Otara project: Thermal performance analysis of Fibre Reinforced Earth Composite Indigenous Housing in Auckland - NZ

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ABSTRACT: Unlike timber framed structures, which is the construction of most residential dwellings in New Zealand, earth buildings passively moderating more extreme seasonal temperature fluctuations by maintaining warm indoor temperatures in winter and keeping cool in the summer, due to the thermal mass of the thick rammed earth walls. In temperate climates like Auckland, this works well. The thermal mass of the rammed earth walls causes the indoor air temperature of earth buildings to follow the daily variation of the outdoor air temperature with significant attenuation and time lag, creating a thermally stable indoor environment.

This paper discusses the thermal performance of the UKU harakeke soil-cement houses, based in two locations in south Auckland. The projects are two indigenous Maori dwellings, that have been developed with a high level of consultation throughout the local community. The materials (earth as a building material – and New Zealand Flax (harakeke) have been historically valued by Maori groups for their cultural and practical significance. The project has involved research in the literature on the existing understanding of harakeke and earth use as reported in the *Traditional knowledge and Practices with Fibre extraction* [1].

Monitored data (temperature & humidity) were collected on both sites and compared with simulated results (Visual Doe 3.1 - LBL/ TAS – EDSL, UK) for validation purposes. The simulation runs (using different values for wall thickness) aimed at evaluating the thermal performance of the fibre reinforced earth composite for minimum values of thermal mass. This paper reports on the initial results for summer monitored and simulated data. The final results of this study will inform further studies into earthquake building resistance, so these could be cross-evaluated into practical and economical applications of low income housing solutions.

Keywords: bioclimatic analysis, thermal comfort, housing, building simulation, earth construction

1. INTRODUCTION

Earth construction in New Zealand as in other parts of the world are established technologies. New Zealand in particular has an historical appreciation for this technology regardless of the existent seismic constraints. Examples of earth construction pre-dates European contact, and this is mainly due to the availability of construction materials, and the recognized connection of indigenous communities to the land and the appreciation of natural resources.

The spread of earth buildings in NZ related also to the durability, relative ease of construction, good levels of sound and thermal comfort given the thermal mass, and being a relative inexpensive construction process.

In 1998, a suite of limit state earth building standards were published [2], [3], NZS 4297 Engineering Design of Earth Buildings, NZS 4298 Materials and Workmanship for Earth Buildings and NZS 4297 Earth Buildings Not Requiring Specific Design. The release of these standards have given support to building enthusiasts of earth technologies.

However, given the issues of seismic performance there is the need for engineers to be involved in the design and implementation of earth construction. This, along with the financial barriers, has been seen as a limiting factor for indigenous Maori communities to re-use this technology and benefit as in the past, from the long-term permanence of earth construction.

A number of challenges have been posed for a successful approach to the demands of low cost housing amongst Tangata Whenua (People of the land=Maori) groups in New Zealand, which involved:

Structural integrity with respect to seismic loadings; minimising input from professional engineers; achievement of thermal comfort levels; life cycle analysis to ensure long-term permanence of buildings; infrastructure solutions; design solutions that can incorporate steeper terrains; affordable technology; technology that can be adopted by non-technical workforce and construction technology that allows a significant proportion of the building to be relocated. A solution that incorporates traditional flax and earth technologies (as a building material) was developed [4], and two demonstration projects (Waimango and Otara) were designed and built near Auckland. An extensive community involvement was essential for the effective development of this Sustainable housing (UKU) initiative.

This paper deals specifically with the issues of analysing thermal performance levels, and provide this information so it can be crossed with data on seismic and economical performance.

2. DESIGN CONCEPT & COMMUNITY INVOLVEMENT

2.1 Community involvement

One of the critical elements of this research initiative was the ability of Maori communities to apply the technology derived from the study effectively into their housing solutions. Through identification of viable project management, feasibility, design, training programmes and construction teams, the communities have been engaged since the initial meetings, and researchers are able to facilitate the communitie's involvement gaining their feedback on the developments associated with the project.

