RESIDENTIAL THERMAL INSULATION STANDARDS IN AUCKLAND

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SYNOPSIS

This report investigates the cost effectiveness of various combinations of foil and fibre glass insulation levels in the walls and roof of residential buildings in Auckland. The report is based on a standard 94 m^2 light-weight construction house which is fully house heated with the thermostat set at 18°C. The annual dynamic heat load has been calculated by using the computer program SUSTEP. The optimal insulation level and sensitivity has been determined for present day electricity costs and future energy costs which increase at 1% real rate of increase per annum. The energy saving role of insulation has been examined and basic recommendations of criteria for nation wide insulation standards have been made based on findings in this report.

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INTRODUCTION

The Standards Association of New Zealand in the documents NZS 4218P:1977 and NZS 4214:1977 have set provisional thermal insulation standards for residential buildings in New Zealand. The ..." provisional standard states requirements for thermal insulation of residential buildings that are believed to represent the best practicable means of reducing heat loss within current building methods and techniques ..".

Thes standards will certainly help to reduce the energy loss from residential buildings but whether the energy demand for residential space heating will be reduced as a result remains to be seen because higher insulation levels also offer the potential for higher comfort levels for the same previous energy cost. Studies by Cooke, Blakey, and Phillips indicate that there is not a clear direct relationship between energy savings and insulation levels because the consumers' socio-economic level, attitude, and user habits all play their part in determining the degree of savings brought about by changes in the insulation level. [1,2,10]

It is considered that insulation standards should be based on economic criteria rather than presumed energy savings criteria. It is contended that reduction in energy consumption will be effected by the relative increase in energy prices and that higher insulation levels will allow higher comfort levels in the face of certain increasing energy costs. This report investigates the cost effectiveness of the two major forms of insulation in New Zealand- namely foil and fibre glass. The limitations of a study such as this lies in the indeterminate nature of future energy cost predictions.

2. SUMMARY OF CONCLUSIONS

1. Steady state calculations of heat loads in a building is not a valid method for measurement of energy use. Only those computer programs that address the dynamic thermal flow (eg: NBSLD, TEMPER, SUSTEP, HEAVEN) are accurate enough to optimise energy conservation design.

   Any insulation standard based on total year degree days is also invalid because the temperature distribution profile affects the energy savings.

2. Over a period of one year there is a direct linear relationship between the total U value of each part of the thermal envelope of the house and the annual heat load required to maintain the house at or above an assumed temperature.

   aggregate ?

   It is possible to express the dynamic monthly heat load in the form of a steady state equation using the element U value, the mean effective temperature which accounts for sol-air temperatures and a constant which accounts for heat gain and loss due to capacitance effects, ventilation, solar insolation and fortuitous heat gains.

   ASHRAE TETD

   In determining the optimal cost effective level of insulation for each part of the thermal envelope the above relationships can be utilized to reduce computer time and human effort.

   The ratio of the summer to winter mean effective temperature found from the above relationship can be used to compare shape factors of different designs.

3. Each higher level of insulation in part of the thermal envelope of a building results in a smaller absolute heat load and greater absolute savings. Each additional unit of insulation generates a diminishing unit of savings because the annual heat load is directly proportional to the U value

Cont'd....

or inversely proportional to the thermal resistance of that part of the thermal envelope.

At higher total thermal envelope insulation levels the heat load is less and continues to decrease at a slower rate as the insulation level increases. At higher total thermal insulation levels each additional unit of insulation generates a further diminishing unit of savings until further additions of insulation can no longer generate any further units of savings.

4. Once a certain thermal comfort level has been accepted, any energy savings depends upon reducing heat loss, increasing solar gain in winter (but decreasing solar gain in summer so that the cooling load is reduced) and maximising the efficiency of the plant.

Heat loss savings can be regarded as an additive process. An increase in the insulation of any part of the thermal envelope generates additional savings which is independent of the level of insulation of the remainder of the thermal envelope. Once part of the thermal envelope has been insulated to a level of optimum cost effectiveness the most efficient and economical way to further increase savings is to optimise all remaining parts of the building on a cost effectiveness basis.

On a limited budget, the way to maximise savings is to reduce heat loss (or increase solar gain) in order of priority based on the rank ordering of cost in use or net present value optimum for each part of the thermal envelope and method of increasing solar gain.

5. Apart from residual heat load months occuring during the change from summer to winter and vice versa, the energy savings for all levels of insulation is dependent upon the U values of the insulation and is not dependent upon the monthly temperatures.

The annual savings generated by any level of insulation depends upon the distribution profile of the mean monthly temperatures. The potential energy saving for the residual heat load months are affected by a change in the temperature profile.

The same level of insulation in a house in a colder zone generates greater savings because the potential period for energy savings is greater. This in turn makes higher levels of insulation in colder zones more economically viable. Although energy savings in colder zones is greater, so too is the absolute heat load.

<u>Because both the consumer is interested in optimum cost effectiveness and the Power Boards are concerned with reducing electricity demands there is a strong case for zonal insulation standards</u>.

6. The sensitivity of cost effectiveness is so small that a range of insulation combinations can be used to satisfy cost effectiveness at present day electricity costs and future energy costs which may increase at the real rate of 1% per annum. These ranges for Auckland are as follows:-

Walls foil on gib board
or 50mm - 75mm fibreglass

roof 75mm - 100mm fibreglass

At or below 1% real rate of energy price increases, any higher level of insulation outside these ranges would be unwarranted on a cost effectiveness basis.

<u>NOTE</u> These insulation standards recommended for Auckland are based on:-

a) The cost effectiveness of the insulation which takes into account the cost of the insulation as well as the savings it produces.

b) A minimum inside temperature of 18°C. A higher inside temperature of 20°C would invove greater energy costs even if higher insulation standards were used. In raising a house from 18 to 20°C there would be a greater absolute heat load involved to maintain the house at this new higher thermal comfort level. With the greater heat loss involved it would be justifiable to use a higher insulation standard on a cost effectiveness basis. But higher levels of insulation generate diminishing energy savings. This rate of diminishing returns becomes more predominant at higher insulation levels. As well as involving extra insulation to maintain the house at 20°C the heat load would not be reduced to the previous level by using insulation at the new cost effectiveness level. So if absolute energy savings were the criteria then a sub-optimum insulation standard would then be required to reduce the heat load down to the previous heat load for the 18°C internal temperature house.

7. An insulation standard which is based on economic criteria takes into account the cost of the insulation, the cost of energy, the cost of money or interest rate, and the energy savings this standard can produce. The purpose of such an insulation standard would be to save more for less. Any rise in insulation standards results in greater savings of energy for a set thermal comfort level. But to base insulation standards on absolute energy savings alone would be uneconomic for the country and for the consumer. If insulation standards use energy savings as a criterion then these savings should not be greater than is economically viable to achieve so that the consumer can make adjustments and choose the appropriate level of insulation himself.

8. In setting insulation standards it should not be assumed that there will be a direct decrease in energy consumption because higher insulation standards allow a higher level of comfort for the same previous energy costs. The consumer may prefer to enjoy a higher thermal comfort level as well as reducing his energy costs.

3. HEAT LOAD CALCULATIONS

3.1 DYNAMIC v STEADY STATE HEAT LOADS

Tests by the Building Environment Division of the Institute for applied Technology, U.S. National Bureau of Standards have found that "Steady State" design is not a valid method for measurement of energy use or for sizing of HVAC equipment in structures. In order to evaluate dynamic rather than steady state thermal behaviour of a structure, the National Bureau of Standards employed a computer program known as NBSLD and which, when used with dynamic weather changes which constantly take place in any given area, will predict the heating and cool- ing loads and the temperature changes that will occur within a structure. To verify the results predicted by the computer against the actual results the structure being studied was actually built in the environmental laboratories where the weather conditions could be controlled. It was found that the computer program using dynamic analysis predicted the maximum heat flows within an average of 4.3% of the actual measured rates. But calculating the maximum heat flow rates by steady state methods, a variance of 29% to 69% resulted from the actual measured rates - and all the steady state predictions were high- er than the measured heat flow rates. 7

The Energy Conservation Design Guidelines for Office Buildings by the General Service Administration makes this statement:-

"Only those computer programs that address the dynamic thermal flow". (eg: NBSLD, SUSTEP, TEMPER, HEAVEN) "are accurate enough to optimise energy conservation design." "A major advantage in such a program is the ability to analyize a large number of alternative measures for the same building." 7

3.2 SUSTEP

The computer program SUSTEP was developed by the Division of Building Research CSIRO and is based upon the response factor technique due to Muncey. It is capable of calculating hour - by - hour temperatures in unconditioned buildings or whole - house sensible heating or cooling loads to maintain a given indoor temperature profile. It may do this for periods ranging up to several years. It performs this task efficiently and in a manner which realistically models the dynamic interaction between buildings and climate.

No thermal program is "perfect". Extreme speed of execution in SUSTEP is achieved partly because there is no differentiation between rooms (or zones) and partly because some flexibility has been sacrificed.

There are three basic assumptions regarding the thermal and physical factors in SUSTEP.

1) The conduction heat transfer through all building materials is assumed to be one dimensional.

2) All building materials are assumed to be homogeneous with constant thermal and physical properties over the entire temperature range considered.

3) The surface film resistance at the inside and outside surface of the building being examined is assumed to be constant. Note:- heat loss due to wind effects are not taken into consideration ie: convection cooling.

In view of the limitations of SUSTEP greater attention should be given to the relative heat loads the program can compute for different types of design and construction, rather than placing to much value in absolute heat load predictions.[3]

3.3 STANDARD HOUSE AND THERMAL CONDITIONS

The purpose of this study is to investigate the implications of different insulation levels upon the heat load of houses in Auckland. There are many various types of houses in Auckland, each with their own peculiar shape, orientation and micro-climate. One cannot examine all cases of housing. Instead the standard housing described in table 3.3 -a has been chosen as being a house typical to those lived in Auckland, or for that matter, any part of New Zealand. Through climate data files SUSTEP is able to compute heat loads using actual meteorological data. Mangere has a climate which is typical of the remainder of Auckland and may actually err on the colder side compared to inner city areas. The standard house is regarded as being sited on an unobstructed level site. The house is orientated to the South as most homes are not maximally orientated for solar insolation due either to site constraints or lack of foresight at the design stage.

The indoor temperature was set at 18°C and the heat source was deemed to be via a 2kW electrical resistance heating system at floor level. There are many arguments about what a reasonable thermal comfort level should be and what type of heating system should be used. Electrical resistance heating has been nominated because it is 100% efficient at the supply end of the generation line. (From generation to supply end there are heat losses and I will not get involved at this stage in the efficiency of the generation plant). Any plant which does not modify the moisture content of the air would suffice so long as the **efficiency of** such a plant was known.

The temperature of 18°C lies within the Fangar thermal comfort zone. A particular ASHRAE transaction study concludes that under no circumstances should comfort levels fall below 20°C. It is this kind of woolly research which helps to escalate our present day energy problems of supply and demand.[4]

?

Commonsense should prevail. The body can adapt to seasonal changes in temperature. In this study the thermostat controls the minimum temperature of 18°C. In this way the effects of different levels of insulation can be compared on a cost basis. However in the months of no load the temperature may be well above 25°C for the same ventilation rate of 1.5 AC/HR. People are prepared to open windows and doors in summer to allow the excess heat from ill designed homes to escape. (A rule of thumb is the greater the cooling load required in summer, the greater is the heating load required in winter). By the same token they should be prepared to put on a jersey in winter rather than expect shirt-sleeve comfort all year around.

In using 18°C as the minimum inside temperature to make a cost comparison of different insulation levels in no way am I accepting that even this temperature should be a minimum standard. Temperature profiles show that the minimum temperature inside a home occurs during the small hours of the morning when the majority of people are in bed. It would be more sensible to approach thermal comfort levels from a zonal and activity basis than on absolutes.

Table 3.3 -b, c, d, and e give the R C pairs for each component of the building fed into AUSTEP.

Table 3.3 -f gives the remaining building input factors while table 3.3 -g gives the daily internal heat emission profile contributed by metabolic heat loss and heat loss from appliances.

Table 3.3-a

Standard House Construction

Refer to " Building Economist "

Floor area - 94 m^2

Concrete pile basement/fibrolite lined base

Weather-board cladding

Corrugated iron gable roof

Particle board floor

Gib board walls and ceiling

Plan ratio 1:1.6

250 mm eaves overhang i.e. 25% horizontal shading

25 m^2 of 3 mm glazing : 10 m^2 on one long side, 3 m^2 on the other, and 6 m^2 on each of both ends.

Orientated with long window to the South.

