



## A Summary of Housing Related Research at the Otago Energy Research Centre

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## Acronyms

**BRANZ** - Building Research Association of New Zealand

**CSAFE** – Centre for the Study of Agriculture, Food and Environment

**DCC** – Dunedin City Council

**EECA** – Energy Efficiency Conservation Authority

**EMAN** – Energy Management

**FRST** – Foundation for Research Science and Technology

**HNZC** – Housing New Zealand Corporation

**HERS** – Home Energy Rating Scheme

**HEEP** – Household Energy End-use Project

**HIPs** – Home Information Packages

**NEECS** – National Energy Efficiency and Conservation Strategy

**NERI** – National Energy Research Institute

**OERC** - Otago Energy Research Centre

**SHAC** – Sustainable Habitat Challenge

**UORG** – University of Otago Research Grant

**WEP** – Waitati Energy Project

**WHO** – World Health Organisation

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## A Summary of the Otago Energy Research Centre's Housing Related Research

The Otago Energy Research Centre was formed in 2007 to bring together researchers with a common interest in the transformation of New Zealand's current energy system to one which is efficient, secure, sustainable, and carbon neutral.

Research carried out within the OERC informs the transformation of all parts of the energy system, including new and improved energy supplies and energy technologies. Housing related projects are the topic of this report, but the OERC facilitates research on a wide variety of other topics including heat pump, and wind turbine technologies, bio-fuels, low-energy options for domestic transport, peak oil, and the sourcing of energy from photosynthesis. Research on the 'user' side is a particular strength, with researchers from social science disciplines interested in the complex interactions between energy supply, energy technologies and energy use.

The OERC continues to grow and overcome the challenges associated with being a multidisciplinary research environment. Multidisciplinary research requires the embracing of common ground across research disciplines and the acceptance of fundamental differences in theoretical and methodological approaches. The benefits of such an approach are immense for the exceptionally broad and complex field of energy-related research.

The OERC is committed to developing strong research relationships with communities, local government, industry, business and government, as well as within the University of Otago.

In this report, we summarise seven completed or current research projects and highlight plans for future research. The first project, *'The impacts of Housing on Health in Dunedin, New Zealand'*, is a collaborative effort which demonstrates the need to improve Dunedin housing stock and reduce the effects of fuel poverty on health.

*'A Survey of Housing and Heating Practices'* explores how energy efficiency relates to housing prices and how people heat their homes. It also shows that most homes heat the living area, commonly in the morning and evening, but that generally, New Zealand homes are poorly designed for retaining heat. This study provides a base for modelling future thermal upgrades.

The *'Monitoring of Energy Efficiency Upgrades in State Houses in Southern New Zealand'* study shows that upgrades made to 500 homes by Housing New Zealand Corporation were generally insufficient to enable the houses to meet WHO standards. It also shows that occupants are reluctant to heat their entire homes. *'Retrofit Alternatives for State Houses in Cold Regions of New Zealand'* studies retrofitting options in two Dunedin houses and establishes a list of the most cost and energy efficient alternatives for upgrade improvements. In order of greatest benefit, the top three options are installing insulation in the roof, in the floor, and installing a wood burner or pellet fire.

Projects exploring the market include research into *'Mechanical Ventilation Systems and Heat Transfer: Is There Free Heat in the Roof Spaces of New Zealand Houses?'* Claims made by manufacturers regarding the amount of 'free heat' available in roof spaces to be harvested by mechanical ventilation systems were proven untrue during winter, when the system blew colder air into the dwelling area than was there already.

The *'Household Energy Use Survey'* is currently underway as part of the Waitati Energy Project and will collate and analyse questionnaire data on Waitati residents' energy use behaviours. This data will define the parameters of an energy use in an energy conscious community and act as a benchmark for comparisons in the future.

The strengths and weaknesses of the HERS auditing tool are investigated in *'Visualising Home Energy Efficiency: Investigating the use of HERS audits as a tool for improving the energy efficiency of New*

*Zealand's housing stock*'. This project shows that the high cost of the audit and of recommendations made by the audit in most cases, were weaknesses that outweighed the strengths of adding support and scale to New Zealand housing standards. But it also notes that the system is in an early stage of development and may yet overcome these weaknesses.