Rural and urban communities were identified across a significant geographic area in the upper North Island. As an initial phase, the project involved the design and construction of two buildings (one urban and one rural) using conventional earth construction techniques with one modified trial wall. These are the Otara base case building (Figs. 1-2) and the Waimango base case building (rural building). Both buildings have been monitored for different periods of the year since July 2005. This paper focuses on the Otara building during the summer period (2005-2006).

The choice of the land for the Waimango and the Otara sites was based on reasonable proximity toThe University of Auckland and also for being able to meet the criteria of a rural and urban development site.

2.2 Design concept

In consultation with the two trusts (Waimango Papakainga Trust and the Kokiri Te Rahuitanga Trust at Otara) [5] The approval and initial sketch designs for a single room 6mx6m square floorplan was carried out. The design used a reinforced concrete floor and wall footings with continuous vertical reinforcement passing through a timber top-plate. The roof is a Pacific gullwing plywood diaphragm on exposed rafters. Considering the main goal of introducing the communities to earth construction techniques the wall materials were generally soil-cement with one panel constructed from flax fibre-reinforced earth composite.

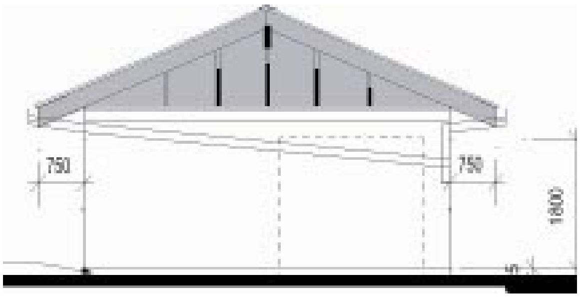

Figure 1. Elevation of UKU building (Otara)

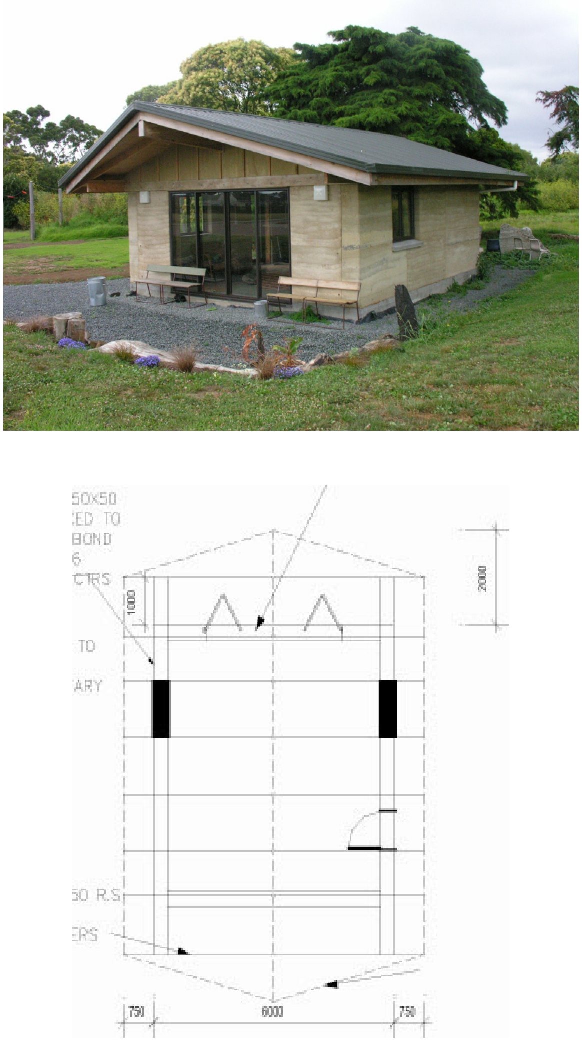

Figure 2: View and plan of UKU building (Otara)

3. METHODOLOGICAL APPROACH AND FIELD DATA COLLECTION

3.1 Bioclimatic analysis

Table 1 shows the annual changes of outdoor air temperature: the average minimum and maximum for each month, along with the averages relative humidity in the morning and afternoon. When compared to the range of temperatures an average person would take as comfortable, this would result within the comfort band, (T neutrality = Jan: 23.5°C & T neutrality= Jul::21.04°C) for January: (21.5-25.5°C) & Comfort band for July (19-23°C). As a temperate climate, the fluctuation of temperature during summer and winter, coupled with the high humidity levels, suggests clearly that thermal mass is highly beneficial in such climatic conditions. Temperatures that might fluctuate with high amplitudes on a diurnal basis, will be instead stored in the thermal mass and utilised later at night, so the degree of diurnal temperature swing can be reduced overall, both in summer and winter.