Table 3.3-b

R-C Pairs of Roof

ELEMENT CHANGES	150 mm FIBREGLASS		100 mm FIBREGLASS		75 mm FIBREGLASS	
	m^2°C/W	m^{2}kJ/kg	m^2°C/W	m^{2}kJ/kg	m^2°C/W	m^{2}kJ/kg
OUTSIDE AIR FILM	0.03	0	0.03	0	0.03	0
METAL ROOF	0	1.97	0	1.97	0	1.97
ATTIC SPACE	0.10	0	0.10	0	0.10	0
INSULATION	3.3	6.3	2.5	4.2	1.9	3.15
12 mm GIB	0.076	12	0.076	12	0.076	12
INSIDE AIR FILM	0.09	0	0.09	0	0.09	0
THERMAL RESISTANCE	4.10		2.80		2.20	

ELEMENT CHANGES	50 mm FIBREGLASS		25 mm FIBREGLASS	
	m^2°C/W	m^{2}kJ/kg	m^2°C/W	m^{2}kJ/kg
OUTSIDE AIR FILM	0.03	0	0.03	0
METAL ROOF	0	1.97	0	1.97
ATTIC SPACE	0.10	0	0.10	0
INSULATION	1.25	2.1	0.63	1.05
12 mm GIB	0.076	12	0.076	12
INSIDE AIR FILM	0.09	0	0.09	0
THERMAL RESISTANCE	1.55		0.93	

ELEMENT CHANGES	FOIL INSULATION		NO EXTRA INSULATION	
	m^2°C/W	m^{2}kJ/kg	m^2°C/W	m^{2}kJ/kg
OUTSIDE AIR FILM	0.03	0	0.03	0
METAL ROOF	0	1.97	0	1.97
ATTIC SPACE	0.10	0	0.10	0
INSULATION	0	3.76	-	-
AIR GAP	0.363	0	-	-
12 mm GIB	0.076	12	0.076	12
INSIDE AIR FILM	0.09	0	0.09	0
THERMAL RESISTANCE	0.66		0.25	

Table 3.3-c

R-C Pairs of Wall

ELEMENT CHANGES	100 mm FIBREGLASS		75 mm FIBREGLASS		50 mm FIBREGLASS	
	$m^2 {}^oC/W$	$m^2 kJ/kg$	$m^2 {}^oC/W$	$m^2 kJ/kg$	$m^2 {}^oC/W$	$m^2 kJ/kg$
OUTSIDE AIR FILM	0.03	0	0.03	0	0.03	0
WEATHER BOARDS	0.15	19.2	0.15	19.2	0.15	19.2
INSULATION	2.5	4.2	1.9	3.15	1.25	2.1
12 mm GIB	0.076	12	0.076	12	0.076	12
INNER AIR FILM	0.09	0	0.09	0	0.09	0
THERMAL RESISTANCE	2.85		2.25		1.60	

ELEMENT CHANGES	25 mm FIBREGLASS		FOIL INSULATION		NO EXTRA INSULATION	
	$m^2 {}^oC/W$	$m^2 kJ/kg$	$m^2 {}^oC/W$	$m^2 kJ/kg$	$m^2 {}^oC/W$	$m^2 kJ/kg$
OUTSIDE AIR FILM	0.03	0	0.03	0	0.03	0
WEATHER BOARDS	0.15	19.2	0.15	19.2	0.15	19.2
AIR GAP	-	-	0.61	0	0.18	0
INSULATION	0.63	1.05	0	3.76	-	-
12 mm GIB	0.076	12	0.076	12	0.076	12
INNER AIR FILM	0.09	0	0.09	0	0.09	0
THERMAL RESISTANCE	0.98		0.96		0.53	

Table 3.3-d

R-C Pairs of Floor

ELEMENT CHANGES	FOIL UNDER JOISTS		NO EXTRA INSULATION	
	$m^2 {}^oC/W$	$m^2 kJ/kg$	$m^2 {}^oC/W$	$m^2 kJ/kg$
GROUND	1.5	4800	1.5	4800
AIR SPACE	0.335	0	0.12	0
INSULATION	0	3.76	-	-
AIR GAP	0.10	0	-	-
PARTICLE BOARD	0.15	19.2	0.15	19.2
CARPET & underlay	0.26	1.89	0.26	1.89
INSIDE AIR FILM	0.09	0	0.09	0
THERMAL RESISTANCE	2.44		2.12	

Table 3.3-e

R-C Pairs of Windows

no drapes taken into consideration

ELEMENT	SINGLE GLAZING		DOUBLE GLAZING	
	$m^2 {}^oC/W$	$m^2 kJ/kg$	$m^2 {}^oC/W$	$m^2 kJ/kg$
OUTSIDE AIR FILM	0.05	0	0.05	0
3 mm GLASS	0.003	5	0.003	5
AIR GAP	-	-	0.43	0
3 mm GLASS	-	-	0.003	5
INNER AIR FILM	0.09	0	0.09	0
THERMAL RESISTANCE	0.14		0.58	

Table 3.3-f

SUSTEP Input Data

	North	East	South	West
Shading Coefficient	1	1	1	1
Horizontal sun break	25	25	25	25
Outer skin absorbtivity	.7	.7	.7	.7
Low temperature emissivity	.9	.9	.9	.9

Geographic Location — Latitude:- -37.5

MANGERE — Longitude:- 175.3

Ref Long. :- 180.0

Azimuth = 0^{o} (House is facing South) - by noninsulation /wall?

Driver temperature for the ground:- 15.5 °C

Air changes per hour:- 1.5 AC/HR

Continuous Heating to 18°C
Thermostat has 1°C differential

Heating Plant has maximum output of 2kW

(Note:- Parallel Path Heat Flow Type was not available for under the floor heat loss considerations. However this does not affect the study of the Wall and Roof Insulation Levels as section 5 outlines in detail.)

SUSTEP Output Data

Output was given in MJ for each month. this was a heating load only as SUSTEP does not give a cooling load simultaneously.

Table 3.3-g

Daily Internal Heat Emission Profile

HOUR	TOTAL CONTRIBUTION (W)	OCCUPANT CONTRIBUTION (W)
0000	400	400
0100	400	400
0200	400	400
0300	400	400
0400	400	400
0500	400	400
0600	400	400
0700	400	400
0800	2000	600
0900	150	150
1000	150	150
1100	150	150
1200	150	150
1300	150	150
1400	150	150
1500	150	150
1600	150	150
1700	4000	450
1800	4000	600
1900	1000	600
2000	1000	600
2100	1000	600
2200	1000	600
2300	1000	600

The fortuitous heat emitted by the occupants and appliances are delivered over the previos hour to the time listed above.

3.4 HEAT LOAD RESULTS

All heat loads have been converted to kWh energy units. This simplifies calculations of electrical heating costs which are required later.

3.4.1 Annual Heating Loads and Savings - Mangere.

Table 3.4.1-a gives the annual heat loads and savings for different insulation regimes of a standard light weight construction house in Mangere. The temperature is thermostatically controlled not to fall below 18^{o}c and the minimum average air changes per hour is 1.5 AC/HR

Each higher level of insulation results in a smaller heat load and greater absolute savings compared to the uninsulated house. However, each additional unit of insulation produces a diminishing unit of savings as later sections of this report will show.

3.4.2 Annual Heat Loads Versus Changes in Roof and Wall Insulation.

Graph 3.4.2-a shows the changes in heat load for different insulation levels in the roof while the insulation level in the walls is held constant at 50mm and 75mm of fibreglass.

Graph 3.4.2-b shows the changes in heat load for different insulation levels in the walls while the insulation level in the roof is held constant at 150mm of fibre-glass

On both graphs the U value of the added insulation is also shown for each changing level of insulation. For higher insulation levels the added insulation U value approximates the total element U value as.

$$U_{TOTAL} = 1/\text{Resistance of fibre-glass} + \text{Resistance of remaining elements.}$$

As can be seen the U value v insulation thickness curves closely follow the annual heat load v insulation thickness curves. Although there are seasonal and diurnal changes in solar insolation and temperature, over a period of one year this seems to even out so that a linear relationship between insulation U values and the corresponding heat load can be seen. To determine the degree of this relationship the heat loads for each corresponding total element U value have been plotted on a scatter diagram (see graph 3.4.2-c). The correlation co-efficient r has been calculated for each group of scatter plots separately because each group represents the heat load - insulation U values relationship for different total house insulation conditions. Although only four scatter plots have been shown for each group this does not affect the reliability of such a correlation test as intermediate plots can be interpolated with sufficient accuracy to increase the total number of data points.

The results of the correlation test are as follows:

(1) 50mm fibre-glass insulation in walls. Changing levels of insulation in roof.

Annual
Heat load kWh = 1286 (total roof "U" value) + 1660

r = 0.998

(11) 75mm fibre-glass insulation in walls. Changing levels of insulation in roof.

Annual
Heat load kWh = 1265 (total roof "U" value) + 1521

r = 0.998

(111) 150mm fibre-glass insulation in roof. Changing levels of insulation in walls.

Annual heat load kWh = 807 (total wall "U" value) + 1461

r = 0.998

When $r = \pm 1$, the correlation is said to be exact. With a correlation of 0.998 this shows that over a period of one year there is a direct relationship between the annual heat load and the total "U" value of the surface element being examined in the building. (for a set thermostat level)

We know that higher insulation levels result in lower heat loads. The value of the above result is that one can optimise the insulation levels for each element with less computer time and cost. As will be outlined more fully in the OPTIMISATION section, each surface element can be studied separately and optimised on a cost basis without the levels of insulation of the elements influencing the outcome. When we consider the heat load equation.

Heat load = m (total U value) + c

The slope m for cases of wall insulation at 50mm and 75mm fibre-glass differ by

$$\frac{1286-1265}{1286} = 1.6\%$$

The slope m is the same for both cases when the wall is held at 50mm and then 75mm fibre-glass insulation.

The differences between the constant "C" in each heat load equation (1660-1521 = 139 kWh) is the difference in the wall insulation level influence upon the heat load.

The mean of the difference in the heat loads of the walls at 50mm and 75mm over the range of roof insulation levels is 148.5 kWh with a standard deviation of 8.2 kWh

To make a study of a different house using SUSTEP with the thermostat set at a certain level one can generate the following groups of study

A1, A12 to 15, A16 to A19, A20 to A23

by programming only the following

eg: A1, A12, A15 then one from each group following ie: A16, A20

That means the same job of 13 programs can be generated by 5 programs or 3 initial programs and 1 from each future group to be studied.......

Cont'd

For example

(a) CASE A1 nil nil nil
to find load of uninsulated house

(b) CASES A12 nil 50 150
A15 nil 50 50

This gives the heat load equation of

$$\text{Heat Load} = 1286 \, (\text{Total Roof "U" Value}) + 1660$$

(c) CASE A16 nil foil 150
This gives the heat load

$$2284 = 1286\,(0.244) + C_2$$

$$C_2 = 1970 \text{ kWh}$$

To find any other case use the Heat Load equation

$$\text{Heat Load} = 1286 \, (\text{Total Roof "U" Value}) + 1970$$

for eg CASE A19 nil foil 50

"U" = 0.645

Calculated heat load = 1286 (0.645) + 1970
= 2799 kWh

SUSTEP LOAD = 2792 kWh

This gives a 0.25% difference in annual heat load between using an extra program of SUSTEP or doing a simple calculation taking a matter of tens of seconds. Computer turn-around time can be of the order of half an hour and at a much higher computation cost with no better order of accuracy.