Looking to the future, the concept of '*Energy Culture*' is proposed as means of investigating reasons for the slow uptake of energy efficient technologies within the public and industrial domains. For example, why is it that technologies like cell-phones are rapidly and enthusiastically taken up into everyday life, while technologies like heat pumps experienced comparatively little up take for many years despite being proven to save money and energy whilst promoting a healthier living environment?

A consistent focus on the complex and at times contradictory issues of energy efficiency from the wide variety of research fields in the OERC will ultimately help the consumer make informed choices toward an energetically efficient, secure, sustainable, and ultimately carbon neutral future.

## Research Induces Research

### **2003 - Impacts of Housing on Health in Dunedin New Zealand: Sarah Shannon, Bob Lloyd, Jacob Roos and Jan Kohlmeyer**

In 2003 Energy Management students of the University of Otago physics department carried out a WHO/DCC (Dunedin City Council) funded project exploring the link between poor housing and ill health. Their data was then offered to Building Research Association of New Zealand (BRANZ) who required South Island data to complete an overview of New Zealand indoor temperatures for their Housing Energy Efficiency Project (HEEP). It was found that all participant households were living in thermal conditions below the 16°C minimum recommended by the WHO, with 15°C being the accepted average for thermal living conditions. WHO actually recommends 20°C for children, elderly and sick, which must occur for some of the life of any house.

The WHO identifies three thermal zones. Adequate standards of comfort are set at 18°C for all occupied rooms and 21°C in the living room. Under the definitions of fuel poverty, this would be a satisfactory heating regime. At around 16°C there is an increased risk of respiratory disease and living in temperatures of 12°C and below can put strain on the cardio-vascular system.

The baseline temperatures of 91 volunteer houses, occupied by at least one full-time student, were sampled as a representative of the poor housing sector. A profile of these houses was presented to identify areas of improvement.

Temperature sensors were placed in the living room and one bedroom in all of the houses and household information was gathered via participant surveys. From early August to late October hourly readings averaged 13°C in the living room and 12.5°C in the bedroom. The average outdoor temperature was 8.5°C.

The average temperature that houses were heated to, primarily in the evening, was 16°C, the minimum indoor temperature recommended by WHO. Surveys showed 100% of respondents expected indoor temperatures to be below 15°C on a cold winter day, with 50% claiming that their household heating equipment was sufficient for their needs. Most students opted for warmer clothing, more physical activity or leaving the house rather than spending extra money on heating.

A minimum temperature of 2°C, measured at 6am in one living room illustrates the amount of heat loss that occurs in old, un-insulated houses.

Eighty six percent of Dunedin housing stock was built before national insulation standards were put in place in 1977. Old housing stock teamed with a cool climate, poor solar access and a relatively poor population by New Zealand standards means that 36% of Dunedin households are likely to be affected by fuel poverty. This is the situation where the energy required to heat a home to optimal thermal conditions exceeds 10% of a households total income.

While students, who make up 20% of Dunedin's population, are in the low risk category in terms of housing and health, 13.3% of the Dunedin population is over 65 years of age and this may contribute to higher seasonal mortality rates than some countries with more extreme winter climates.

Results of this study show that Dunedin city needs to promptly implement short term housing and thermal improvement strategies for the aged population and long term strategies need to be developed to improve housing stock in general for future generations.

## **2005 – Survey of Dunedin Housing and Heating Practices: Bob Lloyd, Tim Bishop, Colin Smithies and Paul Thorsnes**

A combined energy and economics study surveyed 65 houses to establish the average heating requirements and practices for Dunedin single form homes. The houses were selected randomly but all were purchased by owners in 2005 and were of similar quotable value. The aim of the project was to establish a set of characteristics as part of a larger study into the preferences for energy efficient housing and how this correlates with purchase prices.

Interviews with occupants determined heating practices within the house, whilst a physical inspection assessed the type of construction, levels of insulation and temperature variants. These results were computer modelled alongside heat loss, climate, and solar gain to predict the annual energy needed to heat the whole house.

The average floor space measured was 125m<sup>2</sup>, with 60% of house area heated, most of which is used to heat the living areas in the morning and evening. These characteristics combined with various levels of insulation and solar gains are important factors affecting a household's energy requirements.

