Unitec Research Committee

Final Report

Modelling and monitoring the Unitec standard house to improve sustainability and indoor environmental quality.

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Executive Summary

A testing facility has been established on the Unitec campus which allows monitoring of temperatures and humidity levels in a standard 3-bedroom house, operating as a control, to compare with the performance a second house modified with alternative materials or construction techniques. This appears to be very rare for thermal testing, with most experiments being carried out at an elemental level (ie individual materials within a laboratory setting), or in situ on a small section of construction as part of a larger building.

A pilot study was completed to ensure that the monitoring process was functioning appropriately, and data collection commenced in December of the first test case, investigating the performance of a high-spec glazing unit to replace standard double-glazing. Initial findings indicate that the high-spec glazing makes a significant improvement in the thermal comfort of the house, which confirms results from laboratory-based materials tests. Monitoring is ongoing, and further analysis will provide more detailed evaluation of the benefits provided by the glazing in terms of year-round temperature performance and any resulting energy savings.

In parallel with the physical testing of the house performance, computer simulations have been used to model the theoretical performance, and test the accuracy and ease of use of commonly used environmental modeling software. This part of the project has proven more difficult than expected, and has not yet produced results with the desired accuracy to compare against the monitored data. However, the difficulties experienced have provided an insight into potential problems and improvements that need to be addressed before these systems can be used more widely by practitioners.

Background

Housing in New Zealand has been well documented as providing a low quality living environment in terms of temperatures and air quality, and is inefficient in its energy use. This project aims to identify variations on a standard 3-bedroom modular house that will contribute to an improved standard of indoor environment and more sustainable energy use. The project is based on the standard “Unitec house”, built by students on the Wairaka campus. This house design is similar in design and construction to thousands of houses already occupied across New Zealand, and thus provides an ideal model for examining the potential for improvements to a common housing type. The focus of this part of the project is to identify and test building materials and techniques that have potential for improving the building performance. A detailed monitoring programme which captures temperature and humidity data over a range of seasonal conditions allows a detailed analysis of the performance of the tested variations.

New computer technologies for representing buildings are expected to transform the construction industry, and are already having a significant impact on architecture and engineering design processes in other countries. Ecotect is a recent addition to the BIM tools currently available, and allows environmental evaluation of buildings at an early stage of the design process. Historically the strength of tools such as Ecotect lies in comparing various options to identify relative improvements in the performance of design modifications. However, the New Zealand Building Code permits the use of modelling tools to validate the adoption of non-standard design solutions. To date there has been no review of how well New Zealand environmental conditions can be modelled in Ecotect, or how the modelled performance compares with the actual building performance. This project addresses this lack with the development of a computer model of the "Unitec house", followed by simulation of its performance under conditions which allow comparison of modelled with as-built performance.

Aims and Objectives

The original aims of the project, listed below, have remained the same throughout the project.

1. To develop a database of building environmental performance data including weather data, internal temperatures, humidity.
2. To identify practical improvements to the performance of the Unitec standard house.
3. To refine the use of computer predictions of building performance through validation against actual data collected.
4. Use research processes and data to develop teaching materials and projects for students in areas of building information modelling, buildability, building science, sustainability and industry project.

The four aims have not been addressed equally, and outcomes of some have been more successful than others, as is described in the Outcomes/Findings section below.

Methodology

This project has taken a quantitative approach to approach the two aspects of the study. Extensive work has been done to develop, test and evaluate a building design, including establishing control data and developing material for future research and analysis beyond the initial scope of this project. In a parallel process, computer simulation tools have been investigated and evaluated against the same building design.

The methodology initially proposed, as set out below, has been broadly followed, with some modification, as noted.

1. Conduct a literature review to identify potential modifications, best practice for design of sensor placement and monitoring processes, and development and use of BIM and other models in environmental design

   The literature review was useful for identifying appropriate use of sensors and monitoring processes, and provided a great deal of material on the use of computer models and in an environmental context. The original emphasis on BIM taken for this project had to be de-emphasised, as the use of BIM models in this way is a reasonably recent development and there is little published material to draw on. However, there is an extensive discussion in the literature regarding the use, performance and validation of various computer models, which has been valuable. Using literature to identify potential materials or construction systems for testing has not been possible, as nothing was found that could be translated into the context of the Unitec house. The literature focused heavily on commercial or apartment developments and was not applicable to small- scale timber construction.