Table3.4.1-a

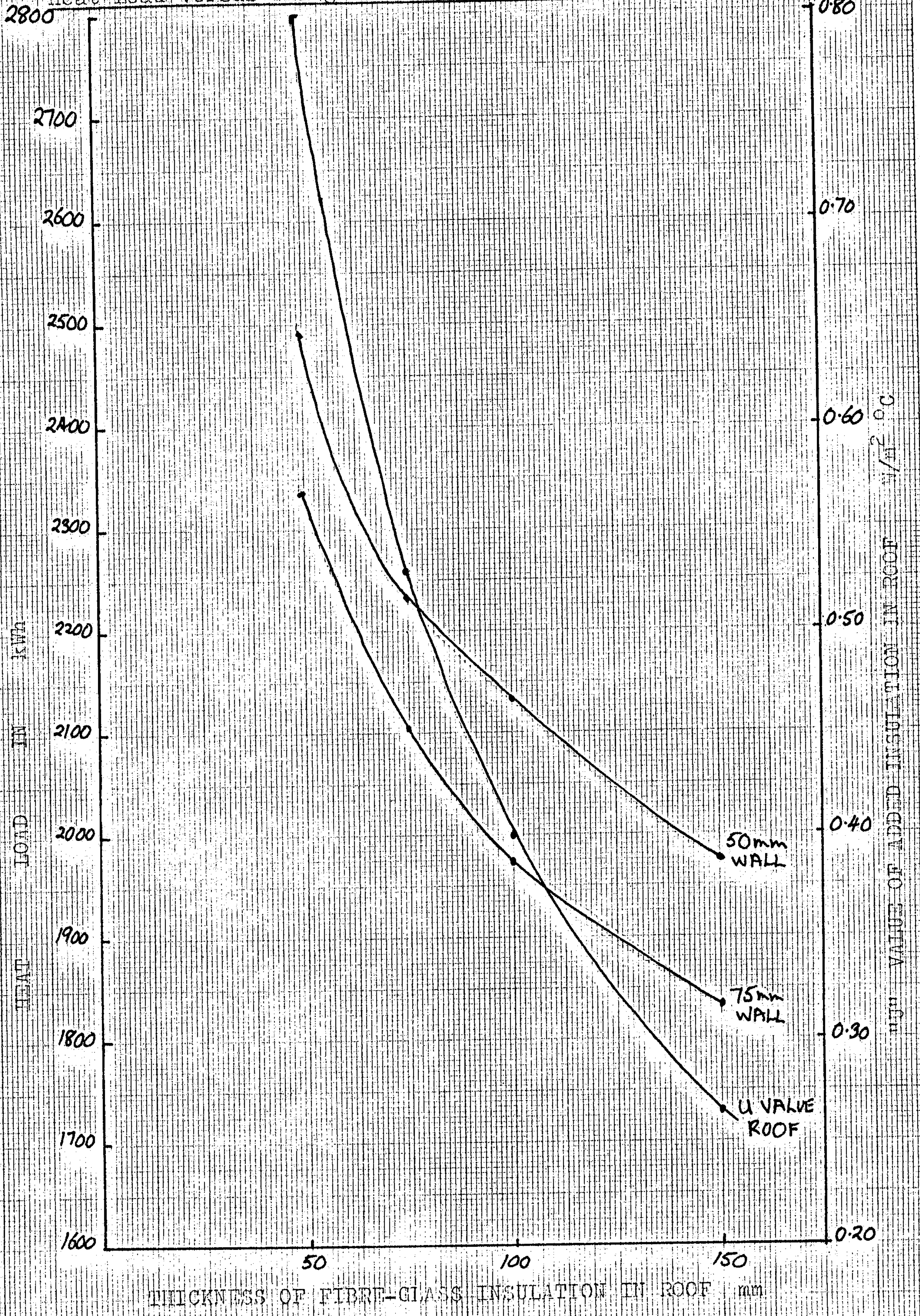
Annual Heating Loads and Savings - Mangere

South facing light weight standard house
Thermostat at 18°C 1.5 AC/HR

	CASE	INSULATION REGIME FLOOR	WALL	ROOF	HEATING LOAD MJ	kWh	SAVING kWh
A000	A1	nil	nil	nil	20 166	5 602	0
A009	A2	nil	nil	foil	15 267	4 241	1 361
A002	A3	nil	nil	25	13 927	3 869	1 733
A006	A4	nil	nil	150	10 724	2 979	2 623
A099	A5	nil	foil	foil	13 739	3 816	1 786
A091	A6	nil	foil	25	11 949	3 319	2 283
A096	A7	nil	foil	150	8 224	2 284	3 318
A011	A8	nil	25	25	12 024	3 340	2 262
	A9	nil	25	150	8 213	2 281	3 321
	A10	nil	100	150	6 244	1 734	3 868
	A11	foil	foil	foil	13 631	3 786	1 816
A03	A12	nil	50	150	7 088	1 969	3 633
	A13	nil	50	100	7 663	2 129	3 473
	A14	nil	50	75	8 070	2 242	3 360
	A15	nil	50	50	8 962	2 489	3 113
A096	A16	nil	foil	150	8 224	2 284	3 318
	A17	nil	foil	100	8 767	2 435	3 167
	A18	nil	foil	75	9 230	2 564	3 038
	A19	nil	foil	50	10 051	2 792	2 810
A036	A20	nil	75	150	6 580	1 828	3 774
	A21	nil	75	100	7 099	1 972	3 630
	A22	nil	75	75	7 559	2 100	3 502
	A23	nil	75	50	8 408	2 335	3 267

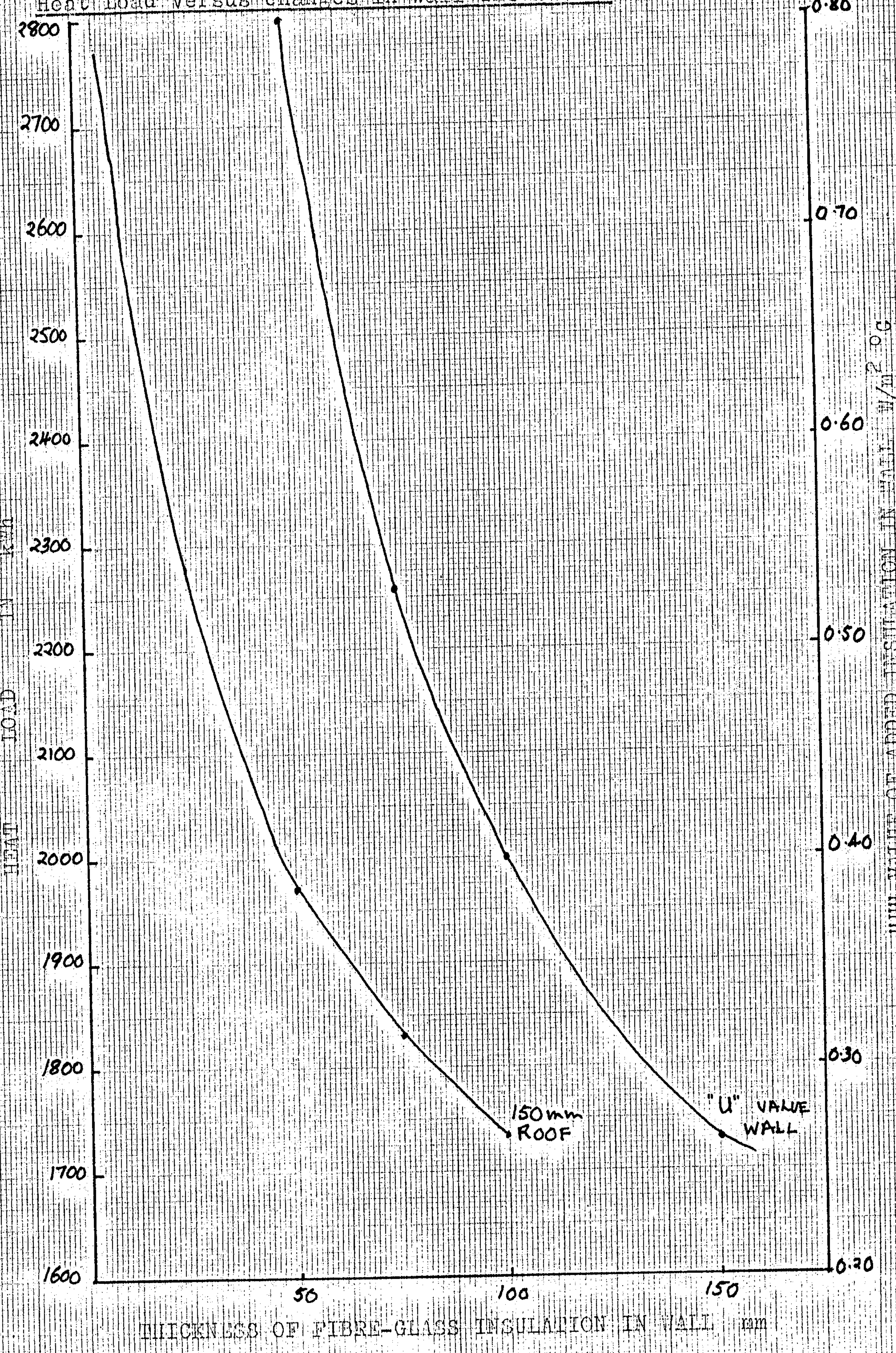
Graph 3.4.2-a

Heat Load versus changes in Roof Insulation



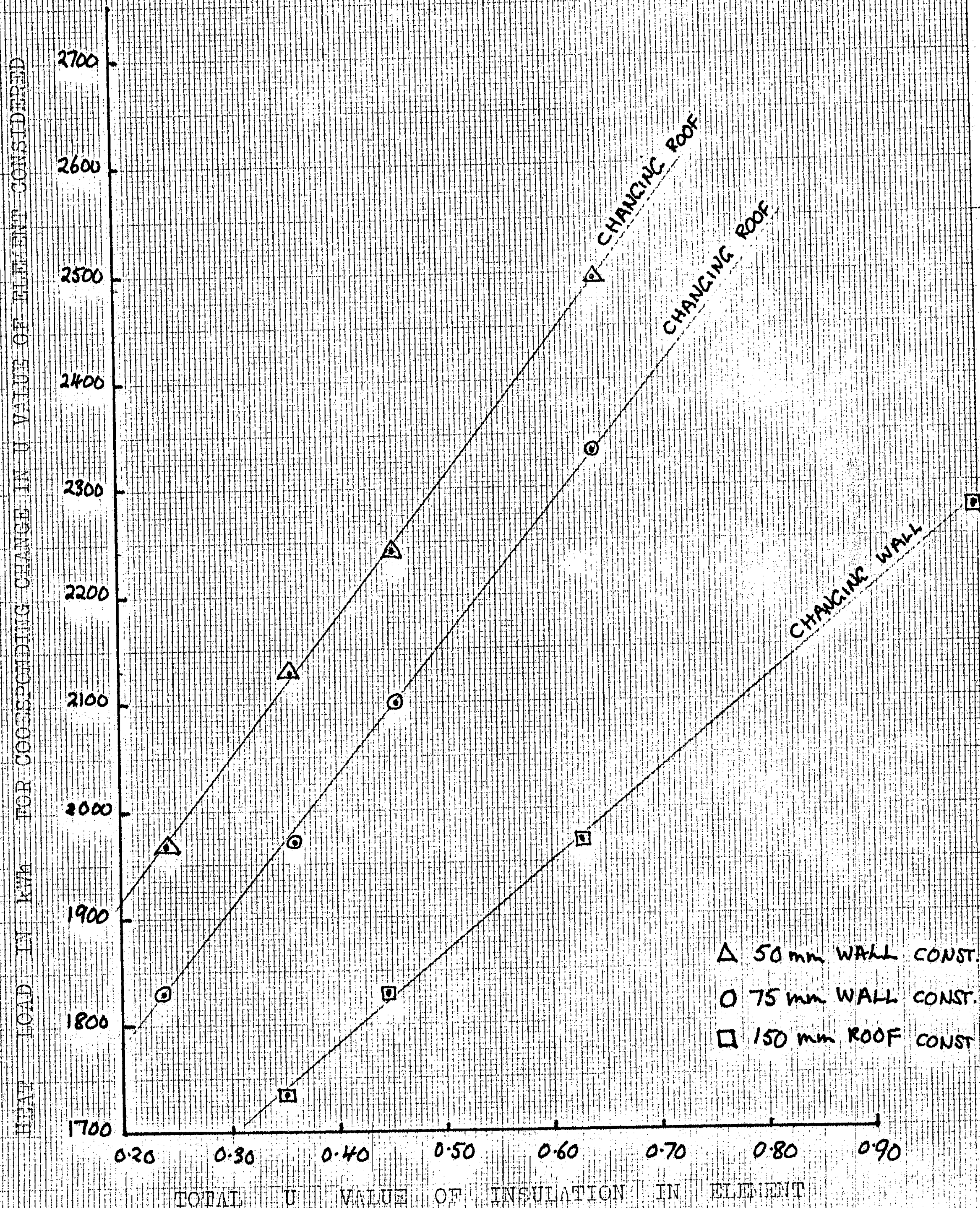
Graph 3.4.2-b

Heat Load versus changes in Wall Insulation



Graph 3.4.2-c

Scatter diagram of Heat Load - Insulation U value relationship



3.4.3 Monthly Heat Loads versus Mean Maximum Monthly Temperatures

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Table 3.4.3 -a gives the monthly heat loads for cases A1, A4, and A10.

006 046

Table 3.4.3 -b gives the mean maximum dry bulb temperature for each month. Saha picked up the maximum dry bulb temperature for each day and then calculated the mean over the month. The arithmetic mean of the diurnal swing over the period of the month was also calculated.

Is this table due to Saha?

Graph 3.4.3 -a shows the monthly heat loads for cases A1, A4 and A10 in a histogram form against the month of the year. The mean minimum and mean maximum temperature for each month are al plotted. The heat load for different insulation levels does not reduce uniformly for each month. There are other climatic variables at work which would show up more clearly on a day to day analysis.