Table 1: Climatic conditions for Auckland (TRY Auckland/monthly averages Temp (C)/RH %)

Month	Aver	Max	Min	RH 9am	RH3pm
JAN	19.3	22.3	16.5	66	65
FEB	18.6	21.6	15.9	65	59
MAR	17.5	20.3	15.0	64	59
APR	15.6	18.1	13.6	81	75
MAY	13.5	16.3	11.2	79	67
JUN	11.4	13.8	9.7	83	77
JUL	11.1	13.0	9.6	84	77
AUG	11.7	13.7	10.2	77	74
SEP	13.1	15.5	11.1	74	72
OCT	14.5	17.0	12.5	74	69
NOV	15.9	17.9	14.2	77	73
DEC	18.0	20.5	15.9	74	70

3.2 Field data collection: objectives and set up

An initial data collection was made in early July 2005, so the weather files were calibrated against the monitored data. This also had informed and calibrated the modelling tools initially considered for the study: ECOTECT (UK) , VISUAL DOE 3.1 (LBL) and TAS (EDSL-UK). From the three models initially used, the experimental data demonstrated discrepancies within the results of VISUAL DOE 3.1 and ECOTECT.
The studies proceeded and another set of data was collected later in summer (December 2005) in which this study has focused on. Another set of data will be collected during July-August 2006 so a full profile for summer and winter will be discussed in a later paper.TAS (EDSL-UK) was used for this set of the simulations/comparisons.

Figure 3. Stevenson Screen at UKU building in Otara.

An external Stevenson screen (Figure 3) along with 6 sensors (data logger escort systems – for temperature and humidity), Figure 4, were set up inside the building at different locations, so an average temperature across the room could be achieved. Simple results were collected and aimed to complement the simulation results at this stage. For further studies, a set up of proper instrumentation, including transducers and heat flux meters (HFM). This will ensure heat flux will be measured accurately across the walls and examine the effect of the rammed earth wall on its heat transfer characteristics, producing the simulated results for walls with reduced amounts of mass or even no mass, but the same R-value. This can be possible recording surface temperature:

$$Q_{wall} = \frac{T_{outside\text{-}surface} - T_{inside\text{-}surface}}{R_{wall}} \quad (1)$$

Where Q_{wall} is the simulated heat flux; $T_{oustide\text{-}surface}$ is the tempetaure of the external wall surface; $T_{inside\_surface}$ is the temperature of the internal wall surface; R_{wall} is the thermal resistance of the wall (excluding air films).

The climate data file used for this study is in TRY format. For the purpose of assessment of performance as a free-running building, a continuous 10 day period, from the 34 days of data collection was chosen to be compared against the simulations. Two values of wall thickness only were compared with the original base case UKU building: 200mm and 110mm wall thickness. No changes of other parameters were considered at this stage. Results are given in terms of average temperatures for the room (across the 6 different sensors).

Figure 4. Data loggers (temperature/humidity) used at UKU housing.

3.3 Evaluation parameters: comfort band

For the purpose of performance assessment of the UKU Housing, a comfort band based on the 10 days of simulations was chosen based on Auliciems [6] adaptive model of comfort.

For a summer hot and humid period (December)

Tn = 17.6 + 0.31 Tmean

Where, 18≤Tn≤28, Tn ±2.0

Figure 5 shows the comfort zone based on the monitored data for December 2005, and the maximum and minimum tempetarure (mean) for each day, along with the monitored values (averages) for the building.

Degree hours of overheating and underheating are also counted above and below the comfort limits.