2. Create a computer model of a standard Unitec student-built relocatable house using Revit and Ecotect[1].

   In addition to Ecotect, a similar model has also been created using EnergyPlus, another widely-used environmental simulation tool.

3. Use Ecotect (environmental modelling) tools to conduct parametric simulations of the design variations identified in the literature review.

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[1] Ecotect is a building information modeling (BIM) tool that uses a 3D computer model of a building (created in Revit) to enable detailed whole-building analysis, including calculations of a wide range of environmental parameters.

Limitations in the Ecotect software have inhibited this part of the project, and the addition of the EnergyPlus software to the project is intended to allow parametric simulations to be conducted in the future.

4. Carpentry students to build test houses – one standard control house and a second house modified with a proposed improvement. Relocation of the completed houses to this site.

   In practice two similar standard houses were initially used in the project, while the control and modified houses were being built.
5. Install monitoring and data logging equipment throughout the buildings to allow an automated and ongoing record of building performance.
6. Monitor the buildings for two three-month periods, to cover the summer and winter. The initial winter monitoring used the standard houses, while summer monitoring has used the control and modified houses. Winter monitoring is planned for 2012.
7. Analyse monitoring data to evaluate the performance of the modified building in terms of environmental performance and living conditions, and to compare data collected from the house with data modelled using Ecotect and EnergyPlus.
8. Identify whether there are weaknesses in the simulation of the building and design variations

Outcomes/findings
As described above, the project has achieved to some extent against all of the initial objectives, although progress in some areas has not been as we hoped. We have had to modify the project schedule in order to overcome a number of obstacles that have been encountered, but although the project has had to be rolled over into 2011 it is possible to identify progress against all of the objectives at this stage.

Objective 1 has been partially completed. The test houses were completed later than originally anticipated, so the intended monitoring during winter 2010 was not possible. Instead, winter data monitoring of two pilot test houses was carried out, which along with the literature review has helped to identify and correct weaknesses in the monitoring equipment and processes. In addition, this monitoring stage has contributed to the database of temperature and humidity data that is being developed, and adds rigour to our findings around the performance of the control house, which is of similar design and construction to the pilot houses.

The new Test and Control house monitoring for the summer period began 20/12/2010. Collection of summer temperature and humidity data for both houses is still in progress. Three variations to the house configuration have also been monitored – the house with all internal doors closed, with all internal doors open, and with windows open during daytime. This allows us to estimate how much the impact of the modifications would vary under occupied conditions. This is an extension on the original project scope.

Winter data for the Test and Control houses will be carried out in winter of 2011.

The weather station was not providing accurate data over the initial winter period. Replacement of equipment and subsequent monitoring and checking has achieved reliable output from 25 Jan 2011. Weather data collection is still in progress.

Objective 2 was achieved for the first test case through collaboration with Metroglass Limited, who provided a higher specification glass to replace the standard double glazed units in the Control House. The glazing in the Test house use double glazed units with low E glass on the inside and a tinted layer to the outside, with argon gas in between. As noted above in the Methodology section, the literature review provided little insight into appropriate modifications for consideration in the NZ residential environment. Interaction with manufacturers has proven a more worthwhile route to take to identify new products or applications coming into the New Zealand market. Further opportunity exists for testing actual performance on behalf of manufacturers, as it is recognized that our testing set-up using whole buildings and with a control house, is unique in New Zealand and very uncommon internationally. Current discussions are taking place with Pro Clima NZ Ltd to consider further modifications to the test house, to test a new to New Zealand house wrap system. This has already been installed in some South Island houses. We can provide data on the comparison between current industry practice and their system which is reputed to provide vastly improved moisture control and air tightness.

From results of the first test case, initial findings indicate that the high spec glazing is reducing internal temperatures from the control house by up to 3.5^{0}C at the hottest times of the day and by 1^{0}C at the coolest times. This is a significant result which can be translated into energy savings and improved comfort levels. Once the winter test has been completed it will be possible to perform a more complete analysis to establish the value of this product in a standard New Zealand house.