Graph 3.3.4 -b shows a scatter diagram of monthly heat loads and mean maximum monthly temperatures. When the monthly heat loads under 100 kWh are disregarded the uninsulated house CASE A1 shows a more direct linear relationship to temperature than the other two higher levels of insulation. A correlation test has been made for each case against the mean minimum as well as mean maximum temperature.

CASE A1 - mean maximum temperature

$$\text{Monthly heat load} = -152.4\ (\text{mean max Temp}) + 3277$$

$$r = 0.956$$

CASE A1 - mean minimum temperature

$$\text{Monthly heat load} = -153.2\ (\text{mean min Temp}) + 2389$$

$$r = 0.941$$

CASE A4 - mean maximum temperature

When low load months under 100 kWh are included, correlation r = 0.288 and the constant in the load equation is less than the maximum monthly load.

Excluding low load months

$$\text{Monthly heat load} = 157.8 \text{ (mean max temp)} + 2987$$

$$r = 0.909$$

CASE A4 - mean minimum temperature

$$\text{Monthly heat load} = -127.8 \text{ (mean min temp)} + 1765$$

$$r = 0.859$$

CASE A10 - mean maximum temperature.

Excluding low load months

$$\text{Monthly heat load} = -135.2 \text{ (mean max temp)} + 2418$$

$$r = 0.777$$

CASE A10 - mean minimum temperature

$$\text{Monthly heat load} = -86.9 \text{ (mean min temp)} + 1181$$

$$r = 0.734$$

The correlation r ranging from -0.734 to -0.956 shows that there is a strong linear relationship between the monthly heat load and the mean monthly temperature. There is a higher correlation for the mean maximum rather than the mean minimum monthly temperature. As can be seen from table 3.4.3 -b the diurnal swing varies from month to month and does not bear any clear relationship to the mean maximum temperature.

As the insulation level increases, the dependence of heat load upon temperature becomes less direct. The monthly heat load depends upon net heat loss. In the uninsulated house the ratio of heat loss to head gain would be higher than for a well insulated house. As the insulation level increases nett heat loss reduces and so does this heat loss to heat gain ratio. The variability of solar gain which is independent of temperature would be masked to a lesser extent. Capacitance effects in the house would even out this solar gain variability over a day, however monthly fluctuations of solar gain would be more apparent in the well insulated house. The major reason why the heat load becomes less dependent upon temperature during the warmer months is because this solar gain factor becomes the dominant factor, and the heat load during the warmer months does not reflect that the internal temperatures may be much higher than 18^{o}C during the day. This excess heat would be released at night thus reducing the heat load requirements to a greater degree than reflected by the mean outside temperature for that month.

In graph 3.4.3 -b it can be seen that the heat load for cases of no insulation and maximum insulation follow a linear relationship with the mean maximum monthly temperature except for heat loads under 100kWh. As the heat load aproaches zero there is still a residual heat load for this intermediate period between no heat load and winter heat load. 100 kWh would represent a 2kW heater on for 1.5 hours each night or the same heater on continuously for 2 of the coldest days of that month.

A correlation test has been made to show the variability of heat load with temperature. Another way of seeing this variability is to consider the differences of monthly heat loads for different insulation regimes. This approach is more approximate but does illustrate the masking effect described earlier on. Table 3.4.3 -c shows the heat load difference between different insulation levels

Each insulation case A1, A4, and A10 experience the same climatic conditions of temperature and solar insolation.

The only variable introduced into this study has been insulation levels. If the heat load of each month is proportional to the insulation level and mean monthly temperature as shown then the differences between two insulation CASES monthly heat load should be the same. Any variation from this would be due to other factors independent of temperature. The mean of the difference between monthly heat loads for different insulation regimes is given. Months with heat loads under 100 kWh have been excluded. Using the uninsulated house CASE A1 as a reference it can be seen that CASES A4 and A10 have a low standard deviation for the monthly heat load differences. However when CASES A4 and A10 are compared for differences in heat load, the standard deviation of the heat load difference becomes quite significant. Both CASES A4 and A10 may have a variation in heat load due to factors independent of temperature. The large heat load difference with respect to the uninsulated house masks this variability.

Table 3.4.3-a

Monthly Heating Load

CASE	FLOOR	WALL	ROOF
A1	nil	nil	nil
A4	nil	nil	150
A10	nil	100	150

CASE / MONTH	A1 HEAT LOAD MJ	A1 HEAT LOAD kWh	A4 HEAT LOAD MJ	A4 HEAT LOAD kWh	A10 HEAT LOAD MJ	A10 HEAT LOAD kWh
MARCH	137	38	0	0	0	0
APRIL	786	218	187	52	51	14
MAY	2508	697	1043	290	388	108
JUNE	4296	1193	2933	815	1977	549
JULY	4000	1111	2608	724	1624	451
AUG	4065	1129	2637	732	1862	517
SEPT	2494	693	971	270	301	84
OCT	1694	470	345	96	21	6
NOV	187	52	0	0	0	0

Table 3.4.3-b

Mean Monthly Temperatures - Mangere

Maximum dry bulb temperature for every day is picked and then the mean of the maximum DBT over the month is taken. The arithmetic mean of the diurnal swing over the period of the month is also taken.

MONTH	Mean MAXIMUM DBT °C	mean DIURNAL SWING °C	mean MINIMUM °C
MARCH	22.2	6.5	15.7
APRIL	19.0	5.5	13.5
MAY	17.0	4.8	12.2
JUNE	15.2	5.9	9.3
JULY	13.6	6.6	7.0
AUG	14.8	5.6	9.2
SEPT	16.2	5.6	10.6
OCT	17.8	6.2	11.6
NOV	21.0	6.3	14.7

Table 3.4.3-c

Monthly Heat Load differences between different Insulation levels

MONTH	A1-A4 kWh	A1-A10 kWh	A4-A10 kWh
MARCH	38	38	0
APRIL	166	204	38
MAY	407	589	182
JUNE	378	644	266
JULY	387	660	273
AUG	397	612	215
SEPT	423	609	186
OCT	374	464	90
NOV	52	52	0

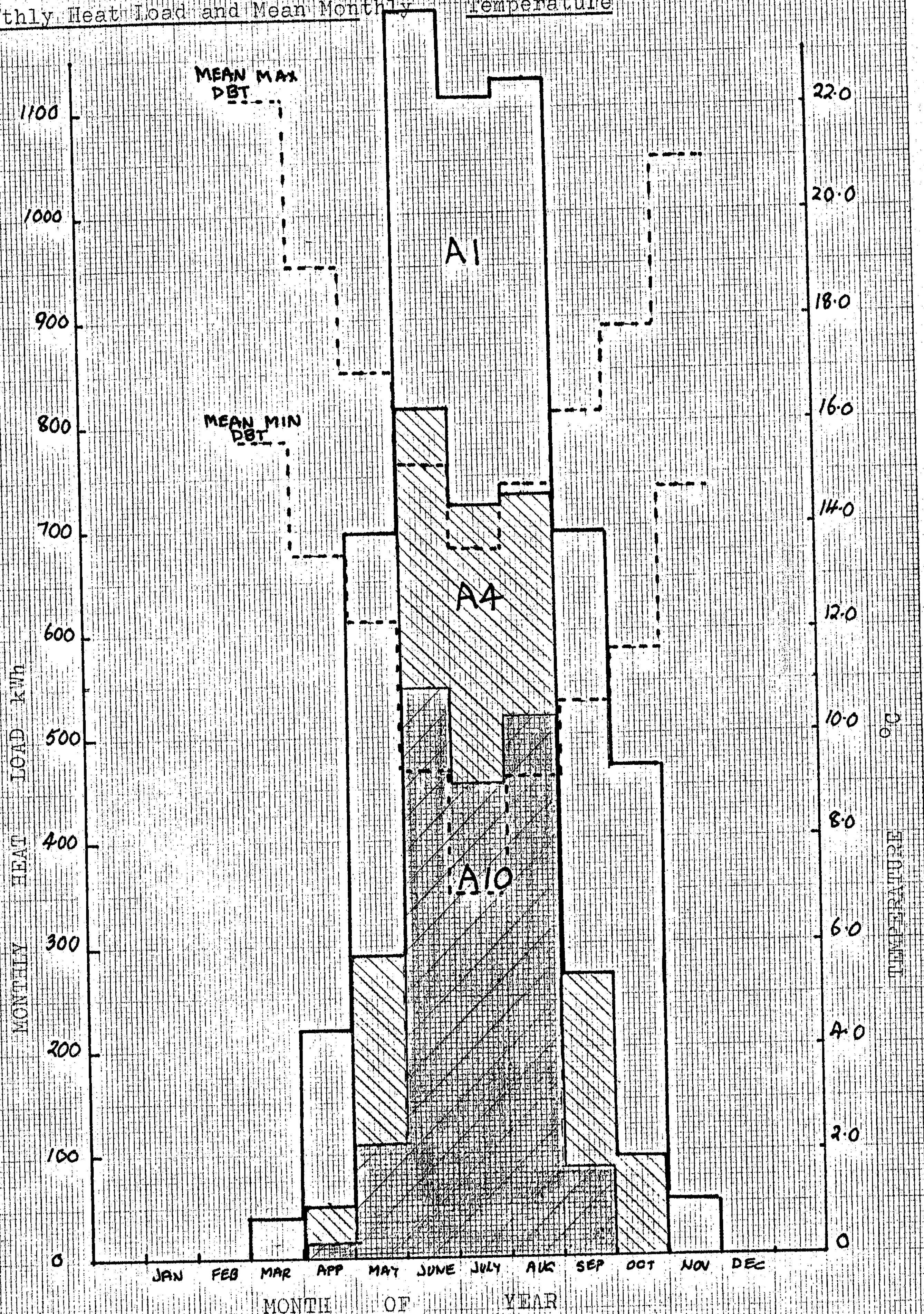
A1-A4 May to September (Oct) Mean Difference 398.4 kWh
Standard Deviation 17.5 kWh or 4.4%

A1-A10 May to August (Sept) Mean Difference 626.3 kWh
Standard Deviation 31.9 kWh or 5.1 %

A4-A10 May to August (Sept) Mean Difference 234 kWh
Standard Deviation 43 kWh or 18.4 %

