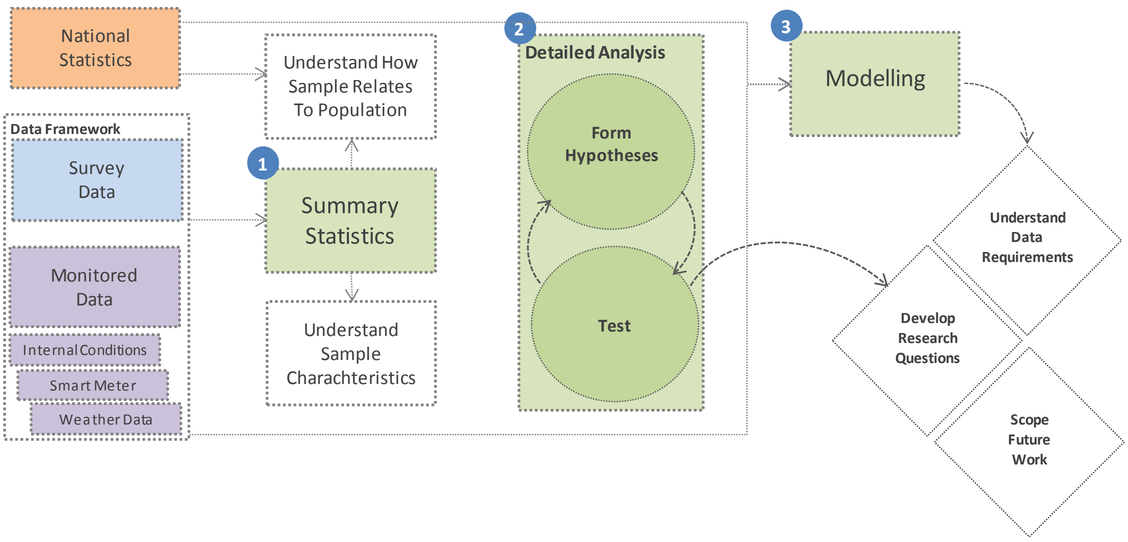


Figure 5: Analytical Approach

3.3 Modelling

As an extension of the data analysis, a stock level model of residential energy demand has been created. The development of models and associated data collection process is an iterative endeavour which is continually informed through the experience gained in undertaking the development process itself. Models in general provide a useful mechanism by which to structure thoughts and ideas and provide a framework to aid the understanding of large datasets.

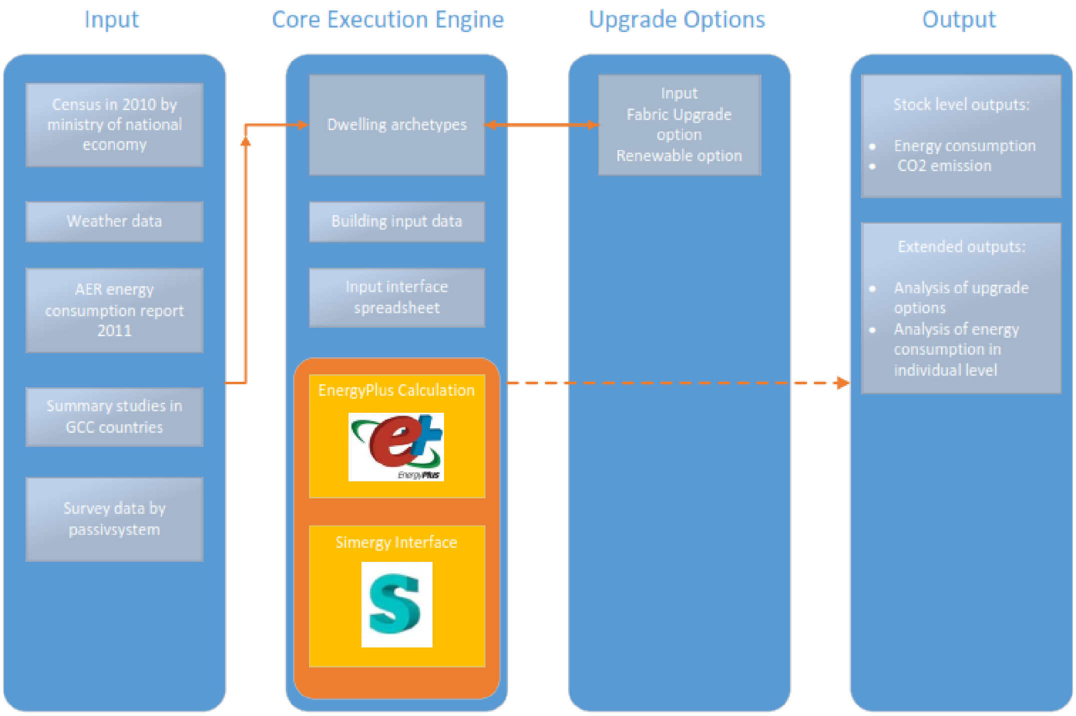


Figure 6: Model structure and components

The model takes a bottom-up approach that integrates Energy-Plus, a dynamic building physics model developed by the United States Department of Energy as the core calculation engine, and Simenergy, a graphical interface for Energy Plus developed by Lawrence Berkley National Laboratory. The structure and main components of this model are described in Figure 6.

Energy Plus was used to simulate energy demand for a series of key dwelling archetypes (see Figure 7) which have been developed utilising data gathered as part of this project or from the literature. This energy demand is extrapolated according to weighting factors derived from national statistics to provide an estimate of energy consumption for the entire Omani residential stock on a national level.

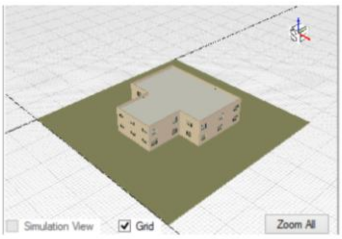
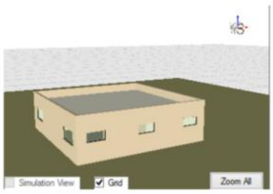
	Villa	**Apartment**	**Arabic House**
Unit layout			
Income group	high	high	low
Floor area	300 m2	150 m2	150m2
No of Floor	2	5	1
Construction	Cement brick	reinforced concrete	Cement brick
Window area	N 20%, S 10 % , E &W15 %	N 20%, S 10 % , E &W15 %	N 20%, S 10 % , E &W15 %
Air conditionating	Air to Air HP	Centeral Chiller	Air to Air HP
Appliance Ownership	High	High	Low

Figure 7: Dwelling Archetypes

Validation

It is important to recognise that there are many sources of error in the process of the model development and also to understand both how uncertainties in the input variables propagate to the output variables via the modelling process, and how the uncertainty on each output variable depends on the uncertainty on each input variable.

In order to test the validity of the model, the energy consumption for each of the archetypes was scaled according to national statistics for the number of each premise type in Muscat and Oman. The scaled results are compared to total residential consumption (from AER, 2010) in Figure 8. The results are promising with the model prediction within 9% of actual for Muscat and within 22% for Oman as a whole. We consider that the larger discrepancy at the country scale is due to the larger number of unknowns at this level: for example, the model did not represent rural houses or 'other' dwellings which are accounted for ~10% of the Muscat stock and ~20% of the national stock according the2010 Census.

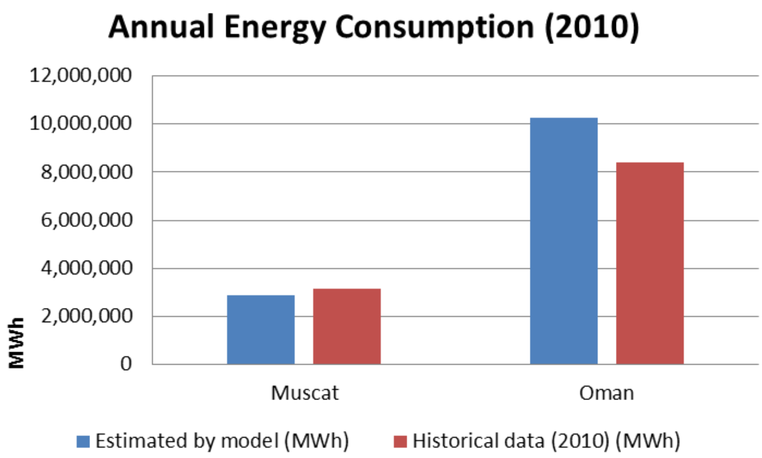


Figure 8: Model Validation

4 Addressing Residential Energy Use in Oman

Each of the drivers of residential use (fabric, systems, and occupant behaviour) can be addressed by policy and understanding the impact of policy on one or more of these areas requires the interactions between them to be understood. Figure 9 gives an estimated breakdown of energy consumption at the scale of the individual archetypes and the residential stock of Muscat as a whole as predicted by the modelling exercise.

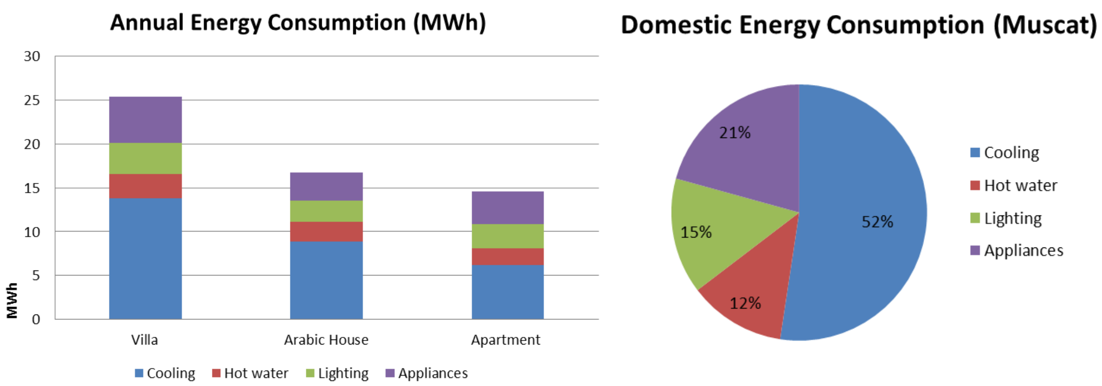


Figure 9: Breakdown of Modelled Energy Consumption

This section focuses on each of the key areas that influence energy use in turn, discussing the key characteristics which need to be understood in order to design policies that address energy consumption. Although the results presented to illustrate this discussion are not statistically significant they provide examples of the sort of valuable insights that can be made through a programme of data gathering & analysis. Further, more detailed analyses, are included in the Appendices.