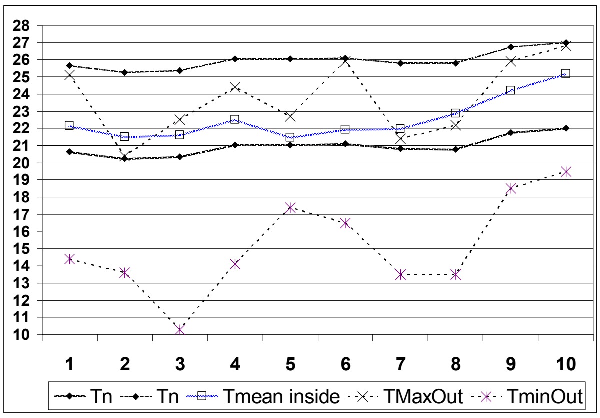

Figure 5: Comfort zone based on monitored data (December/Summer), where Tn=Tneutrality.

4. SIMULATION STUDIES

4.1 UKU house description as per simulation models

The Otara building used for the studies is a simple 6x6m building (as described geometrically on item 2.2). It was designed to operate with no conventional space heating or cooling during summer and winter. The orientation of the building allows maximum winter solar gain, while protecting from undesired winds in winter.

The building fabric is principally earth rammed walls; the floor is a concrete slab on ground. There is a north facing glass wall of single glazing. There are no internal partitions. The entire structure of the walls is of rammed earth, 320mm thickness, including flax fibre reinforced earth composite panels (southern wall, shown in Figure 2). There is one glazed door opening to the east.

Internal heat gains originate from sources that generate heat inside the building. The internal load of heat generated within a space depends on its type and use. Generally, internal loads consist of some or all of the following: occupants, artificial lighting and any other mechanical or electrical equipment operating in the space. It was difficult to estimate the internal loads for the building, since uses were not clearly set during the period of data collection. A constant assumption was made, that one person (90W/sensible-50Wlatent) and 100W in equipment load would be in the building for 24 hours. (lights – 6.25W/m2) would be on from 18:00-23:00.

Flow characteristics of zones, in kg/s, ac/h, between internal and external openings were considered. An air flow network was set up to run integrated thermal and air flow simulations, according to the data provided by the climatic file (wind speed and direction/pressure coefficients database). No data was available to calibrate the models in relation to wind temperature/speed.

4.2 Analysis of results

Two situations (wall thickness: 200mm and 300mm achieved reasonable levels of thermal comfort throughout the simulation period (Table 2), while 110mm as expected followed more closely the outside temperature conditions. The suitability of rammed earth wall construction as an effective building envelope in regard to its thermal performance is confirmed, and this is mostly due to the large mass of the walls and the associated thermal lag in heat transfer. The low R-value of earth walls, is compensated by the thermal mass of the walls, being clear from the results for 110mm, where internal temperatures tend to follow more closely outside temperatures.

Table 2 and Figure 6 demonstrate the results for the simulated and monitored values of wall thickness, when compared to the comfort zone established earlier. Both 300mm & 200mm wall thickness demonstrated minimum daily variations in temperature. Further parametric simulations would need to be carried out between the values of 200mm & 110mm to identify critical values of thermal mass while providing thermal comfort.

Table 2. Simulation period and data for variations on wall thickness used at UKU house design.

Day	Outside Mean T	Out TMax	Out TMin	300mm MeanT	200mm MeanT	110mm MeanT
01/12	17.9	25.1	14.4	22.2	20.8	18.6
02/12	16.6	20.4	13.6	21.5	20.1	17.3
03/12	17	22.5	10.3	21.6	20.3	17.7
04/12	19.2	24.4	14.1	22.5	21.2	19.9
05/12	19.2	22.7	17.4	21.5	20.1	19.9
06/12	19.4	25.9	16.5	21.9	20.6	20
07/12	18.4	21.4	13.5	22	20.6	19.1
08/12	18.4	22.2	13.5	22.9	21.5	19
09/12	21.5	25.9	18.5	24.2	22.9	22.1
10/12	22.2	26.8	19.5	25.2	23.9	23

Further measurements using heat flux meters (HFM) are necessary to accurately identify the limits of use (thickness) of thermal mass when compared to associated levels of thermal comfort.