The total heat loss and the energy requirements of the homes, in conjunction with the occupant's heating schedules showed that most New Zealand houses are not designed to efficiently retain heat.

Questions regarding temperature increase to improve comfort and health without increasing carbon emissions will to be explored further to identify suitable upgrade options for Dunedin housing stock. This work will involve modelling houses with various heating and insulation systems to determine upgrade and heating costs in relation to carbon emissions.

## **2006 – Monitoring of Energy Efficiency Upgrades in State Houses in Southern New Zealand: Bob Lloyd, Mill Shen, Nathan Taylor and Maria Callau**

In 2003 Professor Bob Lloyd lead the Foundation for Research Science and Technology (FRST) funded research team monitoring household energy use for Housing New Zealand Corporation (HNZC) after national upgrades in the Southern regions.

As part of their National Energy Efficiency and Conservation Strategy (NEECS), the Housing New Zealand Corporation (HCNZ) implemented a programme to upgrade around 500 homes per year at an approximate total cost of \$40 million over an initial 5 year period.

Initial research focused on the reduction of greenhouse gas emissions these upgrades caused before extending into home insulation, human health, and bringing ultra-efficient energy technologies to the market.

Data was collected by Energy Management (EMAN) post graduate students and used to model the performance of the upgrade and conduct a cost/benefit analysis. Results showed that the effectiveness of the upgrade was unsatisfactory according to WHO standards.

Indoor temperatures in Dunedin homes over a two year period averaged 14.9°C in living areas and 13.4°C in the bedrooms. Half of all winter temperatures recorded were below 12°C, with the minimum temperature in 100 houses averaging 5°C. Overall, improving ceiling insulation and installing limited under-floor insulation increased the average annual indoor temperature by 0.4°C and the average winter temperature by 0.6°C, without the effects of space heating. Electrical energy consumption was reduced by 5-9%. All of these results remained well below the WHO thermal minimum of 16°C for homes.

The minimal upgrades were insufficient due to the fact that entire houses were not built to meet the thermal standards put in place in 1977.

Insight into behaviours towards home heating was another interesting outcome. Interviewed tenants whose homes received upgrades demonstrated a reluctance to heat their entire homes to a satisfactory level to begin with. This is likely to be another example of fuel poverty and illustrates a need for better house design.

Analysis of data from the first HCNZ Upgrade Project showed retrofitting insulation provided little improvement in a house's thermal performance. Recommendations based on this analysis were developed into two new upgrade designs which were tested in a second FRST project. It is important to note that all outcomes of these two projects are specific to southern regions of the South Island.

### **2007 - Retrofit alternatives for State Houses in Cold Regions of New Zealand REPORT Nº 2: Bob Lloyd, Tim Bishop and Maria Callau**

A second retrofit study continued by Professor Lloyd with students Maria Callau and Tim Bishop, involved designing a retrofitting plan for two Dunedin houses to establish the most energy and cost efficient way to insulate a home. This will serve as an aid for future decision making on the homeowners behalf in terms of budget, priorities and where to start.

House plans along with initial measurements of two houses in Brockville, Dunedin were inputs for a computer model to calculate the calorimetry, or annual energy requirements, to heat both houses. Since one house had insulation installed in a previous upgrade, and the other had none, alternative upgrades were decided upon to establish a cost/benefit value of various heating methods and materials.

Heating and insulation options were compared using their initial costs, energy consumed per hour, and carbon emissions released or embodied in their production. These comparisons determined the value of energy saved relative to their initial cost. The calculated benefits, in order from greatest to smallest were:

- 1) Insulate the ceiling with polyester
- 2) Insulate the floor with foil
- 3) Install a low emissions enclosed wood burner or pellet fire (if not done yet)
- 4) Install a heat pump that will replace electric heaters used elsewhere in the house.
- 5) Improve air-tightness by sealing windows and walls
- 6) Insulate walls with fibreglass and re-gibing
- 7) Install drapes and pelmets with a small space between drape and window to prevent heat loss

Cost and time is a factor in all housing upgrades, therefore further improvements have been suggested for future upgrades. These include installing thicker insulation, decreasing air infiltration especially through walls and windows and ensuring higher quality control during the retrofit process. More efficient space heating was another major recommendation however further analysis of zoned heating and passive solar gain may provide low-energy solutions to this.