4.1 Building Form and Fabric

The size, shape and orientation of a building as well as the thermal properties of the building fabric all contribute to the overall efficiency of the home. Gathering data on these characteristics is important in order to understand the properties of the building stock as a whole and provide an accurate estimate of the costs and benefits of fabric improvement.

The scoping survey gathered a range of data regarding the building fabric including construction date, basic building dimensions and information on construction materials in order to begin to understand the characteristics of the stock. All of the homes surveyed were constructed either of concrete block or cast concrete walls with roof and floors constructed of reinforced concrete**. The majority of the homes surveyed are uninsulated** as shown in Figure 10.

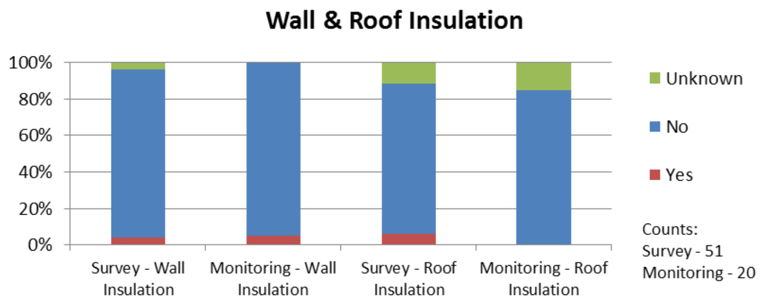


Figure 10: Percentage of Surveyed and Monitored Properties with Wall and Roof Insulation

The thermal performance of the installed glazing is also poor, with 70% of homes being single glazed and only about 10% reporting the presence of some form of reflective coating on the glazing. External shading, such as shutters, were present in about 10% of homes and just over half reported some shading from neighbouring buildings or trees.

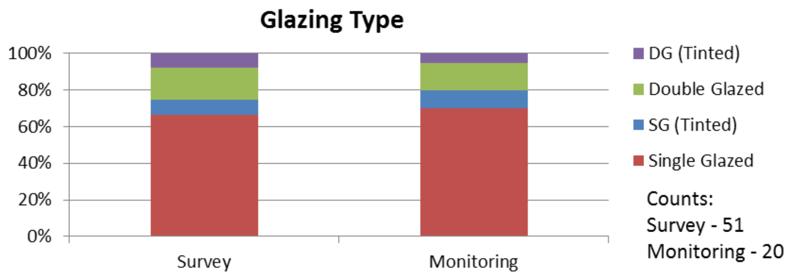


Figure 11: Glazing Type

The **heat transfer parameter** is the power per m^2 floor area required to maintain a temperature difference between inside and outside of 1^{o}C, it is a measure of the fabric efficiency. Figure 12 shows the heat transfer for each home that participated in the monitoring phase of the project plotted against the dwelling age and dwelling type**. It appears that there is little difference in the heat transfer parameter of new and old dwellings.**

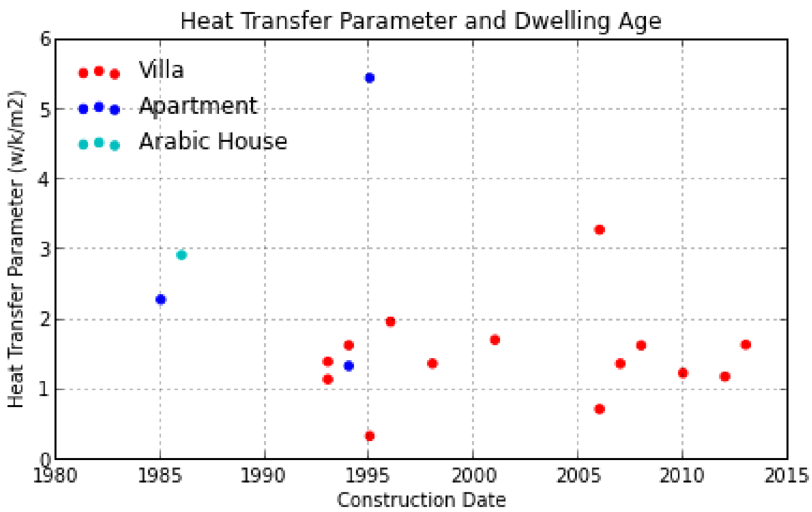


Figure 12: Heat Transfer Parameter by Age

Our investigation of fabric insulation and glazing and the heat transfer parameter indicates that **poor fabric performance is therefore an important characteristic of the surveyed homes** and this is likely to be the case with the wider stock. In order to explore the potential for improvement a number of retrofit scenarios were created and compared using the stock model. Total energy consumption for each of these scenarios and the baseline is shown in Figure 13.

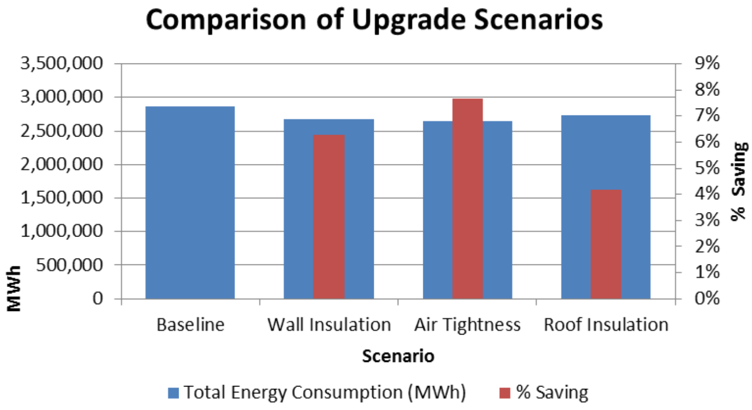


Figure 13: Modelled Impact of Different Fabric Improvements on Stock Energy Use

Each of the upgrade scenarios represents a modest improvement to the physical structure of the home by:

- Fitting wall insulation (5cm).
- Improving the air tightness of the dwelling from the assumed level of 1 air change per hour (ACH) to 0.6 ACH, for example by installing weather stripping.
- Installing roof insulation (5cm).

It appears that these modest improvements have the potential to deliver considerable energy savings. Further development of this approach would consider the costs and benefits of fabric improvements in terms of peak demand reductions, reduced subsidy costs and indeed, improved thermal comfort for building occupants.

4.2 Building Systems

Building systems convert energy in order to meet occupants' requirements for energy services. In order to understand the national stock of building systems and identify potential improvements, the systems, as well as the way they are used and maintained, must be characterised.

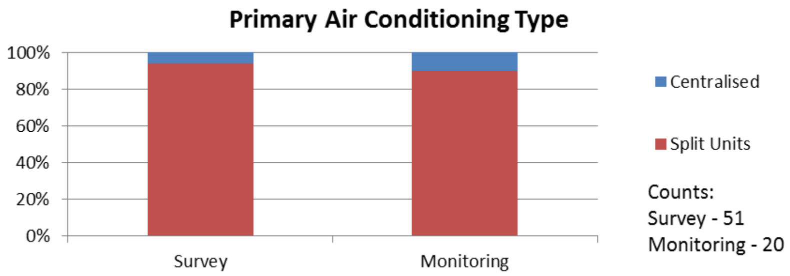


Figure 14: Primary Air Conditioning Type

The survey conducted as part of the scoping study addressed building services, cooling and hot water production, which have an important influence on energy demand. **Split air conditioners, which are controlled as individual units, dominate the sample, and were typically installed in all occupied rooms** as illustrated in Figure 14 and Figure 15.

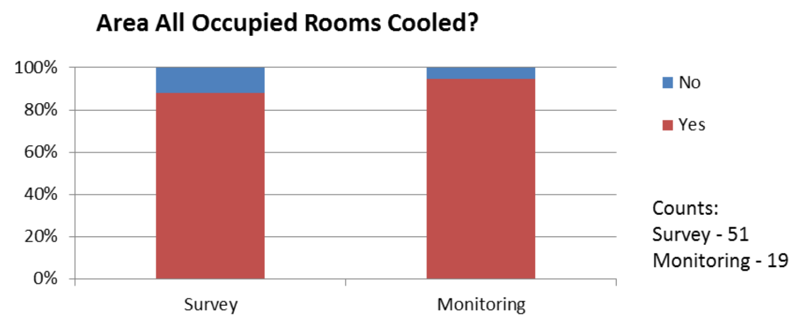


Figure 15: Extent of Cooled Area

Contrary to anecdotal evidence, self-reported rates of air conditioning maintenance among our survey population indicate that over 90% of households maintain their air conditioning system every year.

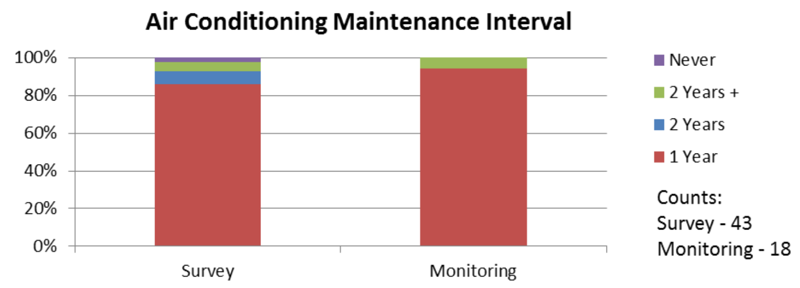


Figure 16: Reported Air Conditioning Maintenance Interval

Gathering detailed data on the efficiency of building systems is important to understand the potential for improvement, either through maintenance schemes or the replacement of poorly performing equipment. Likewise, gathering data on the appliance stock and understanding replacement rates will be important to understand the costs and benefits of appliance efficiency schemes.

4.3 Occupants & Behaviour

The households' requirements for comfort, hot water, clean clothes and other energy services is the fundamental driver of energy demand. **Understanding how consumers' energy-using behaviours are formed and may be influenced to reduce total and peak energy demand is therefore crucial**. Schemes that address behaviour, for example through tariffs or financial incentives, are often among the most cost effective approaches: however, they must be carefully designed.