This methodology should allow to establish heat fluxes to be calculated by using accurate thermistors located in the wall at its internal surface and in the airspace within the room. A constant surface transfer coefficient can than be obtained and assure an agreement between measured and calculated heat fluxes for the temperature differences and air movements that exist in the building.

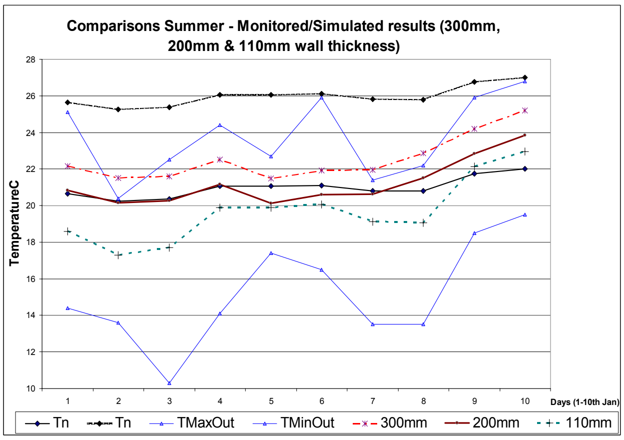

Figure 6. Monitored and simulated results plotted on comfort zone for Auckland. (300mm – monitored, 200mm & 110mm simulated results). (1th – 10th Dec 2005)

The daily profiles (Figure 7) demonstrate the time lag for the different wall thicknesses. Clearly, the 110mm profile, closely follow the outside conditions, making necessary further studies to investigate wall thicknesses between 200mm & 110mm. The profiles suggest that thermal mass governs for thicknesses of 300mm and 200mm (simulated), however is less influential for a wall thickness of 110mm.

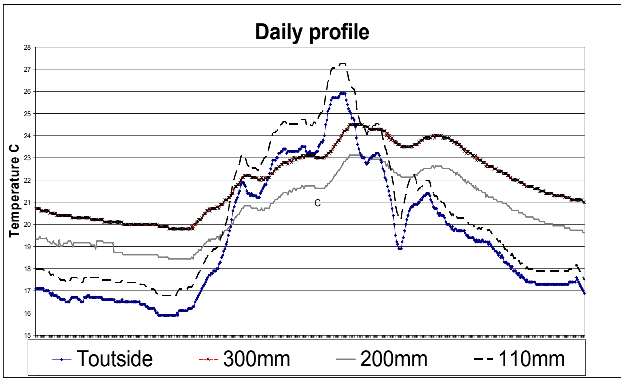

Figure 7. Daily profile (6th December 2005), including Temp. Outside and Temp inside with 300mm wall thickness (monitored results) and 110mm, 200mm wall thickness with (simulated results)

5. CONCLUSIONS

Use of building simulation software for predicting thermal characteristic of a high thermal mass passive solar building was investigated. Two different wall thickness values were tested against monitored data of the actual building.

It was found that the lower value of wall thickness of 110mm followed too close to the outside mean temperatures. Further investigation is needed to explore the values and limits on the use of thermal mass, so it can inform economical – cost effectiveness evaluation of Fibre Reinforced Earth Composite wall as an effective building element from the thermal point of view.

Winter simulations need to be carried out including monitoring of such a period, so that an annual profile can be defined. The effects of large eaves overhangs (lshading of thermal mass during summer for both east/western wall) and exposure during winter should be verified. The investigation on glazing optical properties: transmittance, absorptance and reflectance, along with heat transfer properties: overall conductance for double and triple glazing systems should be included in further studies. Since Conductance is a crucial component in determining the overall glazing system. For higher amounts of solar radiation, the overall building envelope thermal resistance is significantly influenced by the glazing system U Value. Further definition of real patterns of use/ventilation would help in developing an appropriate thermal comfort profile for the UKU Sustainable housing project.

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