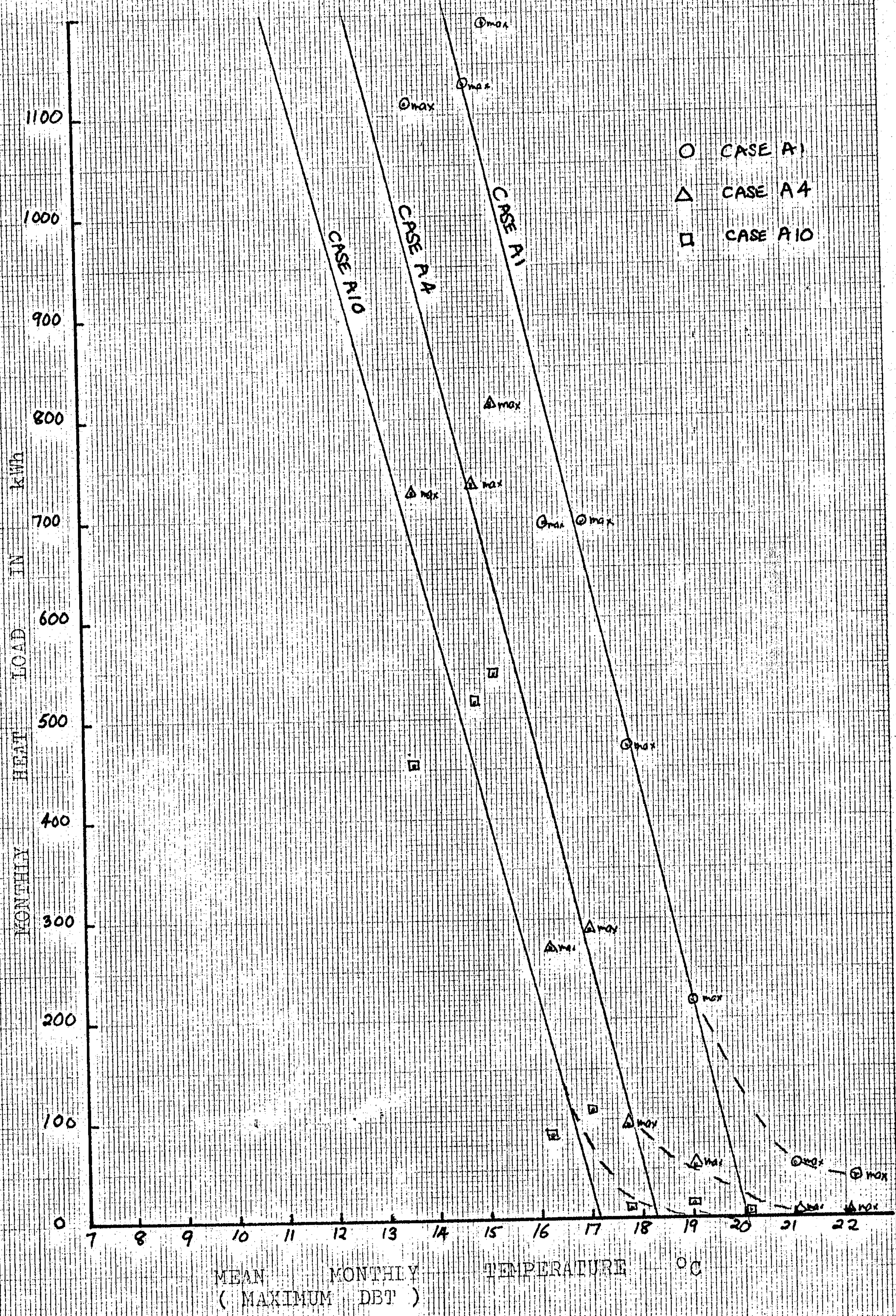
Graph 3.4.3-a

Monthly Heat Load and Mean Monthly Temperature



Graph 3.4.3-b

Scatter diagram of Monthly Heat Load and Mean Monthly Temperature



3.4.4 Monthly Distribution of Annual Heat Load

In section 3.4.2 it was found that the Annual heat load is directly proportional to the total U value of each element (Roof and Walls) in the building, with a correlation co-efficient of 0.998. In section 3.4.3 it was found that the monthly heat load is directly proportional to the Mean Maximum monthly temperature with a correlation co-efficient ranging from -0.956 to -0.777 for higher levels of insulation.

A correlation test has been made for the June month heat load versus total U value. June was chosen because it is the highest heat load month in this particular study. The results of the correlation test are as follows: **(from table 3.4.4-a)**

(i) 150mm fibreglass insulation in roof changing levels of insulation in walls.

June heat load kWh = 166.5 (total wall U value) + 505.5

r = 0.996

(ii) 75mm fibreglass insulation in wall changing levels of insulation in roof.

June heat load kWh = 299 (total roof U value) + 508

r = 0.999

(iii) 50mm fibreglass insulation in walls changing levels of insulation in roof.

June heat load = 289 (total Roof "U" value) + 547

r = 0.999

Over a period of one month there is a direct relationship between the heat load and the total U value of the building element being considered. This relationship is of the form

Heat load kWh = MU + C

This is a steady state heat equation form as will be demonstrated.

$$\text{Heat load kWh} = K \sum_{i}^{n} \left[A_i \; U_i \quad (Tai - Tme) \right] + KC_1$$

Where K is constant of heat load units
A_i is area of the element
U_i is U value of the element
Tai is inside air temperature
Tme is mean effective temperature which will be discussed more fully later.
C_1 incorporates heat loss and gain due to ventilation, solar insolation fortuitous heat sources, and capacitance effects.

By Manipulation

$$\text{HEAT LOAD kWh} = K A_E \; U_E \,(Tai - Tme)$$
$$+ \left(K \sum_{i}^{n} A_E \; U_E \,(Tai - Tme)\right]$$
$$- K A_E \; U_E \,(Tai - Tme) + KC_1$$
$$= K A_E \; U_E \,(Tai - Tme) + C_2$$

A_E is area of element being considered
U_E is U value of element being considered
C_2 incorporates heat loss from remaining elements; and heat loss and gain due to ventilation, solar insolation, fortuitous heat sources and capacitance effects.

The above equation can be put into the form

$$\text{Heat load kWh} = M \;\; U_E \; + \; C \quad \text{as shown.}$$

M_E

Even though SUSTEP calculates the monthly heat load using hour by hour dynamic heat load calculations it is possible to express this heat load in the form of a steady state heat equation using the element U value, mean effective temperature and a constant which accounts for all other factors.

This mean effective temperature Tme takes into account the diurnal variation of the outside air temperature and also takes into account the sol-air temperature. The sol-air temperature would be different for the roof and walls, so there would be a different mean effective temperature for each different type of element. The purpose of solar design is to maximise these mean effective temperatures during the winter while minimising these during the summer through design of the shape and orientation of the building. The ratio of the winter/summer mean effective temperature could serve as an index of success for that particular element of design with regard to shape, orientation and heat loss. (Winter to summer solar gain through the windows is also another index which enables comparisons).

To calculate Tme roof element

Use Case A12 (changing insulation in roof)

a) June Heat Load $= 289\ (U_E) + 547$

b) June Heat Load $= KA_EU_E\ (Tai-Tme) + C_2$

$$C_2 = 547 \text{ kWh}$$

$KA_EU_E\ (Tai-Tme) = 289\ U_E$

or $Tme = Tai - 289/(K \times A_E)$

$Tai = 18^\circ C$

$K = 0.72$

$A_E = 94 m^2$

$Tme = 13.73^\circ C$

Check using Case A15

Calculated

June Heat Load $= 0.72 \times 94 \times 0.645 \times (18-13.73)$

$+ 547$

$= 733.4$ kWh

SUNTEP LOAD $= 732$ kWh

difference $= 0.2\%$

Check using Case A20

June Heat Load = 0.72 x 94 x 0.244 x (18-13.73)

+ 508

= 578.5 kWh

SUSTEP LOAD = 579

difference = 0.01%

To calculate Te wall element

a) June Heat Load = 166.5 (U_E) + 505.5

b) June Heat Load = K $A_E U_E$ (Tai-Tme) + C_3

C_3 = 505.5

similarly Tme = Tai - 166.5/(K x A_E)

Tai = 18°C

K = 0.72

A_E = 72.6 m^2

Tme = 14.81°C

Check using Case A4

June Heat Load = 0.72 x 72.6 x 1.887 x (18-14.81)

+ 505.5

= 820.15 kWh

SUSTEP LOAD = 815 kWh

difference = 0.6%

To summarise so far it has been found that the June heat load has a direct relationship with the U value of the element being considered and the mean effective temperature for that element. In other words heat loss through an element can be described by a steady state form K $A_E U_E$ (Tai-Tme)

The heat load for all months could be described in the same way using a different mean effective temperature for that month and a different constant which accounts for the dynamic heat loss and gain factors where solar gain, ventilation loss and capacitance effects interact.

A general form of heat load for all months would be

$$\text{MONTH L HEAT LOAD} = K\sum_{i}^{n} A_i U_i \,(Tai - Tme_L) + KC_L$$

It was found that the monthly heat loads were proportional to the mean maximum monthly temperatures. It can be seen from the above equation that any difference between the mean effective temperature and mean maximum temperature could be incorporated into a constant.

$$\text{eg: Month Heat Load} = U\,T_{mm} + C$$

T_{mm} is mean maximum

This equation is still of the same form as above. It has been pointed out why this relationship between heat load and temperature becomes more diffuse because as heat loss from elements becomes less as insulation levels rise, the constant KC_i becomes a proportionally larger factor in the heat load. This also happens when the mean effective temperature approaches the thermostatically controlled inside temperature during the winter months.

Solar gain becomes a more dominant factor in the heat load for higher levels of insulation. In the autumn and spring months net heat loss approaches zero but there is still a residual heat load due to cold periods of the month. During summer the heat load becomes independent of the mean monthly temperature. Although there is no heat load there would be a cooling load if one required the internal temperature to be maintained at 1[illegible]°C. Allowing temperatures to fluctuate without thermostat control allows capacitance effects to be realised.

The diurnal temperature would be evened out and excess heat stored during the day would be released at night. This would reduce any heat load required when the temperatures fall at night. This aspect of allowing temperatures to free float will be examined in detail in a later report.

Graph 3.4.4 -a shows the cumulative heat load over one year for cases A1, A4, and A10. Although SUSTEP computes the total monthly heat loads, the heat loads have been shown as a smooth line curve rather than in a histogram form because the cumulative heat load is a continuous process. The graph shows more clearly the effects of the residual heat load months.

Slopes α_1, β_1 and γ_1 compared to slopes α_2, β_2, and γ_2 show that the residual heat loads during the change over period from summer to winter approach the rate of the winter heat load accumulation more rapidly than do the residual heat loads during the change over period from winter to summer i.e.the change over from summer (no heat load) to winter (heat load season) is more rapid than the change over from winter to summer.

The rate of heat load accumulation is less at higher levels of insulation than at lower levels of insulation. Higher levels of insulation reduce the rate of heat loss - this is reflected by this graph. Over one year this means a lower annual heat load.

Higher levels of insulation in the walls or ceiling produce diminishing returns for each increment of insulation as Graph 3.4.2 -a and -b show. The heat load produced by an additional increment in the walls or roof is independent of the level of insulation in the other element as graph 3.4.2 -c shows and the section on optimisation outlines more fully. And yet each increasing level of insulation in the walls or roof result in a shorter heating season. The implications of this is that higher levels of insulation generate greater savings. So increasing insulation levels generate diminishing savings per increment during the colder part of winter and yet the annual savings are increasing because of the shorter heating season.

There comes a point where higher levels of insulation do not generate any more savings than the previous level of insulation because once the annual heat load is nil there are no further savings to be made.

To see this pictorially suppose that Auckland's winter season distribution were such that winter was extended. In comparing graphs 3.4.4 -b and graph 3.4.4 -c the difference in the heat load savings A^* and B^* would represent the difference in savings generated by the same insulation regime because the heating period (and potential savings period) is extended along with the extended winter.

Graph 3.4.2 -c shows the linear nature of the heat load versus U value for a particular element of wall or roof. A comparison of Graph 3.4.4 -d and graph 3.4.4 -e shows why the interdependence of heat load and insulation U value does not show up for the order of U value in each separate element of wall and roof. The heat load when the element U value is 0.2 $W/M^{2o}c$ represents the heat loss due to ventilation and the other element Should the U value for that element approach zero (ie: infinite thermal resistance) there would still be a heat loss due to the other elements. Heat savings is an additive process. When the Total House U value is considered - that is the total heat loss from walls, roof, windows, floor and ventilation - the heat load curve for lower Total house U values firstly has nil heat load then changes smoothly into a linear heat load relationship with Total House U value. At the higher levels of insulation (lower U values) the heat load is less and continues to decrease at a slower rate as the insulation level increases. (U value→ 0

Table 3.4.4 -a shows that the ratio of the June heat load to annual heat load increases for increasing levels of insulation. This means that the ratio of the balance-months-heat-load to annual heat load is decreasing or,that compared to the uninsulated house,the savings for higher levels of insulation are decreasing at the same time as increasing levels of insulation generate reducing savings for each additional increment of insulation. This serves as confirmation of the visual explanatio

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Should the seasonal temperature distribution of Auckland's climate be such that the winters were more severe over a shorter period of time with the same number of Degree-days as now then the annual savings generated by higher levels of insulation would not be the same as for our present conditions of climate, and nor would the optimum cost effective level of insulation be the same.

Suppose the distribution of winter temperatures were such that the heat loads were the same. Because each level of insulation generates the same savings for that particular insulation level regardless of the temperature (the heat load is dependent upon temperature, the heat savings is not)and because the potential energy savings period is shorter, then each level of insulation would generate smaller annual savings.

The effect of increasing levels of insulation generating increasing savings would not be a dominant factor because a severe change from summer to winter temperatures would not result in residual heat months. Each level of insulation would generate less savings as compared to the existing savings. The cost effectiveness of each insulation regime depends upon the energy savings and capital cost of the insulation (Later sections on investment analysis will explain the interrelationship of cost effectiveness savings and capital cost). The ordering of the cost effectiveness of each insulation regime would change so that a lower level of insulation would be the optimal cost effective form of insulation as compared to optimal insulation form for the existing situation.

Fortunately from an economic and thermal comfort point of view, New Zealand does not have regions of extreme distributions of climate where insulation cannot produce savings over a larger part of the year. It is not economic to use high standards of insulation just to reduce heat loads during a small part of the year. Also high peak loading is uneconomic for the electricity department.

Lack of time has prevented a study of other centres in New Zealand. However using the same line of reasoning, but approaching from the opposite direction, most areas in New Zealand have climates which are colder than Auckland and have lower temperatures over a longer winter period. The same insulation levels as studied in Auckland will generate greater savings at colder locations therefore higher levels of insulation would tend to be the optimum on a cost effectiveness basis. Whether this is significant or not depends upon the sensitivity of cost effectiveness of insulation and the relative heat loads of other centres compared to Auckland.