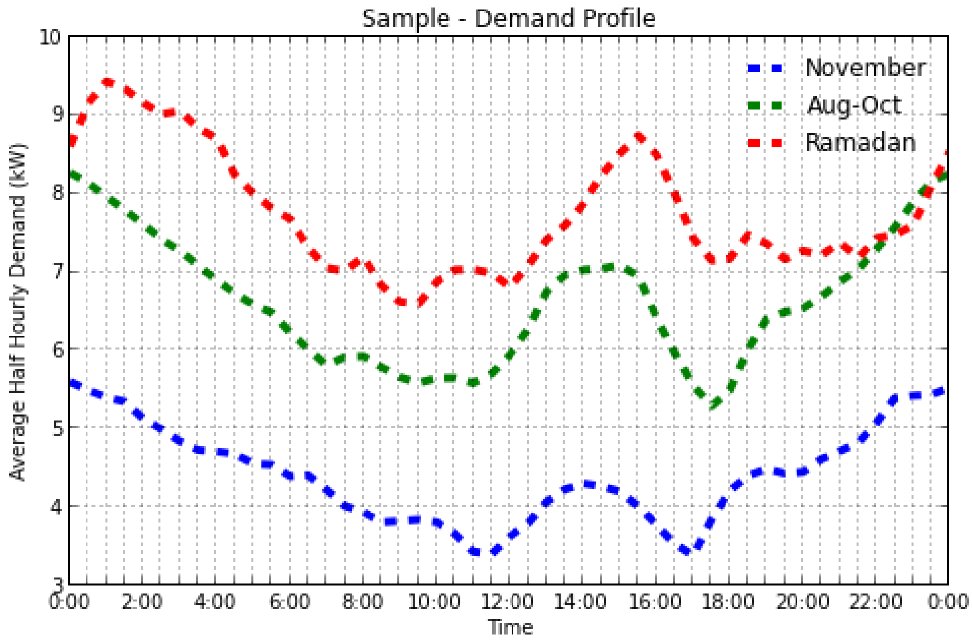


Figure 17: Sample Demand Profiles

Figure 17 illustrates this point showing the influence that patterns of energy services demand have on energy demand. It shows the monitored homes average demand profiles (in terms of average kW/half hour) for three distinct periods during the monitoring phase. Comparing the period of Ramadan (taken to be 9th of July to 8th of August) and the following months from 8th of August to the end of October (which were similar in terms external temperature- see Appendices, Figure 39) **it is interesting to see the shift in peak demand in Ramadan from midnight to approximately 2 am**, coupled with an overall increase in demand levels. In November, there is a significant overall reduction in demand linked to lower temperatures.

The nature of the split unit air conditioning where units are often controlled on an individual basis means that **the way occupants control their systems can have a significant bearing on energy use**. The survey asked householders to specify their control approach (e.g. always on, timed schedule etc), both for cooling and residential hot water (DHW): **the majority of householders reported switching their air conditioner as and when required**.

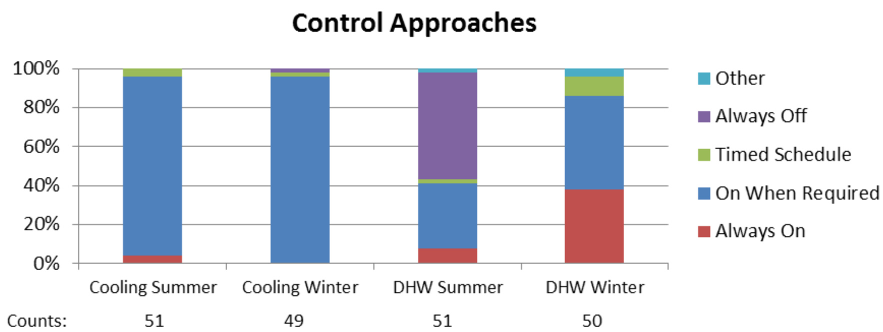


Figure 18: Survey Control Approaches

When away for an extended period of time (e.g. on vacation) the majority of households reported that they switched their systems off except for 3 of the survey respondents, who reported leaving their cooling on a timed schedule and one who reported leaving it always on.

However, the self-reporting of behaviours may not always provide reliable data and therefore **mixed methods approach (which involves triangulating householders responses with monitored data) can provide important further insights**.

The rooms where air temperature was monitored were also fitted with PIR sensors to detect occupant activity. An algorithm has been designed that analyses the temperature traces and PIR data in order to identify times when the room is being actively cooled and times the room is occupied. This algorithm is described more fully in the Appendix.

For each room in each home, the proportion of time the space is actively cooled is calculated as well as the proportion of these times that the space is occupied or unoccupied. Figure 19 and Figure 20 show output for the living spaces over the entire trial period.

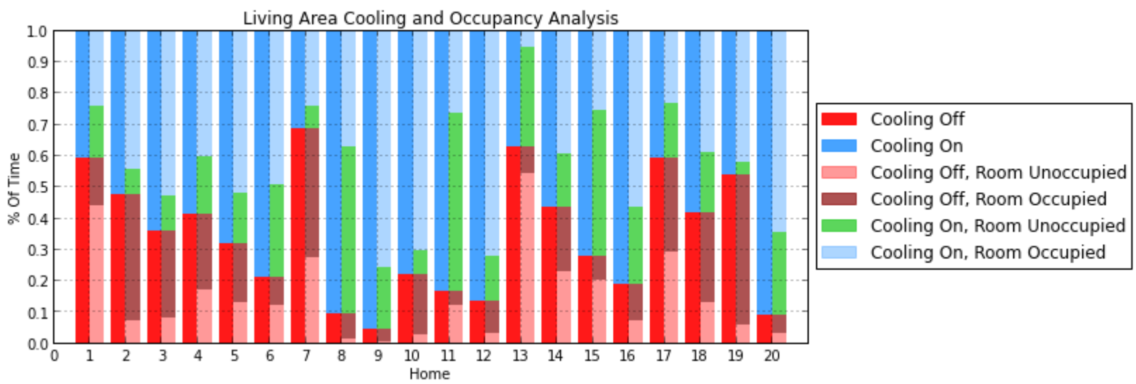


Figure 19: Living Area Occupancy and Cooling

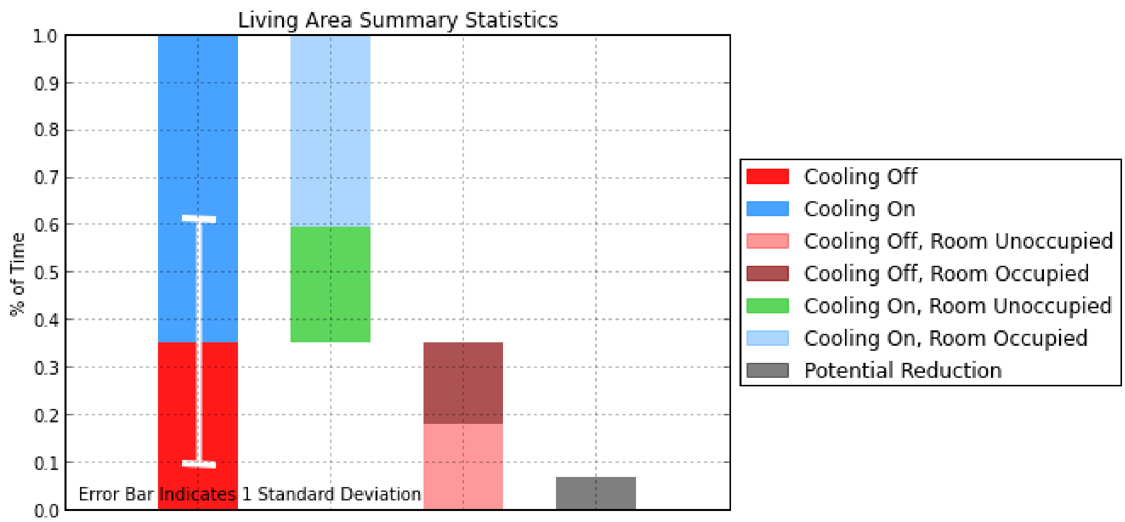


Figure 20: Living Area Occupancy & Cooling Summary Statistics

Note: This analysis relates to 'time cooled', non-linear effects caused by the nature of air conditioning and thermal mass of dwellings means that these results cannot be directly equated to energy savings.

The results of this analysis indicate that **there is a tendency for air conditioning to be left on while rooms are unoccupied but also for air conditioning to remain off while rooms are occupied.** This means that in the sample of 20 properties monitored there is a potential through better control to avoid wasted cooling energy when the cooling system is on but nobody is in the space. This occurs about 20% of the time. Better control may also mean that the cooling system will be operated during times where the space is currently being occupied but not cooled. This occurs about 15% of the time. Therefore if better controls were introduced which had both these impacts then there would be a total reduction in the percentage of time the cooling was active of about 5% while delivering improved thermal comfort through better matching cooling to occupancy.

In order to understand how well the household's chosen control strategy meets their comfort requirements, householders were asked to rate the thermal comfort provided by their home. The results indicate that **householders are generally satisfied with comfort conditions in their homes**.

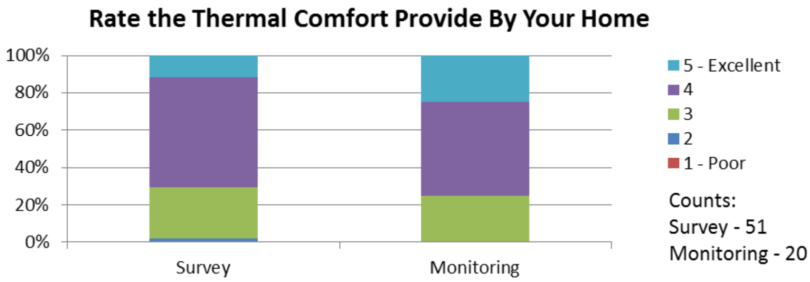


Figure 21: Thermal Comfort Rating

The adaptive comfort model[9], relates comfort conditions to external temperature taking into account how peoples' behavioural, physiological and psychological adaptation affects their perceptions of comfort. It is typically applied in the case of naturally ventilated buildings, never-the-less it is plotted here for reference.

In general, occupied conditions in the homes fall within the comfortable region. However, the average environmental conditions in six properties fall outside the theoretical adaptive comfort zone. One property is kept very cold and five properties are either at a similar temperature to outside or warmer than outside. The adaptive model would present these home owners as being uncomfortable which conflicts with their reported responses in Figure 21, **this may be an indication that current comfort models do not adequately represent Omani preferences**.