Although heat pumps proved to be one of the more energy efficient heating methods it was recommended that they should not be used to replace enclosed wood burners unless the home was in a heavily air-polluted area. This is because the demand for electricity associated with having a heat pump on the nationwide grid, forces electricity generating companies to increase their use of carbon emitting energy sources, such as coal. It should not be forgotten that heat pumps are still a comparatively low carbon-emitting form of heating energy as well as being very energy efficient.

In this study it was found that Dunedin households spend 30% less on energy than average households nationwide. This suggests that southern households have adapted energy conserving behaviours to compensate for poorly designed homes and resulting heat loss. Better thermally designed houses will ensure that energy spent on heating is not lost as quickly. Computer modelling showed that it would take the same amount of energy heat a house to 20°C in the evening before the upgrade as it would to heat a house to 20°C for a whole day after the upgrade. This exemplifies energy efficiency, which is different to energy conservation, but when the two are combined there is potential for this type of upgrade to have a bigger effect on reducing energy in southern homes than in the north.

The importance of providing thermal comfort in existing housing stock through low carbon emitting measures will convey health benefits for both people and the environment. The initial costs of efficient upgrades will be less than the long term social and environmental costs of living in unhealthy housing.

## Research and the Market

### **2008 – Is There Free Heat in the Roof Spaces of New Zealand Houses? Mechanical Ventilation Systems and Heat Transfer: Inga Smith, Bonar Carson and Mark Bassett**

Dr Inga Smith, Teaching Fellow in Energy Management and OERC Steering Committee member, has recently conducted an investigation in conjunction with Building Research Association of New Zealand (BRANZ) into the effectiveness of heat transfer within mechanical ventilation systems. Dr Smith's team consisted of a physics student; Bonar Carson, who received an OERC Bursary for the project, and Dr Mark Bassett, Principal Scientist at BRANZ.

A third of all building related complaints are a result of moisture problems, half of which are related to indoor condensation. Some manufacturers claims that the "free heat" available in roof space above the dwelling area is the solution to all moisture related problems. The claim of "free heat" in the absence of independent assessment led Dr Smith and her team to investigate.

During the summer of 2007/2008 Dr Smith and her team began taking temperature and humidity measurements inside two "villa" style Dunedin houses. One house had a previously installed mechanical ventilation system, the other house served as a control with passive ventilation only. The study used a control period, where both houses used passive ventilation, and an experimental period, where one house was passively ventilated and the other mechanically ventilated.

Measurements on winter-like days during that summer indicated that the temperature in the roof space dropped below that of the dwelling below. The mechanical ventilation system continued to operate at a low rate and cold air was blown into the house. Therefore "free heat" was not available for the mechanical ventilation system to heat the house in this case.

Recommendations were made for further analysis during the winter to study the implications of preliminary results. A hypothesis that little "free heat" would be available during winter months was put to the test in August 2008. Analysis and modelling of results are currently being prepared for publication by Dr Smith and Dr Bassett.

### **2008- Waitati Energy Project: Household Energy Use Survey: Dr Martha Bell and Dr Janet Stephenson**

Waitati is a small settlement near Dunedin which is consciously attempting to respond to upcoming energy constraints and climate change through encouraging more energy-efficient behaviour and improve levels of home insulation. OERC members and their students carry out research projects, such as the Household Energy Use survey, that can assist the community in achieving its goals.

The Household Energy Use survey was suggested by Waitati community members as a good way of understanding the community's current energy use patterns. OERC has funded Dr Martha Bell, Otago Sociology Research Fellow, to run a baseline survey of households collecting data on such things as transport patterns, housing types, heating methods, appliances, insulation and solar gain. This study will establish the parameters of existing energy use and the needs and values of the community. It will be used as a benchmark against which to compare the Waitati community's transition over time to a more sustainable energy future. Analysis of data was carried out during late 2008 to early 2009, and the findings presented back to the Waitati community in April 2009.