Leslie has found that the same house in each of the following four centres have the relative heat load as listed:-

Mangere	- 1
Kelburn	- 2.3
Christchurch	- 2.9
Invercargill	- 3.5

This suggests that the potential for additional savings for each level of insulation is substantial and that an insulation standard based on cost effectiveness should be made on a zonal basis. [5]

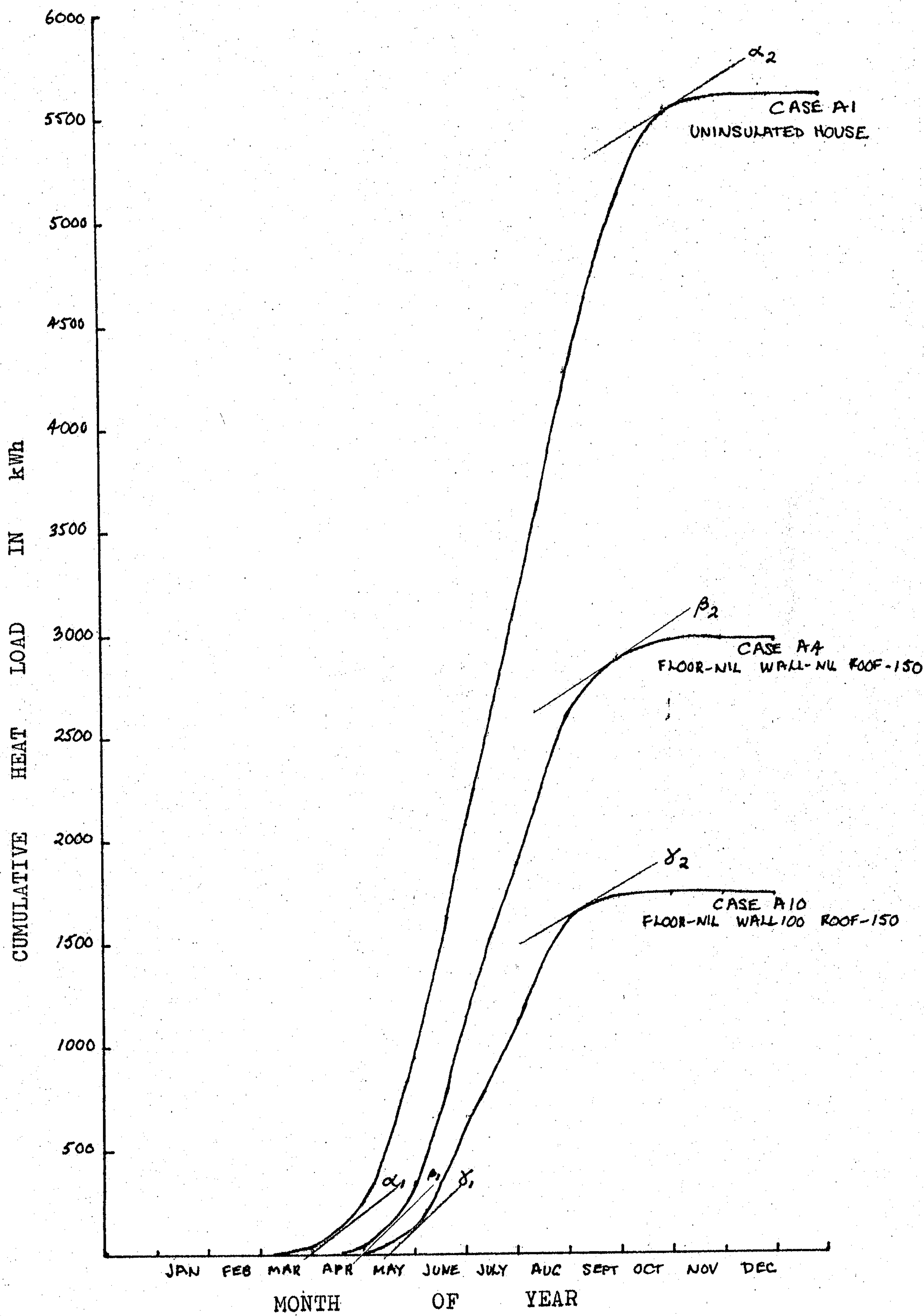
Table 3.4.4-a

June Heat Load, June:Annual Heat Load Ratio, Element U Value

CASE	INSULATION REGIME FLOOR	WALL	ROOF	ANNUAL HEAT LOAD kWh	JUNE HEAT LOAD kWh	RATIO JUNE to ANNUAL LOAD	ELEMENT U VALUE $W/m^2{}^oC$
A4	nil	nil	150	2979	815	0.274	1.887
A9	nil	25	150	2281	684	0.300	1.020
A12	nil	50	150	1969	615	0.312	0.625
A20	nil	75	150	1828	579	0.317	0.444
A10	nil	100	150	1734	555	0.320	0.351
A23	nil	75	50	2335	700	0.300	0.645
A22	nil	75	75	2100	645	0.307	0.455
A21	nil	75	100	1972	617	0.313	0.357
A20	nil	75	150	1828	579	0.317	0.244
A15	nil	50	50	2439	732	0.294	0.645
A14	nil	50	75	2242	679	0.303	0.455
A13	nil	50	100	2129	653	0.307	0.357
A12	nil	50	150	1969	615	0.312	0.244