[9] De Dear, R. and Brager, G., *Developing an Adaptive Model of Thermal Comfort and Preference* In *ASHRAE Transactions* 104 (1): 145-67

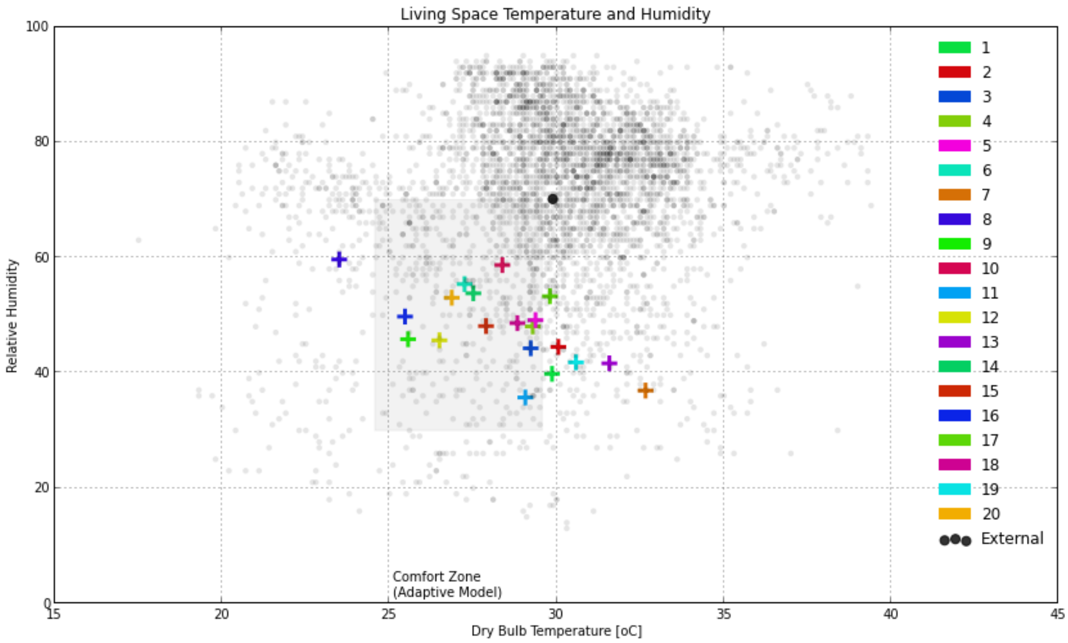


Figure 22: Mean Living Space Temperature and RH For Each Dwelling Compared to Adaptive Comfort Modelling and Monitored External Conditions

Understanding and influencing occupant behaviour is complex but has the potential to deliver cost effective energy savings. Here we have focused on requirements for thermal comfort, i.e. how occupants control their systems to achieve comfortable conditions and resulting cooling demand. All areas of energy services demand should be addressed in order to identify opportunities for energy saving and design schemes that achieve these savings.

4.4 Identifying Drivers

In order to explore the key drivers of energy demand the relationship between monthly electricity demand and a number of the key household characteristics are plotted in Figure 23.

Within our sample, the number of occupants and number of occupied rooms have a relatively strong relationship to the energy used in the home (the number of occupants and number of occupied rooms are correlated). A possible hypothesis here is that the nature of air conditioning in these homes, which generally operates on a room by room basis means that **larger households utilise and therefore cool more rooms concurrently.**

Floor area also has a positive relationship with energy use. However it appears that **dwelling size is not as strong a determinant as might be expected**. It also appears that newly constructed buildings have reduced energy use per unit floor area but our earlier analysis indicated that this may not be explained by improved fabric and cooling efficiency alone.

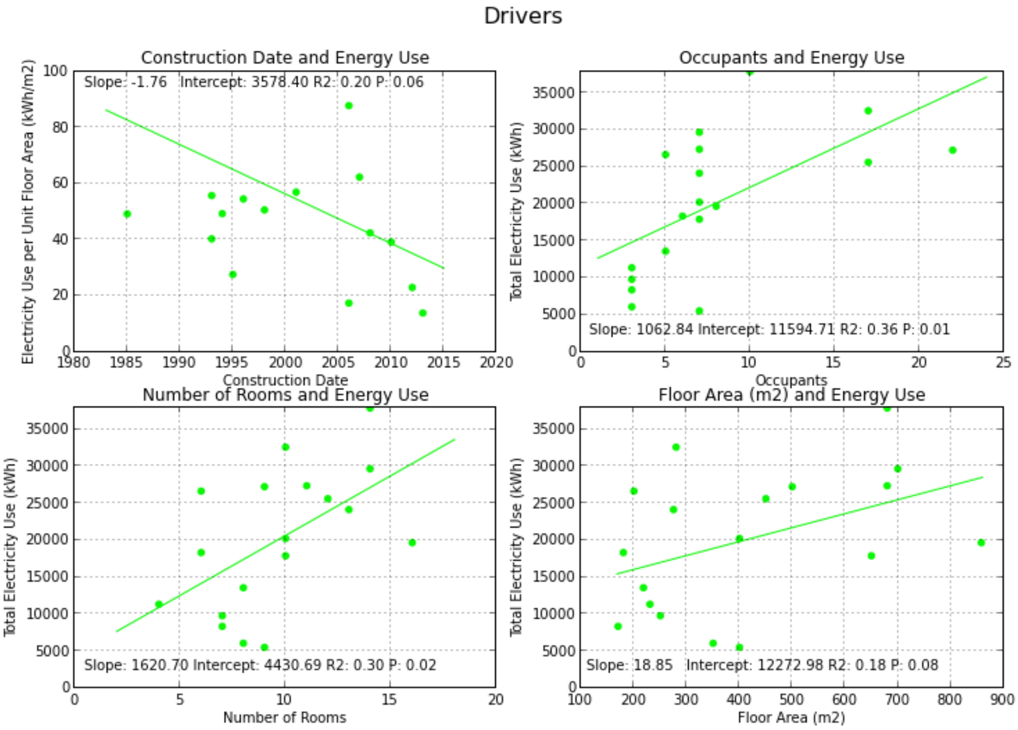


Figure 23: Construction Date and Energy Use

5 Discussion & Recommendations

5.1 Residential Energy Use

The analyses carried out as part of this scoping study have highlighted a number of interesting trends and begun to uncover opportunities for energy saving that should be investigated further.

1. ***'Buildings don't use energy people do'*** is almost a cliché among buildings and energy research. However, once again the analysis presented in this report has shown the importance of behaviour and building occupants as drivers of energy use.

   Our exploration of the drivers of energy use appears to show a strong relationship between the size of the household and the measured energy use for the household whereas the size of the dwelling appears to be less important. The number of rooms in the dwelling (in other words the number of separate spaces available for occupation) also had a strong relationship with energy use.

   This relationship is likely explained by the predominance of split unit air conditioners, which operate on a room by room basis, and the typical control patterns which according to the survey responses are to switch on the cooling as and when required. Note therefore, that if there was a move to more centralised delivery of AC throughout a building there would be considerable potential for energy use to increase.

   Deeper analysis of control patterns, revealed a propensity both to leave cooling switched on while rooms were unoccupied and to occupy spaces without using cooling (which on balance shows moderate potential to reduce waste by matching cooling use to occupancy). Use of cooling is strongly linked to a desire to achieve thermal comfort and in general, the surveyed householders were satisfied with the levels of comfort provided in their homes (although our analysis of the environmental data revealed that conditions in some homes do not fall within a typical measure of adaptive comfort).

   Finally we examined electricity demand patterns, revealing the variations caused by altered activity during Ramadan, again highlighting the important link between behaviour and energy use.

   Strategies that address occupant behaviour will therefore be an important tool in addressing total residential demand.

2. ***Ample Potential to Address Poor Efficiency.*** The survey revealed low levels of insulation and double glazing among the population, while the indicative results of the stock model

showed **potential for significant energy savings from very modest improvements in building thermal performance**.

While our analysis of the drivers of energy use appeared to show a trend towards improving energy performance among newer homes, deeper analysis of the heat transfer coefficients indicated that this may not be entirely explained by improved fabric and system performance.

Contrary to anecdotal evidence, the majority of our survey population reported regular maintenance of air conditioning systems. This is an area that should be addressed further in future studies.

5.2 Lessons from the Scoping Project

In addition to providing insights on residential energy use this project has:-

1. ***Shown the value of a mixed methods approach*** to energy research. Combining survey data, self-reporting and monitored data has helped us to develop a deeper understanding of people's attitudes to energy use, approaches to controlling their building systems and perceptions of thermal comfort.

2. ***Demonstrated the potential and importance of an Omani stock model.*** Although the model presented here is preliminary, the results of the validation are already promising, particularly for Muscat. Expanding the scope of this model and refining assumptions by gathering data on the Omani housing stock would provide a residential stock model for use by Government as a policy design and evaluation tool providing evidence for cost benefit analyses and impact assessments. The analysis of fabric upgrades presented in this report is a simple example of the type of useful analysis that might be carried out.

5.3 Next Steps - Addressing Residential Energy Use in Oman

This scoping project has piloted a data gathering and modelling approach, provided valuable initial insights and identified areas for further investigation. Improving energy efficiency in the residential stock has the potential to create benefits in terms of reducing the costs of energy subsidies and the cost of constructing infrastructure to meet growing peak demand. In order to better understand and quantify these potential benefits, we consider that the scope of a follow-on project should consist of three main work areas:

- Characterising the existing residential stock by surveying households as well as gathering environmental and energy use data.
- The development of an Omani stock model based on nationally representative data to provide the Omani government with a robust policy evaluation tool.

- Tests of a range of basic interventions in order to gather robust data on the potential for energy efficiency improvements for modelling and policy design and the development of an indigenous supply chain for energy efficiency in Oman.

This approach is illustrated below.