Objective 3 has proven to be a major challenge. Ecotect was initially chosen as the simulation tool for modelling the project because of its availability and connection with the Autodesk Revit suite of programs. Designed for use primarily by architects (Roberts & Marsh, 2001), Ecotect allows a wide range of environmental characteristics of a building to be modelled, including whole-building energy analysis, daylighting, thermal performance and acoustic performance. A US survey in 2009 found that Ecotect was the most commonly used environmental modelling tool among architects (Attia et al., 2009)

Historically the strength of tools such as Ecotect lies in parametric studies on a building which compare various options to identify relative improvements in the performance of design modifications. However, the New Zealand Building Code permits the use of modelling tools to validate the adoption of non-standard design solutions. Because of its availability through Revit, and its demonstrated popularity with architects, it is possible that Ecotect will become one of the tools used in Building consent applications.

Although existing sources are supposed to be compatible, numerous problems have been discovered in inputting the data. As Ferrari et al. (2010: 582) have described,

> The data transfer in the present day still requires a set of complex procedures such as preparing the files to be passed from one application to another, while the documentation of this process is vague and incomplete.

Transfer of data from Revit 2009 into Ecotect 2009 was only partial. Small panels of external walls were not transmitted and failed to complete the volumes necessary for a successful simulation. This was eventually overcome by saving the 3d model in Revit 2010 before transferring to Ecotect. However this transfer continually provided a "room within a room" in one instance. This was only overcome by manually removing the additional room from within Ecotect. Thermal data was not input to Revit and transferred (as is supposed to occur) but had to be input through the Ecotect interface. Early output from the model indicating ceiling space temperatures close to that of the occupied spaces questioned whether the true thermal performance of the ceiling void was being simulated. This referred specifically to the insulation being placed on the flat ceiling and not on the underside of the sloped roof material. This suspicion was confirmed by actual measurements. As a result the house was re modelled entirely in Ecotect, rather than using the BIM capability and connection with Revit that has featured prominently in the marketing of this tool. Experience of the process and the difficulties it has presented has provided material that will be developed into a paper on the HCI (human-computer interface) aspects of the tools, which is an additional outcome from the original project intentions.

To help meet the original objectives of conducting parametric studies of the building and to compare modeled outputs with with monitored results, an additional software tool has been adopted. EnergyPlus has been identified as an appropriate tool to help in this, and has been downloaded and installed, but not yet used in the project. This software is recognised by practitioners in the field to have the potential to provide improved accuracy. Initial work, however, has shown that this tool is also far from user friendly. Future modeling work will make use of both Ecotect and EnergyPlus.

For further development of the project a technician needs to be employed to focus on overcoming these hurdles.

We have achieved some small elements of **Objective 4.** In connection with buildability issues, a problem was discovered during the installation of the high specification glass for one ranch slider. This provides valuable input for quality assurance of installation procedures in the future, and can be passed on to carpentry students in the programme.

In addition, a BCons student is undertaking a final year project in CONS7819 Industry Project in connection with the monitoring project, and additional student projects for future use have been identified.

Additional use of the database and results is dependent on the ongoing work around Objective 3 to enable us to learn from simulation data and modify teaching practice accordingly.

Conclusions

Santamouris (2005) suggests that discrepancies between simulated and measured results are commonly the result of poor monitoring practices rather than the quality of the simulation tool. However, any review of the current literature demonstrates that there are many different approaches to modelling thermal performance of buildings (Crawley et al 2005), and that they deliver variations in their results in different situations (Bleil de Souza et al, 2006). It seems disingenuous to claim that simulation is any less subject to poor practice than a monitoring programme would be. In addition to the potential for error within the algorithms and calculation processes of the simulation tools, there is also the necessity of “assumptions, simplifications, and approximations” in order to deal with real world issues that are real world issues are “complicated, uncertain and nonlinear in nature” (Hong et al., 2000: 355)

Marsh (2006) identified a number of sources of potential variances in any monitoring process. These are primarily due to differences between a single sensor and an averaged value from the simulation, resulting from:

1. Localised drafts
2. Heat plumes from equipment and people
3. Unaccounted radiant effects on sensors from heat emitters or solar insolation
4. Sensor measurement error
5. Site specific weather data

The design of this project using an unoccupied building that is closed for most of the testing period should minimise variations from sources 1 and 2 above. The additional monitoring phases exploring the impact of opening internal doors, and opening windows will allow analysis of the degree to which these factors impact on the results. Careful location of sensors to avoid location in direct sunlight, in accordance with identified best practice, minimises the third source of variation. To measure the fourth source, sensors were checked throughout the pilot study phase of the project. A high level of accuracy was observed. Management of the fifth source of variation is ongoing. Site specific weather data is currently being monitored for the site, and sensitivity analyses will be carried out to determine the impact of this on final results.