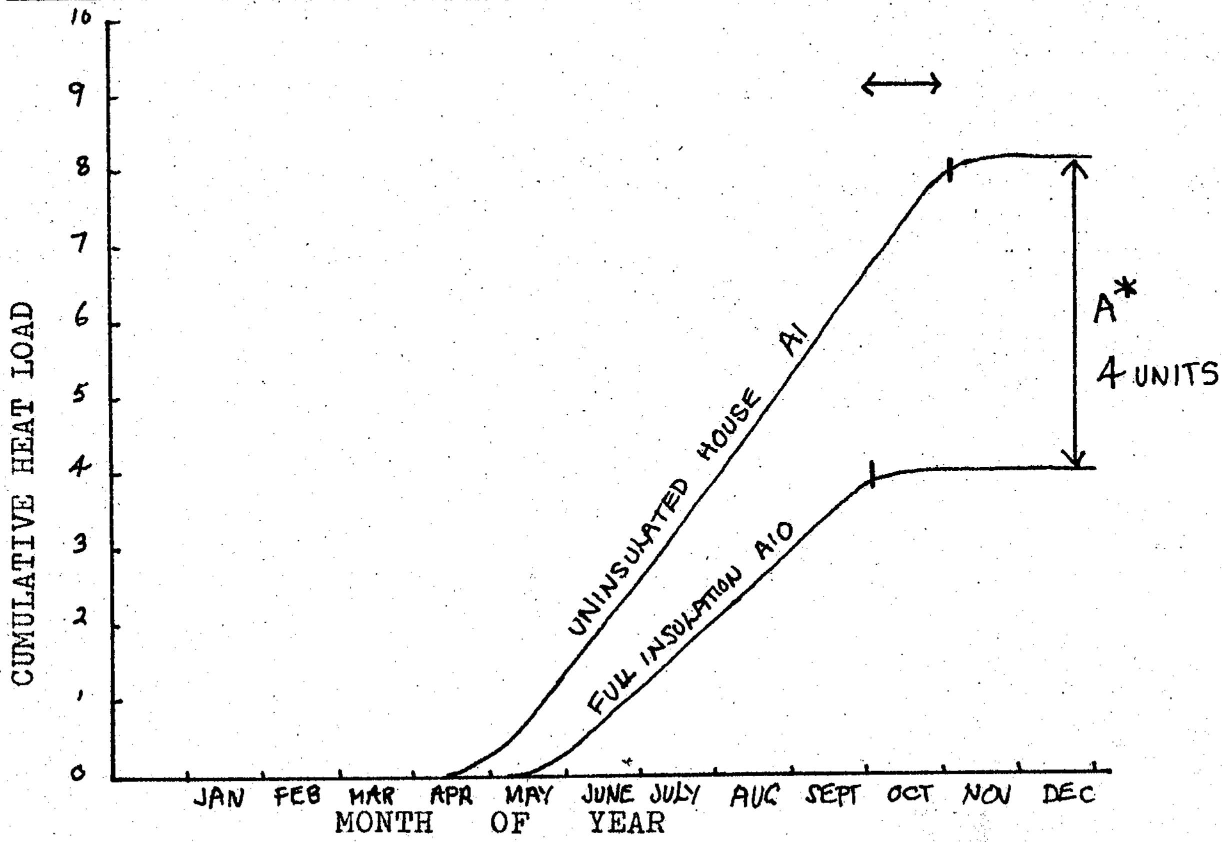
GRAPH 3.4.4-a

CUMULATIVE HEAT LOADS FOR DIFFERENT INSULATION REGIMES



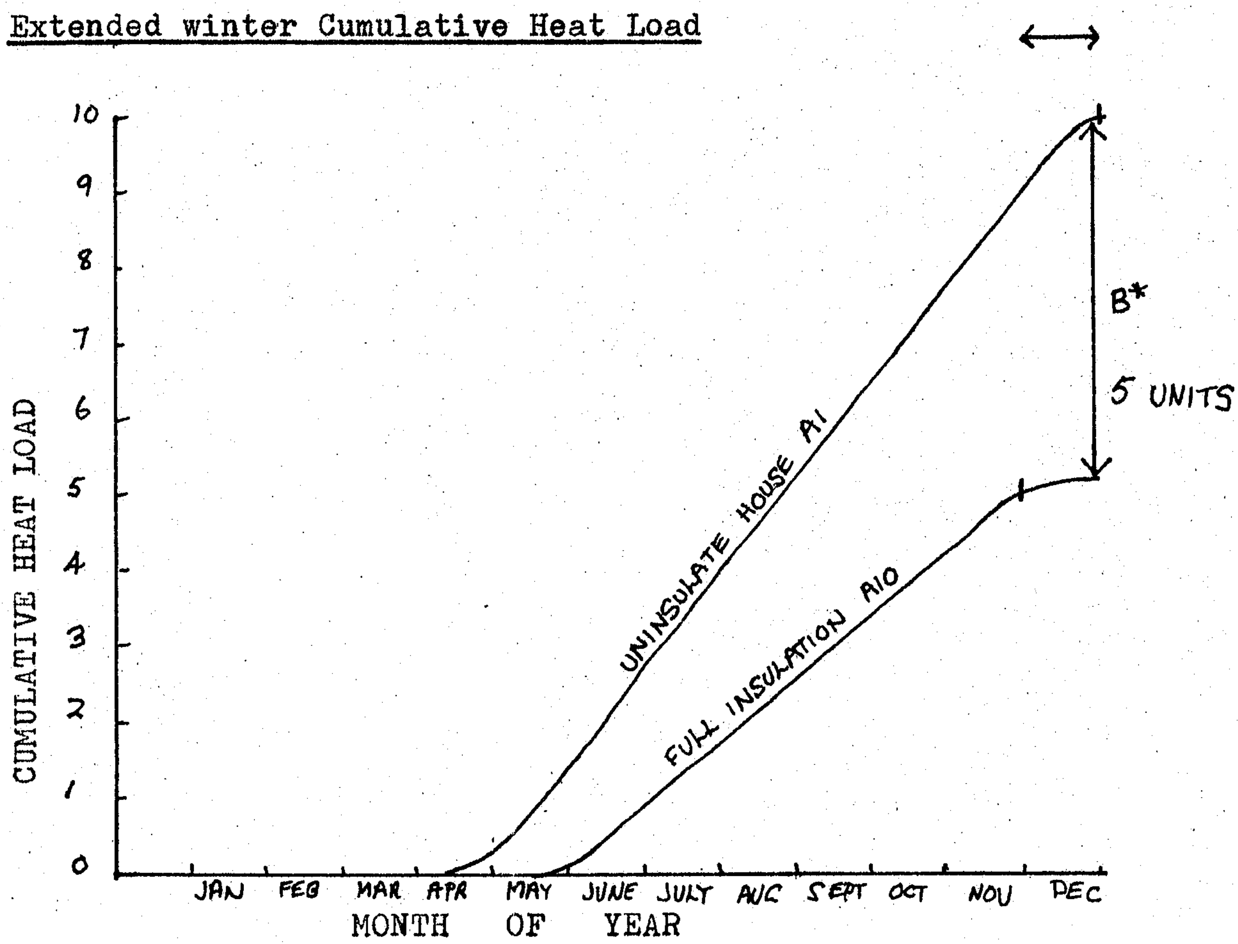
Graph 3.4.4-b

Existing Cumulative Heat Load



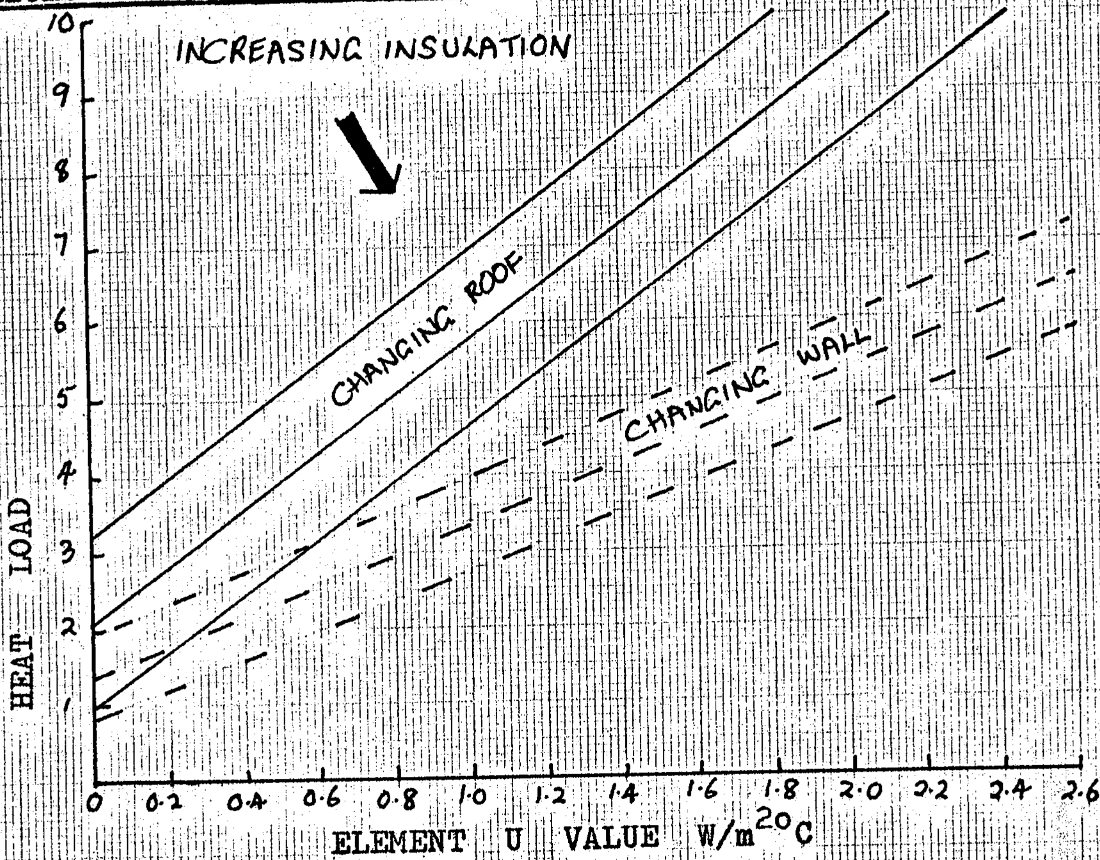
Graph 3.4.4-c

Extended winter Cumulative Heat Load



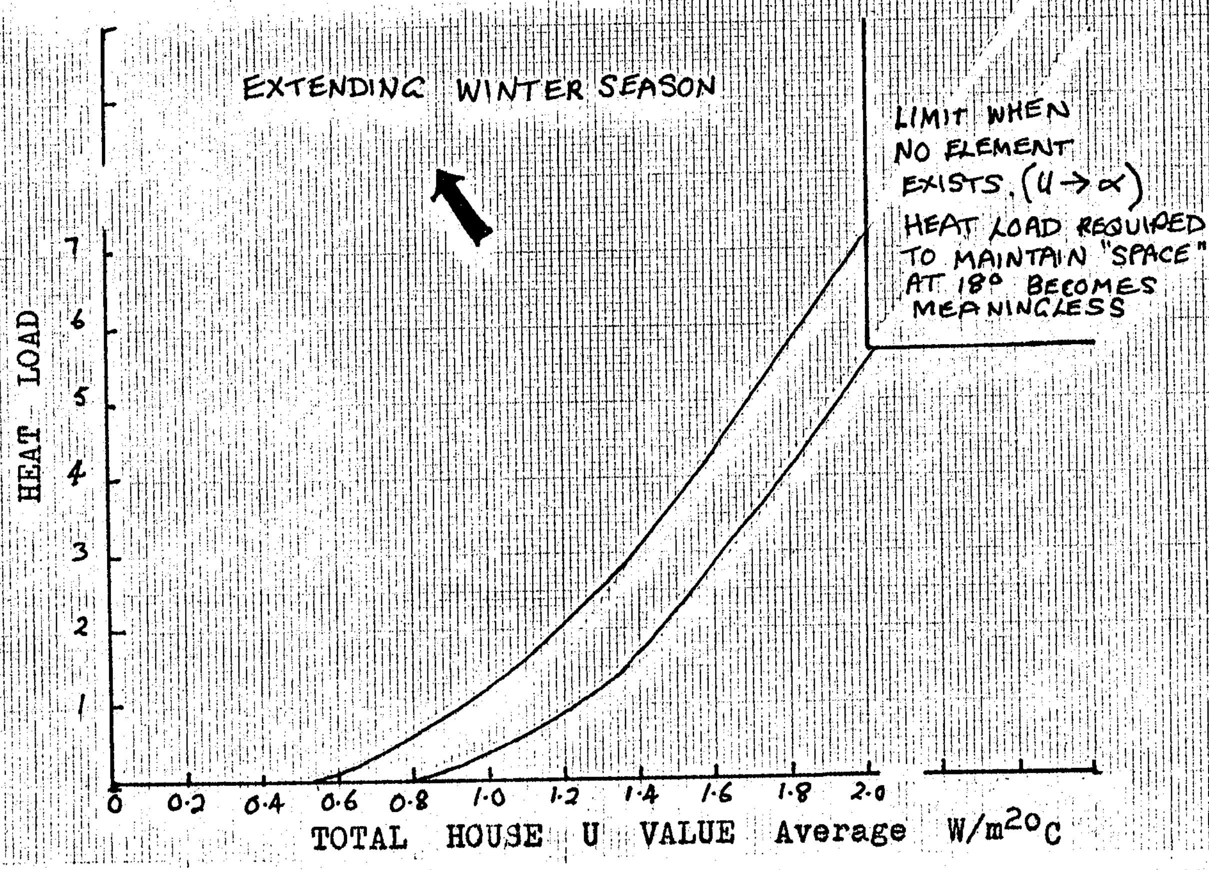
Graph 3.4.4-d

Element U Value and Heat Load



Graph 3.4.4-e

Total House U Value and Heat Load



4. COSTINGS

4.1 INSULATION COSTINGS

Costing of insulation was made by taking the mean price quoted by 6 retailers and insulation fitters in Auckland taken at random. Costing of insulation thicknesses not available on todays market was based on prices of other thicknesses. These extrapolated costs do not affect the results of this report as these levels of insulation lie well outside the optimum thermal level.

See Table 4.1 -a for all costing.

The installation cost of foil on the back of gib board is an area of cost benefit analysis where the cost of installation is shared between the foil and the gib board. Foil can also double up as a vapour barrier and the capital cost as such and as insulation is a spared cost. In view of the absence of any differentiation between the installation costs of gib board and gib foil board and because this study considers insulation without vapour barriers being a factor, I have chosen to offset the above cost benefit areas against each other where the installation cost of foil is nil and the capital cost of foil is fully an insulation cost. This report considers the costs of insulation in the walls and roof only. As section 5 will outline, a cost analysis of double glazing and floor insulation can each be studied independently of each other and of the walls or roof. A study of insulation in floors which included carpeting would require a cost-benefit analysis approach.

This report does not get involved in the question of subsidies on insulation repayment as to do so would distort the true position of insulation and energy costs. The DCF rate of return of savings produced by investing in insulation is so many times higher than current lending interest rates that under normal circumstances one would not subsidise a high rate of return investment.

4.2 ELECTRICAL HEATING COSTING

The cost of electrical heating @ 2.33c/kWh is based on the Auckland Electric Power Board rate for domestic consumers. This report is not involved with whether electricity should be used for home heating nor with whether the present rate of electricity represents the true cost of electricity with respect to other energy sources such as oil and coat and gas.

I personally feel that homes should be using low grade solar energy for home heating purposes rather than high grade energy sources such as electricity.

See Table 4.2 -a for costings

TABLES 4.1 -a

COSTING OF INSULATION

All materials have 50 year life period and involve no maintenance costs.

Costs for 25mm and 50mm fibreglass are based on extrapolated costs of current fibreglass prices.

THICKNESS mm	PRICE/m^2
150	3-45
100	2-40
75	1-90
50	1-40
25	0-90

ROOF

FIBREGLASS Coverage is $94m^2$

150mm

10 bales @ $30-95 per bale	309-50
Labour @ $3c/ft^2$	28-09
	337-59

100mm

7 bales @ $31-60 per bale	221-20
Labour	28-09
	249-29

75mm

5 bales @ $33-10 per bale	165-50
Labour	28-09
	193-59

50mm

165-50 x 1.40/1.90	121-95
Labour	28-09
	150-04

25mm

165-50 x 0.9/1.90	78-39
Labour	28-09
	106-48

Foil over rafters
1m x 50m roll

2 rolls @ $30-53 per roll	61-06
Labour @ 60c/m^2	56-40
	117-46

WALLS

FIBREGLASS Coverage is 72.6m^2

100mm

143-00 x 2.40/1.90	180-63
Labour @ 27c/m^2	19-90
	200-53

75mm

5 bales @ $28-60 per bale	143-00
Labour	19-90
	162-60

50mm

143-00 x 1.40/1.90	105-37
Labour	19-90
	125-27

25mm

143-00 x 0.9/1.90	67-73
Labour	19-90
	87-63

Foil on the back of Gib Board

normal board \$16-97/10m^2
foil on board \$21-60/10m^2
coverage 72.6m^2

Extra cost of foil installed	33-61
10% wastage	3-36
	36-97

NOTE: foil acts as a vapour barrier on the warm side of the wall as well.

FLOOR

FOIL UNDER JOISTS

2 rolls @ \$30-53 per roll	61-06
Labour @ \$4-80/100ft^2	48-56
	109-62

Table 4.2-a

Cost of Electrical Heating

@ 2.33c/kWh

CASE	INSULATION FLOOR	REGIME WALL	ROOF	COST $	SAVINGS $
A1	nil	nil	nil	130-53	0
A2	nil	nil	foil	98-82	31-71
A3	nil	nil	25	90-15	40-38
A4	nil	nil	150	69-41	61-12
A5	nil	foil	foil	88-91	41-61
A6	nil	foil	25	77-33	53-19
A7	nil	foil	150	53-22	77-31
A8	nil	25	25	77-82	52-70
A9	nil	25	150	53-15	77-38
A10	nil	100	150	40-40	90-12
A11	foil	foil	foil	88-21	42-31
A12	nil	50	150	45-88	84-65
A13	nil	50	100	49-61	80-92
A14	nil	50	75	52-24	78-29
A15	nil	50	50	57-99	72-53
A16	nil	foil	150	53-22	77-31
A17	nil	foil	100	56-74	73-79
A18	nil	foil	75	59-74	73-12
A19	nil	foil	50	65-05	65-47
A20	nil	75	150	42-59	87-93
A21	nil	75	100	45-95	84-58
A22	nil	75	75	48-93	81-60
A23	nil	75	50	54-41	76-12

5. INVESTMENT ANALYSIS AND OPTIMISATION

5.1 EXPLANATION OF INVESTMENT ANALYSIS

When a consumer makes any type of investment, including an investment in Energy Conservation Techniques (ECT'S) such as insulation, there are six basic questions he should ask himself in order to maximise profits, or utility:-

1. How much will it cost?
2. When will the funds be spent?
3. How soon will income (savings) commence and how long will it last?
4. What will be the pattern of income (savings) during the economic life of the project?
5. What will be the value of the investment at the end of its economic life?
6. What are the taxation effects?

Each of these factors:-

1. Total capital outlay
2. Incidence of expenditure
3. Total income (savings) generated
4. Incidence of income (saving) generation
5. Residual value of investment
6. Taxation effects

will be of vital importance no matter what type of investment is involved.

The question of timing plays an important part in these basic factors. Money has value over time. Money in the hard today is more valuable to us than the same amount of money available at some point in time in the future - even ignoring the effects of inflation.

Investment analysis involves the rate of return relationships between various investments and related profits or utility through the use of a profitability yard stick - some standardised technique for measuring rate of return on investment.