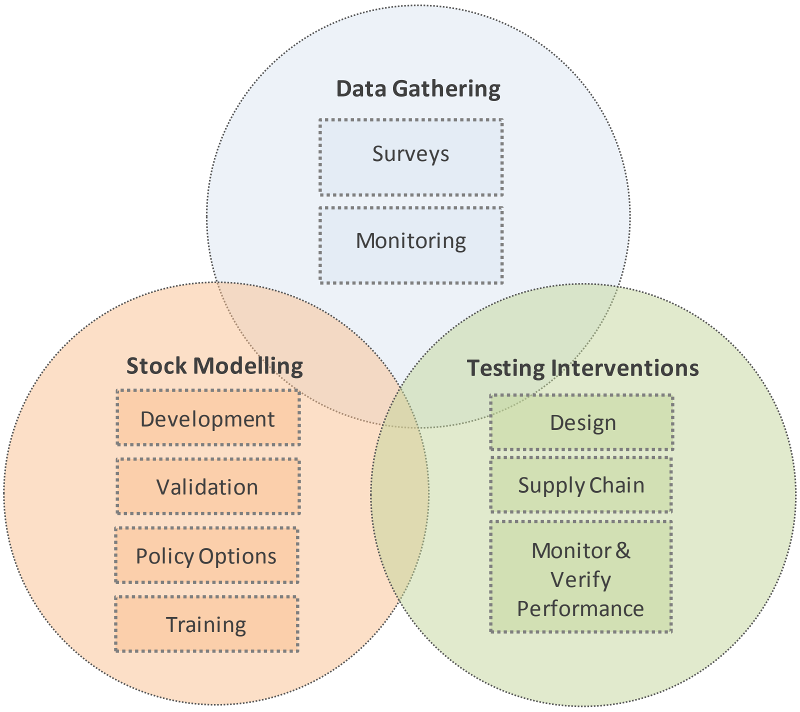


Figure 24: Project Focus

Project Delivery & Scope

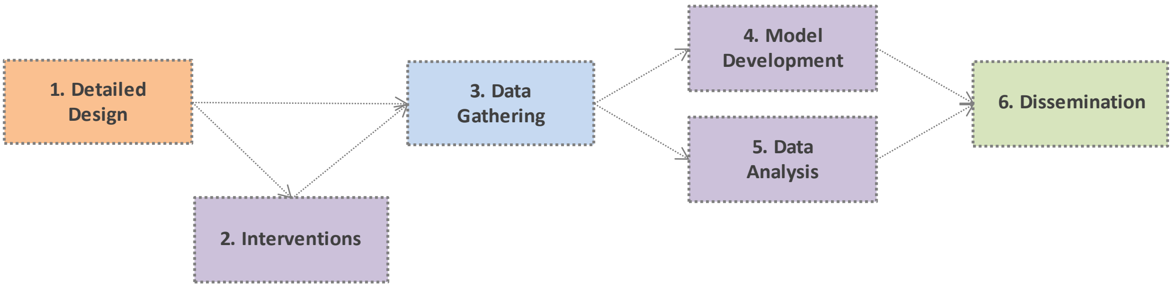


Figure 25: Project Structure

Figure 25 above is a high level structure for a follow on project which is based around 6 work areas.

1. ***Detailed design*** of the data gathering, modelling and intervention strategies will be the first work area of any large project in this area. A sampling strategy will be developed in conjunction with the modelling and data gathering requirements which will take into account the nature of the data to be gathered the importance of achieving robust results and the available budget. Figure 26 on the next page provides an example sampling strategy.

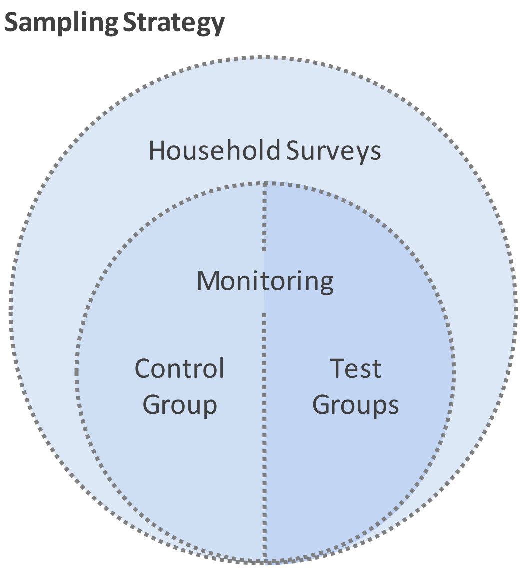


Figure 26: Example Sampling Strategy

During this phase a plan for delivering these interventions will be developed in detail, including physical design of interventions, strategies for putting in place a supply chain for the supply and installation of equipment or the provision of services.

The modelling strategy will be developed in response to the Omani Government requirements and will include a detailed list of data requirements which will inform the sampling approach and data gathering methodology, in order to ensure statistical robustness.

The data gathering strategy will include plans for the recruitment and training of suitable surveyors in conjunction with market research specialists. This stage will also include the development of survey materials, material for selected households, plans for the management of ongoing data gathering and so on. The lessons learnt (available in the Appendix) should be carefully considered and taken into account during this design phase.

2. ***Interventions*** the importance of testing interventions to understand how and why field performance may differ from theoretical performance and whether or not there are any unexpected consequences arising from putting interventions in place, has been highlighted previously in this report

There are many confounding factors that can cause actual energy savings to fall short of model predictions. Monitoring and verification pre- and post- installation can reveal the reasons behind these shortfalls and highlight means of improving real world performance. In addition to the larger data gathering effort described previously, a number of interventions could be tested. The following are some suggested interventions arising from our investigation of energy use in Oman. However, this is a non-exhaustive list and should be developed further during the project scoping phase.

Testing Tariff Designs

The cost of energy subsidies is an important issue in Oman and new means of distributing subsidies more equitably may be a useful way of addressing the behavioural factors highlighted by this scoping study.

New tariff designs may reduce energy subsidies for high energy using households, or may be assigned depending on the size and efficiency of the properties or some other measure. Alternatively, tariffs might be based around peak capacity.

Testing Efficiency Measures

This study has revealed poor levels of fabric efficiency among Omani households. Improving fabric performance may therefore be an effective way of reducing the amount of energy subsidies being paid to households. However, it is important that the potential savings delivered by efficiency measures are well understood in order to conduct a robust cost/benefit analysis.

In addition to fabric measures, approaches which address cooling energy consumption either through maintenance or replacement schemes may also deliver significant savings. Again, testing these interventions in the field will be important in order to deliver the data required for a robust cost/benefit analysis.

3. The ***Data Gathering*** phase will provide an enhanced understanding of the current built stock and its occupant. This data would be essential to develop a realistic stock model to represent residential demand adequately. It will also provide data on the performance of interventions to be used when considering the costs and benefits of any interventions to improve efficiency.

   We consider that an approach similar to the one piloted in the scoping study which combines a large scale survey with monitoring of a sub-group, will provide the right mix of breadth and depth of data required to ensure that a statistically robust understanding of the stock can be developed.

   Households for the survey should be selected at random, according to the sampling strategy developed in work area 1. Of these, a further randomly selected subgroup should be recruited to participate in the monitoring, with further subgroups proceeding to become test groups during the intervention phases.

A data framework will be developed to allow efficient data storage and recovery for the analysis phase.

4. ***Model Development.*** As part of this scoping study UCL have created a relatively simple model of energy use in the Omani stock. This initial work has illustrated the value of a modelling approach as a complement to, and an extension of, monitoring studies.

   Having gathered the required data, a model would be developed and validated. The model will be delivered in a form that is usable by the Omani Government and will deliver validated results. Having the ability to predict the impact of various interventions and conduct cost/benefit analyses would be an extremely important tool for policy design and decision-making and therefore a crucial aspect of the dissemination phase will be training Government analysts in the use of the modelling tool and generating useful insights from the results produced.

5. ***Data Analysis.*** The data analysis phase will run concurrently with the model development phase, providing inputs to guide modelling and any techno-economic analyses surrounding the interventions which have been tested.

   The analysis should not only focus on describing the characteristics of the built stock and the energy services demands of households but also try to understand the drivers of energy demand, as our analysis of the scoping study has demonstrated.

   Further, supply chain issues should be addressed and outcomes from the project will be useful in developing installation standards and regulations as well as an appropriate training infrastructure for suppliers.

6. ***Dissemination***. The results of the study should be disseminated widely among Government officials, academics and others in the private sector who may support supply chain development. Part of the dissemination process may be to make anonymised data freely available to the research community in order to support further study in the area.

   At this stage a plan should be put in place for the maintenance of the data framework, in order to ensure up-to-date data is available to policy makers.

Timescales

We expect that a project of the ambition discussed here would last approximately 3 years in order to provide ample time for planning, recruiting participants, robust testing of interventions and data analysis. Figure 27 below illustrates the timing of each of the work areas.

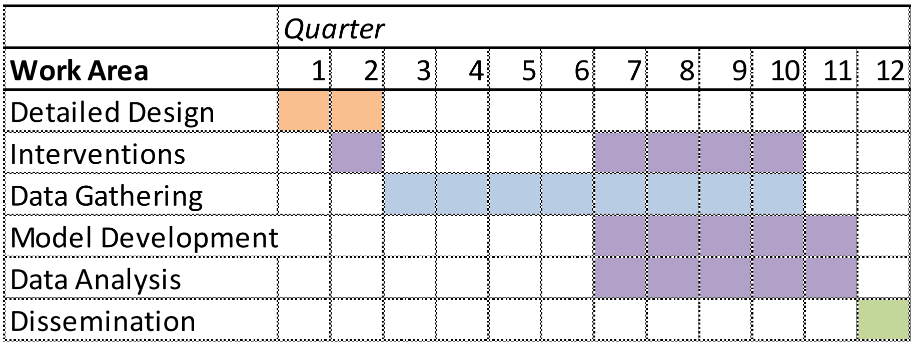


Figure 27: Project Timeline

Budget

The scope and ambition of a further project will depend greatly on the available budget. In order to provide some guidance we have examined the UK Governments recent contracting activities in this area.

- The Department of Energy and Climate Change have recently invited tenders in the range of £500-600k[10] for the development of their new National Household Model.
- The Department of Communities and Local Government recently awarded a contract for approximately £12m[11] for the supply of the English Housing Survey for three years. This involves interviewing approximately 13,500 households and carrying out physical surveys on about 6,000 homes but does not involve environmental condition monitoring or testing of interventions. For reference, there are approximately 23m dwellings in England.

It is also useful to consider the likely cost of a policy intervention, for example a scheme to insulate the Omani building stock, and allocate a small portion of that cost for example 5% to policy design and evaluation.