This project has been successful developing experience with monitoring techniques and building familiarity with the software. Currently major variations identified between the model and the measured data comprise the underestimation of the time lag and hence to the simulation of a real mass of the timber construction of New Zealand houses. Clearly checks on the customisation of material properties require further investigation with a view to their impacts on the thermal lag observed.

Preliminary results indicate that the glazing unit tested has a significant effect on the internal temperatures of the house. Further monitoring over the winter period, and the subsequent analysis, will be able to quantify this impact in terms of energy use and a cost-benefit analysis for the building as a whole.

Implications

Benefits of this work as a whole are wide reaching. An improvement in the internal environment of the house towards world health organization standards is a benefit to the community and ultimately a reduction in some health costs. Diseases related to housing conditions such as asthma and other respiratory ailments could occur less frequently.

By collecting data from various components to the building and measuring against a control house built to the current building code improvements can be noted and recommendations made to industry. This is an ongoing process as there is a lack of data available and a corresponding lack of knowledge of the building physics. Once we can achieve recommended values for the internal environment and reliably forecast these at design stage with computer programs then we are a long way to designing a built environment which uses much less energy and is more sustainable. At least 50% of the buildings in 2050 are already standing. The built environment currently uses 40% of the world's energy so a lot will need upgrading and we need an understanding of the local environment.

Currently there is an immediate and tangible benefit for the wider industry from the results of this project which identify performance details of the double glazing units tested. Benefits here are for the manufacturer, who now has data that show how the glazing performs in-situ in the New Zealand environment. This then has a benefit for home buyers who can evaluate the benefit of the product based on the measured results.

The difficulties experienced with the simulation tools used in the project and the issues raised around interoperability of BIM tools provide useful information for the developers of the tools and for other users. There is currently a high level of interest in this subject and the industry has been slow to adopt the tools available. By effectively "troubleshooting" the process, we can now offer advice and guidance to practitioners moving into this area.

At an institution level, we have now developed a testing facility that offers a unique resource to the construction industry, enabling a reliable comparison of new materials or construction approaches against a well-established and tested control house, with a considerable and still developing database of performance data.

Recommendations

Our principal recommendation from this project to date is that the institution recognizes the facility that we have established here and supports the maintenance of this resource, which includes retaining the current control house to allow continuity of data collection and maximize the scientific rigour for future experimentation with other interested parties.

Publications and dissemination

A draft paper was submitted to the ANZAScA conference outlining the project and findings to date. Referees feedback highlighted the very preliminary stage that the research work was at and indicated that the Ecotect software might never provide the levels of accuracy being sought. It was felt that spending time actually investigating alternative simulation software was more important than trying to rewrite the paper.

Attendance by two of the researchers (Robert Tait & Roger Birchmore) at the ANZAScA conference held at Unitec was funded from the research project funds. Only one registration was charged on the basis of the refereeing contribution made by Roger Birchmore. Attendance confirmed that the use of complete buildings as a test and control is still unique or at best rare, internationally. The value and level of technical investigation being undertaken in the Unitec project compares very favourably to content presented at this conference.

An abstract has been submitted and accepted for the SB11 World Sustainable Building Conference in Helsinki in October, and the paper is currently in preparation. Robert Tait is planning to attend and present.

A paper on HCI (human–computer interaction) around the use of the BIM and simulation tools is proposed, with an Australian conference on the subject identified as an appropriate forum for presentation (OZCHI 2011 - abstracts due June 2011, conference November 2011).

Once a full winter season of data is available, further analysis will allow the development of the intended papers (as stated in the project application) on validation and performance of the computer model, and on the performance of the glazing material tested.

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