## **2008 - Visualising Home Energy Efficiency: Investigating the use of HERS audits as a tool for improving the energy efficiency of New Zealand's housing stock: Jess Hughes**

In conjunction with the Waitati Energy Project and EECA, design for technology student Jess Hughes has completed research into the effectiveness of the EECA HERS audit system. The aim was to observe the interactions and experiences of HERS auditors and clients to identify the strengths and weaknesses of the audit system. Through shadowed observations and qualitative based interviews the feasibility of the HERS system audit system, should it ever become compulsory in New Zealand, was questioned.

Landlords, home-owners, real-estate agents and auditors were questioned on their willingness to make changes to their houses recommended as a result of the audit.

There was a strong concern for improvement in housing and energy efficiency. As an indicator of budget, design, energy value and as a projection of future energy requirements, HERS audits were considered to add strength and scale to New Zealand housing standards. The audits were considered particularly useful for people wishing to sell or buy a home, providing the house has a good energy value.

In reality, most Dunedin houses built before the 1977 changes in housing insulation, receive very poor audit reports and the costs of their repair become an issue. In addition, interviewees felt that \$500 was an unaffordable cost for an audit, even though audits done for the study were free.

The implementation of the HERS scheme was seen as problematic by some auditors. This was adding to the cost of an audit and leading to a lack of useful information for homeowners or landlords to use to improve their rating.

The weaknesses observed in HERS audits outweighed the strengths. Some interviewees suggested that EECA adopt a Home Information Pack (HIPs) auditing scheme instead, which has had ten years to develop in the UK. HIPS schemes have proved to be simpler, less time consuming and more affordable than the HERS scheme.

The main conclusion is that the HERS auditing system is still in its "teething stages" and has many improvements to make before being considered as a compulsory housing system.

## Research and the Future

### **2009 – A Sample of Housing and Energy Related Research happening in the Physics Department: Dr Zhifa Sun**

Dr Zhifa Sun, Senior Energy Studies lecturer and OERC member, has been busy co-ordinating various students in the areas of heat and mass transfer and energy systems. Applications of heat and mass transfer are diverse but the fundamental theories are common, particularly when applied to energy systems.

As a mixture of Master's and PhD projects, research ranges from heat and moisture transfer through to drainage processes, tri-generative systems (power, heating and cooling systems), and non-equilibrium interface phenomena. The latter describes the flow of liquid and gas and how they meet together or in relation to another surface.

The research projects all have a strong focus on practical design, particularly on the energy efficiency of technologies, such as heat pumps and dehumidifiers, and materials such as straw-bales for building walls. Careful experiments and mathematical modelling are used to identify and define the parameters of energy and successful design.

### **2009 – Energy Culture study: University of Otago Standard Research Grant: Prof. Rob Lawson, Dr Janet Stephenson, Prof. Gerry Carrington, Dr Martha Bell, Daniel Gnoth**

A question being asked with increasing urgency is “can society adapt rapidly to a low-energy, low carbon way of life?” A multidisciplinary team of researchers from marketing, sociology, physics and geography have proposed a project to explore the concept of ‘Energy Culture’ and ways in which it may be influenced to affect society’s rapid adaptation.

The central hypothesis for this project is that energy-related behaviour of individuals and organisations is primarily habitual and non-deliberative, and largely shaped by social and personal desires, values, and beliefs, rather than by rational and considered thought. These ‘internal factors’ interact with ‘external factors’ (regulations, prices, promotions etc). These interacting factors can be viewed as ‘energy cultures’, which will differ amongst different social groups.

The Energy Culture project will incorporate and build on the baseline survey of household energy use in the Waitati community described above. It will study two other very different examples of energy use: the households of a Dunedin suburb, and saw millers in Otago and Northland. The research aims to identify clusters of behaviour (‘energy cultures’) within these case studies that are related to some of the internal and external factors noted above. By understanding the underlying drivers of energy-use behaviour, it is hoped that ultimately it will be possible to develop better ways of encouraging the different ‘energy cultures’ to adopt more energy-efficient lifestyles or business practices. This research is of national importance as the government has set high targets for increased energy efficiency in the next few years. Ultimately, it is hoped that the Energy Culture project will lead to the development of pathways by which society can adapt consensually and quickly to a low-energy future.