Detailed design of the sampling strategy would be carried out at the initial stages of the project however we estimate that a survey sample in the range of 2,000 – 4,000 homes would be required with approximately a quarter of these forming a monitored control group and at least a quarter forming a number of test cells for energy efficiency measures. The number of test cells will be dependent on the range of interventions to be tested, which will be determined in consultation with the Omani Government.

Based upon our experience of the UK Government expenditure on similar sized initiatives, we estimate that a project necessary to deliver statistically robust evidence and a tool to develop national residential energy efficiency policies would start at 2m Omani Rial. The actual cost will depend on the precise scope of the follow on project which will be informed by the recommendations presented here and reflect the priorities of the Omani Government.

[10] www.tendersdirect.co.uk/Search/Tenders/Expired.aspx?ID=%20000000002810129&sect=E062&cat=6&Source=Categories

[11] www.spendnetwork.com/tender_document/?tender_id=2011/S%2058-094339&entity_id=DPM085_DFCALG_gov&recordCount=34

Appendix 1 - The Study Population

This appendix provides some further insight into the survey population. The following graphs compare the characteristics of the surveyed and monitored homes to those for the national and Muscat region.

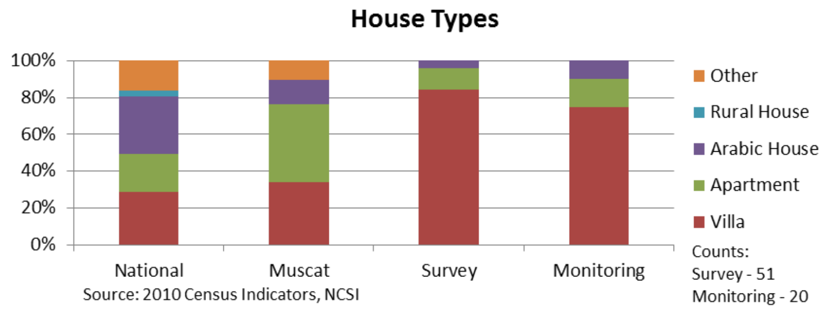


Figure 28: House Types

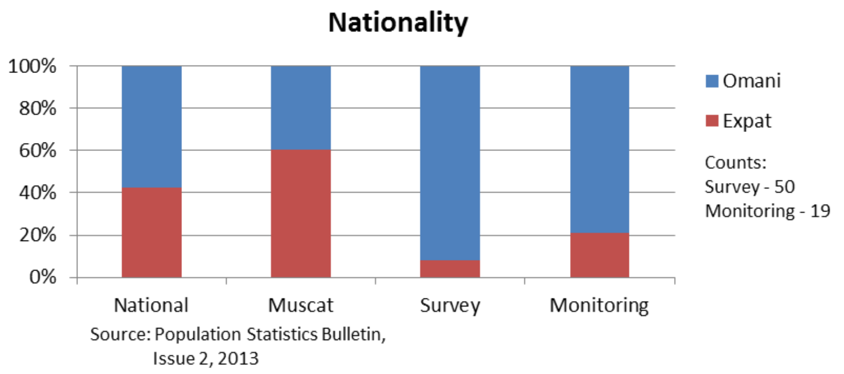


Figure 29: Household Nationality

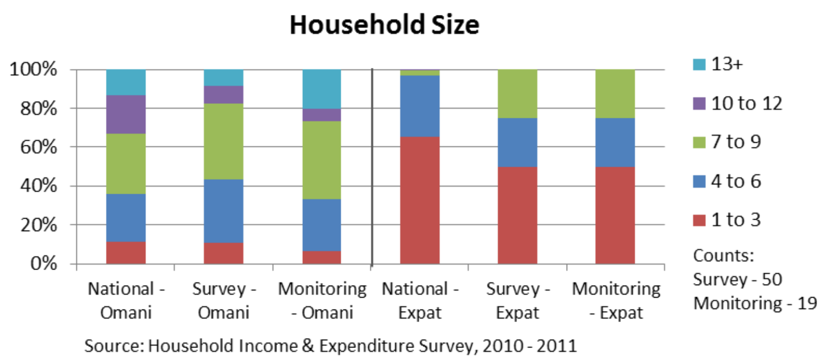


Figure 30: Household Size

Although this study has not aimed to recruit a statistically significant sample, rather to capture as wide a variety of homes as possible, it is useful to understand how the results presented here might relate to the Omani stock as a whole. In this case our sample has:

- A higher proportion of villas than the national housing stock.
- A higher proportion of native Omani's than the national population.
- Slightly more large households, both expatriate and Omani, than the national population.

This has meant that our population has higher energy consumption that average for the

Muscat area as illustrated in Figure 32 below.

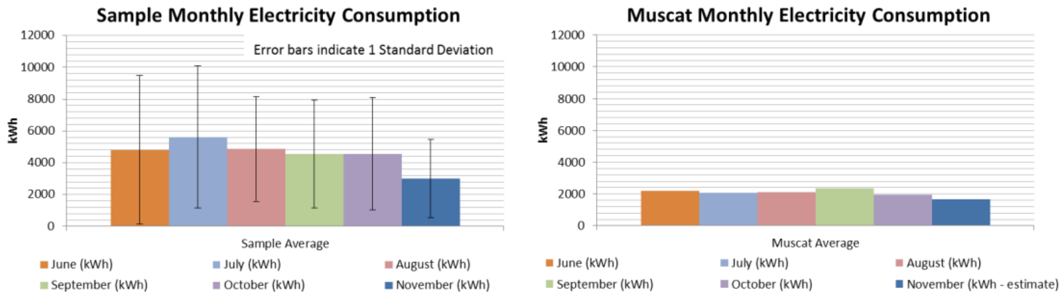


Figure 31: Sample and Muscat Monthly Energy Consumptions

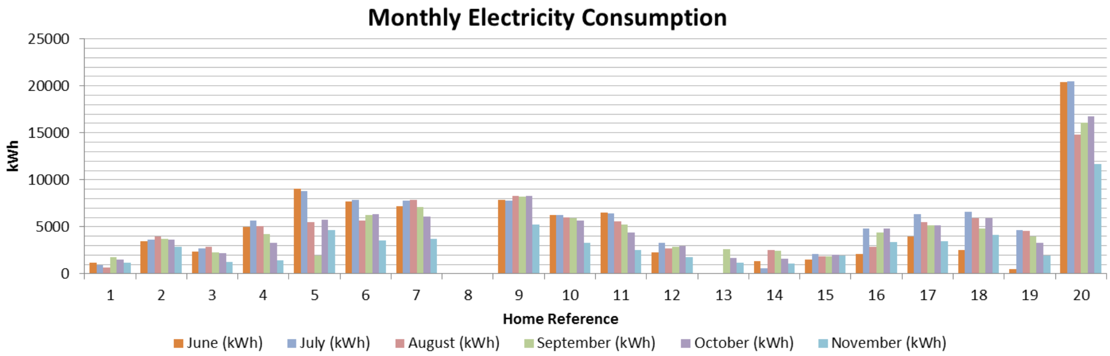


Figure 32: Monitored Household Energy Consumption

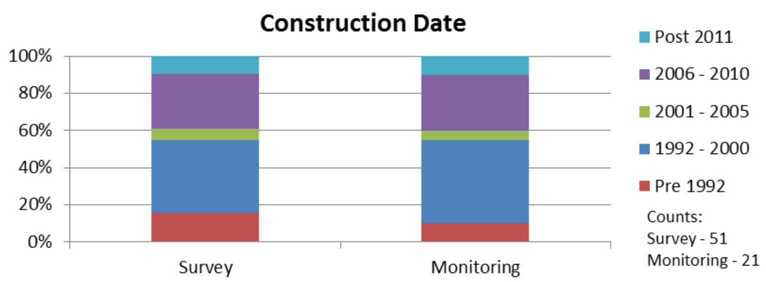


Figure 33: Construction Date

Figure 33 presents the construction dates of the dwellings. The age bands correspond with alterations to building regulations in 1992[12], 2000[13], and 2005[14] while Figure 34 shows the range of floor areas.

[12] Muscat Local Order No. 23/92- Requirements for site planning and architectural detailing requirements for Muscat Municipality

[13] Ministerial Decision 48/2000 Requirements for site planning and architectural detailing requirements for the rest of Oman.

[14] Muscat Local Ordinance No 1/2005 On the amendment of Local Ordinance 23/92

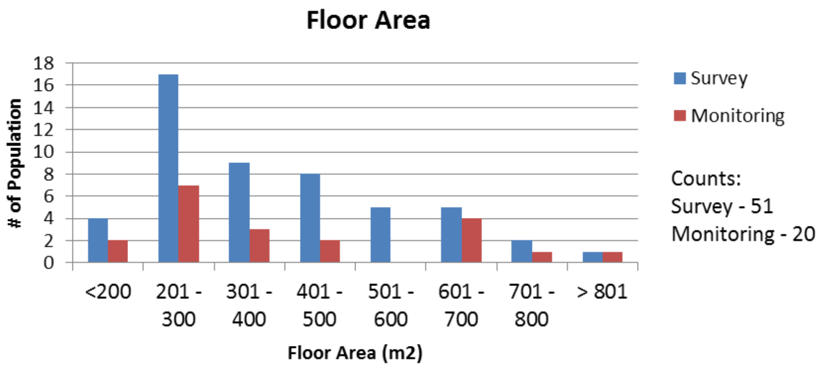


Figure 34: Distribution of Floor Areas

Appendix 2– Lessons from the Data Gathering Phase

Surveys

Issue/Lesson	Mitigation
Recruitment of households for surveys and monitoring was difficult.	A larger data gathering exercise, which aims to provide statistically robust results should have a well-defined recruitment strategy which should not only address the statistical requirements but also practicalities such as advertising and providing incentives for participation.
Constraints in the survey teams' availability made conducting the survey difficult.	A professional market research firm should be engaged for a larger study. These researchers should be available to conduct surveys on evenings and weekends in order to ensure householders are available.
Homeowners and surveyors misunderstood some survey questions leading to inconsistent data (for example floor area).	Where survey questions were unclear these should be rephrased and clarified in any future work. Researchers who are conducting surveys should be adequately trained to ensure they can explain questions to householders and collect consistent data. The use of multiple choice answers helped to ensure consistent answers and should be utilized as much as possible.
Householders were unclear about what was involved in the monitoring phase.	Researchers conducting surveys should have clear guidance to provide to the homeowner regarding the requirements of the monitoring phase including a description of the installed equipment, what is involved in the installation process and what is expected of them during the monitoring period.
The use of an online survey form proved a useful data collection tool, allowing data to be downloaded and formatted for analysis quickly.	Adopt this approach for a future programme.

Monitoring

Issue	Mitigation
Householder reluctance to have a smart meter installed at their property made it difficult to recruit homes.	Further work should be carried out to understand the reasons behind the householders' aversion to smart metering so these can be overcome. Homeowners should be provided with an incentive to comply and participate.

	Alternative, temporary, metering approaches could be used.
The requirement to have a broadband connection presented a barrier to participation – especially for low-income households.	It is likely that households without broadband will be encountered in a data gathering exercise which aims to address the full range of household characteristics. Broadband may need to be provided for these homes, in which case this needs to be provided for in the project budget. Alternatively the monitoring equipment should communicate via other means, for example a mobile connection.
Difficulty accessing wiring for air-conditioners and water heaters meant that these could not be metered in isolation.	Consider alternative approaches to monitoring individual end uses. If budgetary constraints cannot support the additional expense of this approach a subgroup could be subject to this more detailed monitoring.
Efforts to avoid damage to homes by using temporary fixings meant that monitoring equipment did not remain in place leading to data loss.	Alternative fixings should be explored for future data gathering exercises. If an option that does not damage the home cannot be found then the homeowner may need to be incentivised to accept some inconvenience.
Homeowner misunderstanding of equipment meant the loss of sensors, or the re-installation of sensors in incorrect locations.	The monitoring approach should be designed to minimise any requirement for householder interaction.
The AER team had to visit each home as it was installed in order to ensure the quality of the installation was sufficient and in some cases had to re-install equipment. This meant long installation time inconveniencing householders.	Further work is required to identify the reasons behind poor installation standards. Efforts should be made to address issues found, whether this requires further training to ensure installers have a better understanding of signal strength requirements in particular.
Obtaining weather data and meter data from various sources required significant administrative overhead.	A larger trial should include a budget for the development of automated data gathering and storage processes.
The data provided by these authorities was not always in a consistent format meaning manual a tidy-up was required before analysis.	If differing means of data collection are required during a larger study standards for data transmission and formatting should be defined.
AER had to purchase data from the Civil Aviation authority. Solar radiation data was not available.	In the future an agreement for the provision of data at no cost should be considered. Where upgrades to weather stations are required these should be requested in advance of the monitoring period.
The AER team need to invest significant amount of effort troubleshooting installations.	The mitigation actions highlighted here should help to reduce the amount of troubleshooting work required but it is

	unlikely that it can be completely eliminated. Any future budget should allow for one or more resources for troubleshooting.
Reliance on UK support and access to the database systems during and after the installation made the process of activating and quality assuring monitoring installations difficult.	A local resource should trained and provided access to tools for data management as part of the roll-out of a larger data gathering project.

Appendix 3 – Further Analysis

This appendix presents some further analysis of the data gathered as part of the scoping study.

Temperature Difference

This graph plots the daily average temperature difference (outside temperature – inside temperature, positive values are cooler inside than out) and the total daily energy use per unit floor area for each of the homes.

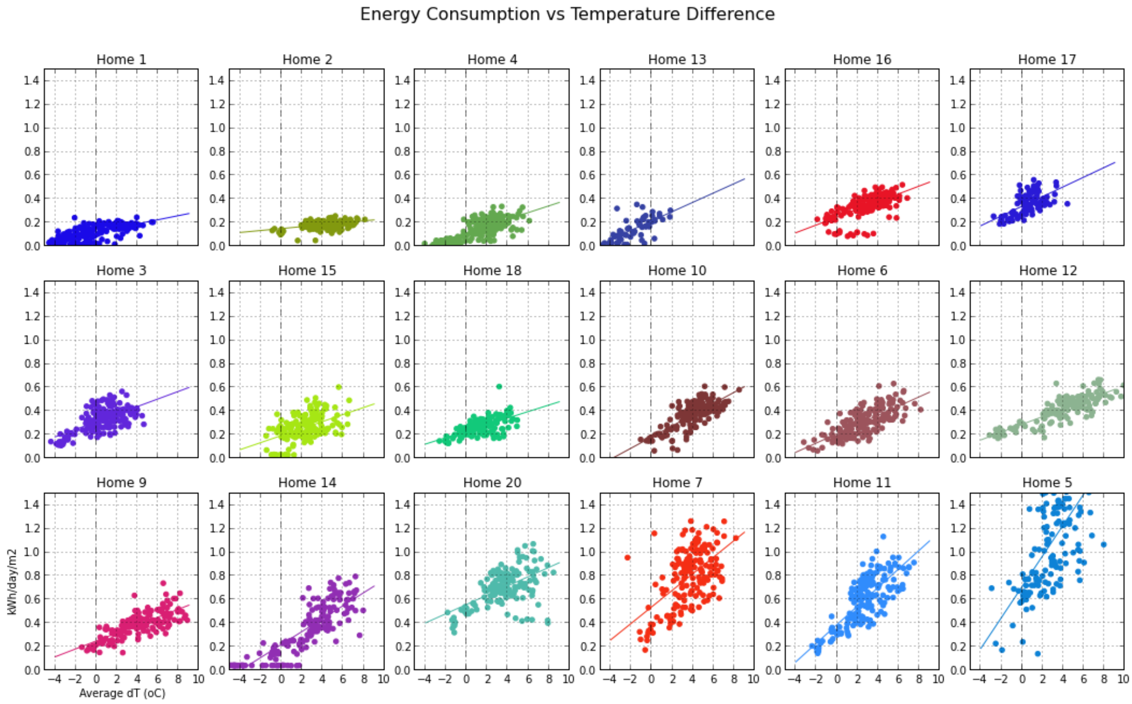


Figure 35: Temperature Difference and Energy Use

The slope of the graphs above is in theory, equal to the amount of energy required to maintain a 1 degree temperature difference, the heat transfer parameter (divided by floor area) or heat transfer coefficient. The intercept is, in theory, equal to the base load energy use of the home.

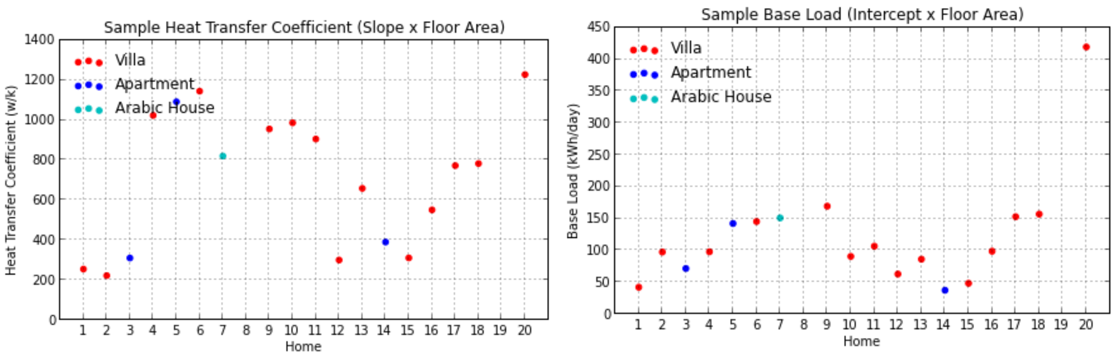


Figure 36: Heat Transfer Coefficient and Base Load

Attitudes to Energy Use

Householders were asked to rate their level of concern about the amount of energy they use and the cost of the energy they use on a 1 to 5 scale, where 5 is very concerned and 1 is not concerned. The survey results for the monitored homes are plotted above along with the recorded energy consumption for each of the homes. It is not a surprise that reported concerns do not reflect in measured energy consumption however this is a good example of the additional insight provided by combining data gathering techniques.

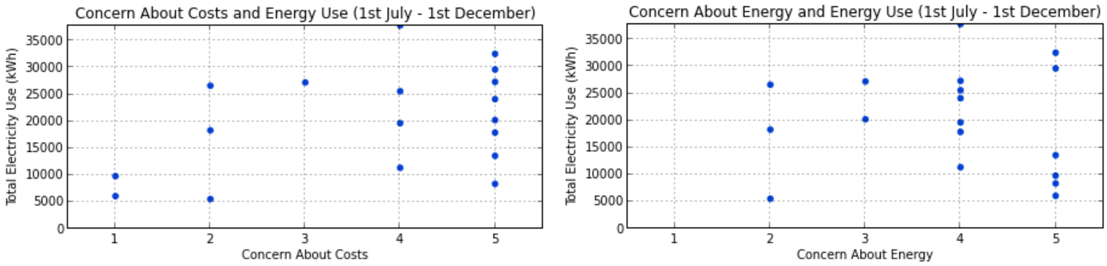
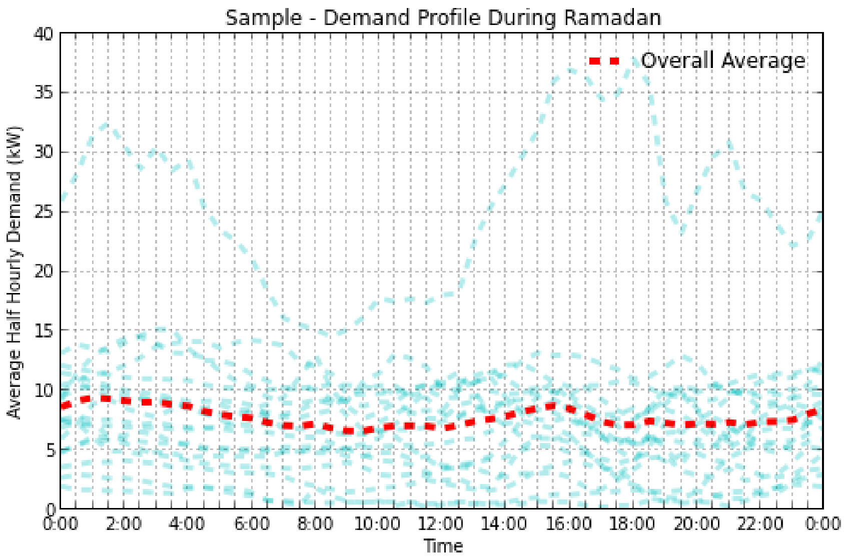
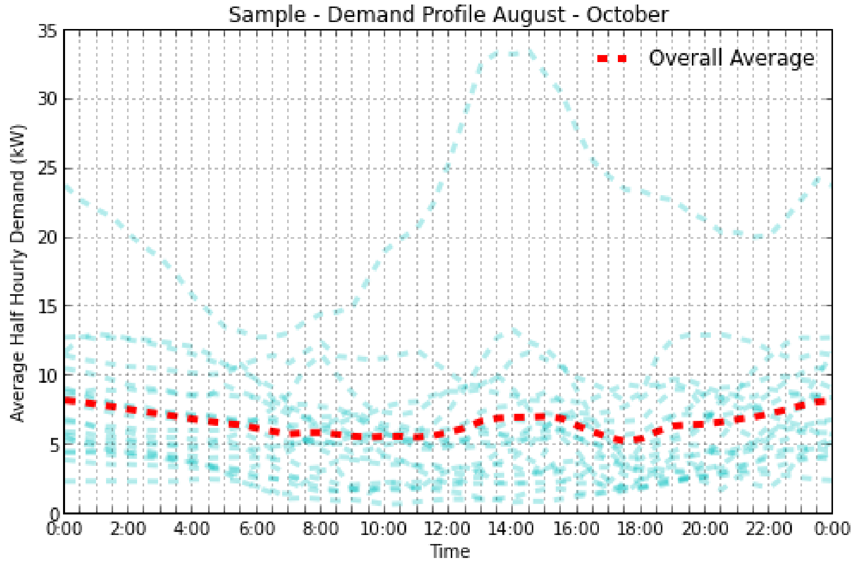


Figure 37: Concern About Costs and Energy Use vs Actual Energy Use

Demand Profiles

The following graphs present the load profiles for the monitored homes over three portions of the monitoring period.





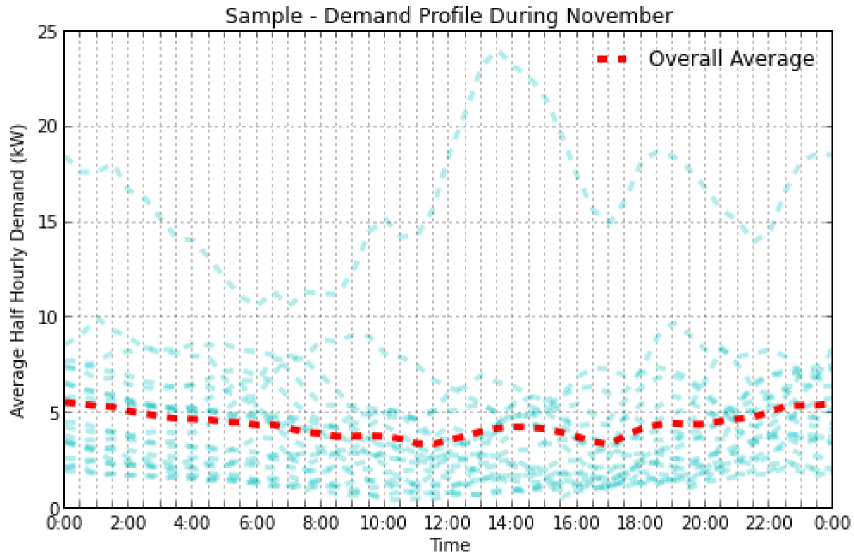


Figure 38: Sample Demand Profile During November

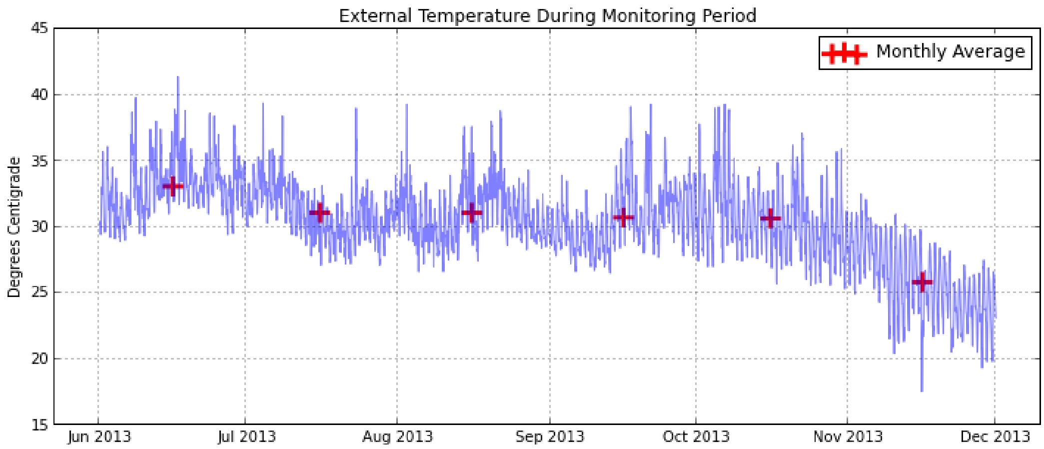


Figure 39: External Temperature for Muscat

A notable feature of these graphs is that the month of July has higher energy use throughout, while November had significantly lower use. This is most likely explained by the average external temperature during this month being 5°C lower than the previous months.

Appendix 4 – Cooling and Occupancy Analysis

This appendix describes the algorithm used to identify periods of active cooling and active occupancy.

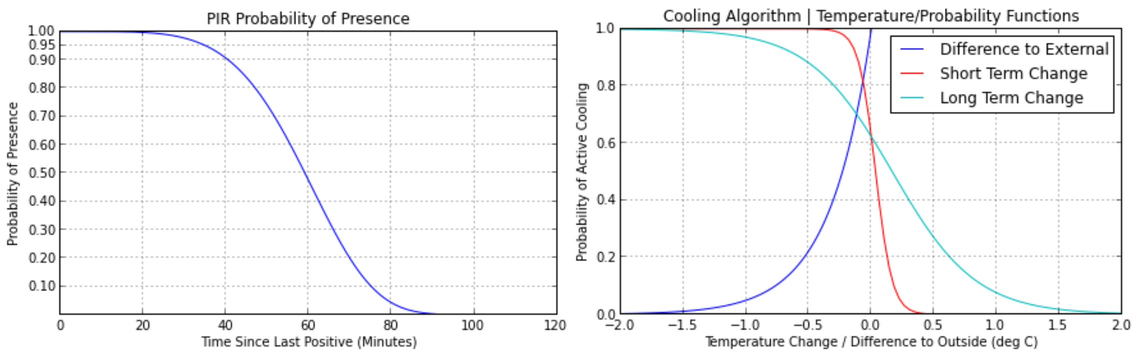


Figure 40: Algorithm Probability Functions

$$P_t = \frac{Po * P_{t-1}}{(Po * P_{t-1}) + ((1 - Po) * (1 - P_{t-1}))}$$

Equation 1: Probability Formula

Input Data

The temperature sensors installed as part of this trial record air temperature every two minutes.

The PIR sensors provide a positive every time they detect movement, and report a negative after 15 minutes of inactivity (this data is used to detect periods where the sensor is offline only.

Times when there is a gap of greater than 30 minutes in the data were ignored for this analysis.

Presence Algorithm

The PIR algorithm iterates through the data and calculates the probability of occupant presence at five minute intervals. The probability at any time (t) is determined using Equation 1 where:

> *Po:* is the probability of presence given the time since the last positive determined by the logistic curve in Figure 40.
>
> P_{t-1}:is the probability of presence in the previous time step.

Finally, occupants are considered to be present during time steps where the probability is greater than 95%.

Cooling Algorithm

The cooling algorithm considers the short term temperature change at 5 minute intervals, the long term trend, over an hour, and the temperature difference between inside and outside. Equation 1 is used three times to calculate the probability given these three pieces of evidence where:

1. *Po:* is the probability of active cooling given the short term temperature trend.
   P_{t-1}:is the probability of active cooling in the previous time step.
2. *Po:* is the probability of active cooling given the long term temperature trend.
   P_{t-1}:is the probability of active cooling having taken the short term trend into account.
3. *Po:* is the probability of active cooling given the internal-external temperature difference.
   P_{t-1}:is the probability of active cooling having taken the long term trend into account.

Again, the cooling is considered to be on where the probability at any time step is greater than 95%.

Validation

Limited truth data was available for the validation of the cooling algorithm and none for the presence algorithm.

A qualitative assessment of the cooling algorithm performance was carried out by examining output traces such as below in Figure 41.

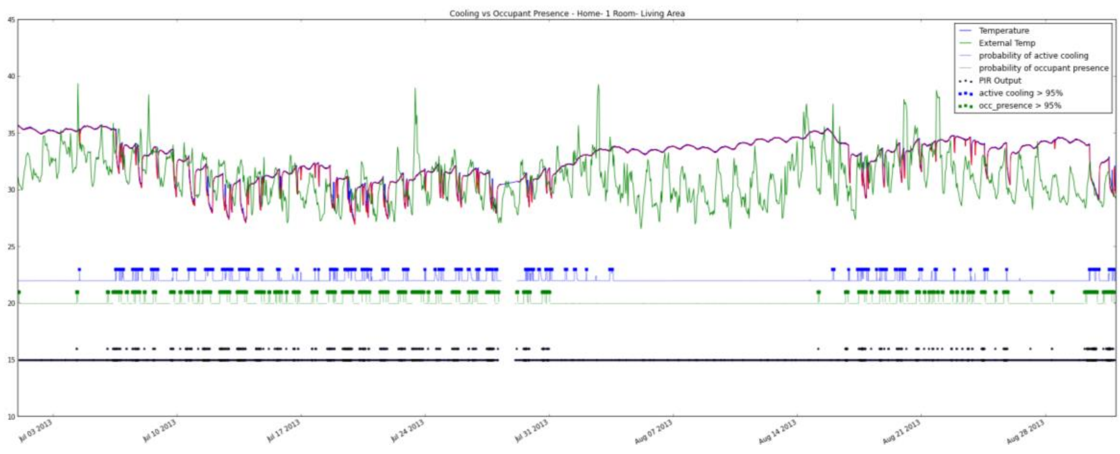


Figure 41: Algorithm Output