Such a yardstick must be capable of

1) Taking into account the time value of money
2) Reflecting the effects upon overall profitability of variations in the basic factors of an investment
3) Indicating the absolute attractiveness of a project as measured against the cost of capital
4) Being applied to all types of investments, thus permitting of comparisons between differing investment opportunities.

The Direct Cash Flow (DCF) method of investment analysis meets all of the above criteria. One disadvantage of the DCF method is that the method is time consuming and requires more work than other methods. The additional work is well worth the trouble where the size of the investment and its complexity is such that correct analysis must be made. This would be true where the rate of return of an investment was of the same order as the cost to borrow funds. However in the area of thermal insulation ECT'S the DCF rate of return is as high as 35% so that the absolute profitability factor is not so important as comparative analysis of different types and levels of insulation.

The cost in the use and net present value methods meet the essential requirements for investment analysis. Comparisons can be made of different types and sizing of insulation and the most cost effective form of insulation can be determined. NOTE: One important factor should be remembered when making investment analyses in any area involving energy expenditure - the future costs of energy are indeterminate and investment analyses can only be based on present energy costs or forecasts of future energy costs. Any long term investment involving energy can be fraught with unexpected and undesired complications. For this reason it is wise to be cautious. Fortunately, in the area of thermal insulation, the sensitivity of the optimum cost effective form of insulation is not very high as later sections will show.[8]

5.2 OPTIMISATION

When using the Cost in Use method of investment analysis the Energy Conservation Techniques (ECT) which offers the lowest Cost in Use is the optimum ECT. Conversely, when using the Net Present Value method the highest Net Present Value ECT is the optimum.

Another cost effectiveness maximisation method is the Marginal Analysis method which provides a systematic approach to problems which involve variable-sized investment opportunities. This method has not been used in this study because foil insulation U values are not variable. However the principles of Marginal Analysis are of particular use to us as shall be demonstrated.

The primary application of Marginal Analysis is to select the optimal combination of ECT's that will generate the greatest dollar energy savings than any other combination of ECT's involving the same or lesser cost.

The basic criteria for the optimal combination is expressed as Condition I, namely, that for each ECT considered,

$$MS = MC$$

where MS = marginal savings or the savings generated by the last increment of an ECT

and MC = marginal costs, or the cost attributable to that last increment.

In selecting an economically balanced combination of ECT's for any given investment size the equilibrium condition for the balanced combination is expressed as Condition II

namely

$$\frac{MS_1}{MC_1} = \frac{MS_2}{MC_2} = \ldots\ldots = \frac{MS_n}{MC_n}$$

where i = 1, 2, 3, ... n techniques.

An important limiting assumption required of condition II is that of independence of the various ECT'S included in the analysis. This means that the amount of energy savings generated by one technique cannot be influenced directly or indirectly by other ECT'S. The cost of insulating the walls, roof, floor, and double glazing are independent of each other. [9]

The heat load section shows that compared to the uninsulated house the monthly savings generated by insulation in either the walls or roof is relatively independent of the total insulation level. (Fluctuations are in the order of 5%). The marginal savings for an additional increment does fluctuate by a larger percentage (18%) on a monthly basis. But on an annual basis the heat load versus insulation U value of either the wall or roof follows a linear relationship (correlation 0.998) so that the savings generated by each increment of insulation in the walls or roof are independent of the insulation value of the other element.

The implications of the principles of marginal analysis combined with the results found by this report are that the optimum levels of insulation in any component of the building envelope can be studied independently. It may be more economically effective to use heavy weight construction on one wall and light weight insulation on the other. Investigations of heat loss from windows can be studied separately on an economic basis so long as the cost of using drapes or shutters as an energy conservation measure are combined in the study of the viability of using double glazing of windows.

Another implication is that if one wishes to maximise energy conservation then savings or heat load reduction is an additive process. Although not included in this report, extra heat load savings of the same magnitude as insulation measures of the walls and roof can be generated. To achieve the same savings by further insulation of the walls and roof would require impractical thicknesses of insulation and astronomical costs due to the diminishing savings generated by each increment of insulation.

If energy savings is an absolute criterion, as well as utilising Energy Conservation Techniques (ECT'S) such as insulation of the building envelope and weather sealing, one should also consider using passive Solar Energy Heating Methods (SEHM) such as the Trombe wall. An investment analysis of ECT'S and SEHM methods would rank them in order of priority. (There would be some social constraints on some methods eg: thermal comfort levels, sizing of windows, ventilation rates and structural and planning limitations). So long as the DCF rate of return for each ECT and SEHM is above the cost of borrowing then on a limited budget the economic ranking ordering would be the priority ordering of the method to use to reduce energy consumption.

(Because the parallel path heat flow in SUSTEP was not available it was therefore necessary for the purpose of this study to consider that the space under the suspended floor was unventilated. There is subsequently a more direct link between the capacitance of the ground and the suspended floor above. Extra foil insulation under the floor as in Case 11 has produced little change in savings as compared to Case A5. Leslie has demonstrated that the capacitance effect of the ground dominates over the capacitance effect of a concrete floor in intimate contact with the ground. In view of the direct link between the ground and the suspended floor, the floor could be regarded as a concrete floor in intimate contact with the ground. The absolute heat load is less than there would be with a ventilated sub floor space. This in no way detracts from the findings of this report for the reasons given above. This report has investigated the savings generated by insulation regimes in the walls and roof. The insulation level of the floor does not affect this savings. SUSTEP does not easily allow the modelling of drapes drawn over the windows at night time. In the same way this factor does not affect the savings generated by the insulation in the walls and roof).

6. ANNUAL COST IN USE

6.1 EXPLANATION OF METHOD

One method of comparing the real cost implications of alternative design decisions involving the expenditure of varying amounts of different types of money is the annual cost in use method. The capital cost of installing the insulation is converted into an annual equivalent and the annual fuel cost to maintain the house at 18°C for this particular level of insulation is added to this annual equivalent. The annual equivalent of the first costs depend upon the life of the insulation and on the rate of interest. The insulation is deemed to have the same 50 year life period of the building. A distinction should be noted between the amortisation period for deriving costs in use and the period for mortgage lending. The amortisation period of 50 years has been chosen to avoid complications of allowing for the residual value of the insulation at the end of the period. The cost in use of each alternative is based on present electricity costs.[6]

Prior to the energy crisis the cost in use method would have reflected the same cost comparisons in the future as historically all costs have risen by the same relative amount. But now energy costs are rising at a faster rate than other costs. There are energy costs in the production, distribution and installation of insulation. It is beyond the scope of this report to predict future energy costs and insulation costs.

The Net Present Worth section looks at the cost comparison trend of insulation in view of increasing energy costs.

6.2 RESULTS

Table 6.2 -a gives the capital cost and annual equivalent for each insulation regime. The annual equivalent has been calculated for three different capitalisation interest rates over a 50 year period.

Table 4.2 -a gives the electricity cost @ 2.33 c/kWh to maintain the house at 18^{o}c for each different insulation regime. This fuel cost is added to the annual equivalent to give the cost in use Table 6.2 -b. There are no maintenance costs or residual value factors involved with the insulation. Although there are plant costs and running costs associated with the plant, these factors are not taken into consideration because the economic comparisons of each regime of insulation depends upon the energy cost and not the mode of heating. Whether electricity rates are a true reflection of energy costs is another story.

Tables 6.2 -c, d, and e each give the rank ordering of the lowest cost in use insulation regime for the capitalisation interest rate of 9%, 12%, and 15% respectively together with the rank ordering of minimum capital cost for that particular insulation regime.

A principle of minimum cost in use comparisons is that dearer money tendsto favour proposals with lower capital costs and, conversely, cheaper money tends to favour first cost alternatives. This principle holds true for like products when comparisons are made on a scale basis. In this study foil insulation is compared to fibreglass insulation and, should one form of insulation have a cost advantage over the other, the above principle may not be consistent for all the insulation regimes about to be compared.[6]

In Table 6.2 -e the higher interest rate of 15% favours the lower capital cost insulation regime alternatives. A rank ordering correlation test gives a correlation co-efficient r of 0.939. In tables 6.2 -c and 6.2 -d the lower interest rate of 9% and 12% do not favour the higher capital cost forms of insulation.

In Table 6.2 -c instead of finding a correlation co-efficient close to -1.000 the co-efficient was found to be + 0.545. These results show that a comparison is being made of differentiated products where one has a cost advantage. An economic comparison of the insulation in the walls and roof can be made separately:-

1. Insulation of the Walls

Foil in the walls rank 1st, 4th, 5th, and 10th at the 9% interest rate.

1st, 2nd, 5th and 8th at the 12% interest rate.

1st, 2nd, 3rd, 5th and 10th at the 15% interest rate.

Even though the lower interest rates favour a higher capital cost of insulation in the walls foil insulation shows that it is more cost effective than fibreglass insulation at the energy cost of 2.33 c/kWh.

When compared to the foil in the wall and same roof insulation the difference in cost in use for 50mm fibreglass in the walls is:-

a) 0.7% at 9% interest rate

b) 3.6% at 12% interest rate

c) 6.5% at 15% interest rate

and for 75mm fibreglass in the walls.

a) 0.8% at 9% interest rate

b) 4.9% at 12% interest rate

c) 8.7% at 15% interest rate.

As can be seen the cost advantage of foil insulation in the walls over fibreglass is not very great at lower interest rates but increases to a significatn advantage at higher interest rates for the electrical energy cost at 2.33c/kWh. At below 12% interest rate 50mm or 75mm fibreglass could be substituted for foil insulation in the walls without the difference in cost in use being greater than 5%.

2. Insulation of the Roof

Foil insulation in the roof does not enter into the first ten rankings. Comparisons of the cost in use of insulation in the roof therefore can be regarded as a comparison of economic scale.

At 9% interest rate 75mm fibreglass in the roof gives the lowest cost in use for all insulation regimes of the wall.

At 12% interest rate 75mm fibreglass in the roof ranks 2nd, 6th, and 8th.

The higher interest rates favour the lower capital costs of insulation and yet 75mm fibreglass ranks first for 9% 12% and ranks second for 15% rate of interest with a 1.2% difference in cost in use from the first ranked insulation regime. At the 2.33cc/kWh rate of electrical energy 75mm of fibre glass in the roof is the most cost effective order of insulation in the roof.

When compared to 75mm fibreglass in the roof and same wall insulation the difference in cost in use for 50mm fibreglass in the roof is:-

a) 1.8% at 9% interest rate
b) 0.2% at 12% interest rate
c) -1.2% at 15% interest rate

ie lower cost in use.

and for 100mm fibreglass in the roof

a) 2.6% at 9% interest rate
b) 4.2% at 12% interest rate
c) 5.7% at 15% interest rate

and for 150mm fibreglass in the roof

a) 8.2% at 9% interest rate
b) 12.4% at 12% interest rate
c) 16.0% at 15% interest rate

Either 50mm or 100mm fibreglass could be substituted for 75mm fibreglass in the roof without a significantly large difference in cost in use especially at the lower interest rates.

Table 6.2-a

Capital Cost and Annual Equivalent of Insulation Regimes

50 year life period of house

CASE	INSULATION REGIME FLOOR	WALL	ROOF	CAPITAL COST $	ANNUAL EQUIVALENTS 9% FACTOR 10.962	12% FACTOR 8.305	15% FACTOR 6.661
A1	nil	nil	nil	-	-	-	-
A2	nil	nil	foil	117-46	10-72	14-14	17-63
A3	nil	nil	25	106-48	9-71	12-82	15-99
A4	nil	nil	150	337-59	30-80	40-65	50-68
A5	nil	foil	foil	154-43	14-09	18-59	23-18
A6	nil	foil	25	143-45	13-09	17-27	21-54
A7	nil	foil	150	374-56	34-17	45-10	56-23
A8	nil	25	25	194-11	17-71	23-37	29-14
A9	nil	25	150	425-22	38-79	51-20	63-84
A10	nil	100	150	538-12	49-09	64-79	80-79
A11	foil	foil	foil	264-05	24-09	31-79	39-63
A12	nil	50	150	462-86	42-22	55-73	69-49
A13	nil	50	100	374-56	34-17	45-10	56-23
A14	nil	50	75	318-86	29-09	38-39	47-87
A15	nil	50	50	275-31	25-11	33-15	41-33
A16	nil	foil	150	374-56	34-17	45-10	56-23
A17	nil	foil	100	286-26	26-11	34-47	42-98
A18	nil	foil	75	230-56	21-03	27-76	34-61
A19	nil	foil	50	187-01	17-06	22-52	28-08
A20	nil	75	150	500-19	45-63	60-23	75-09
A21	nil	75	100	411-18	37-51	49-51	61-73
A22	nil	75	75	356-19	32-49	42-89	53-47
A23	nil	75	50	312-64	28-52	37-64	46-94

Table 6.2-b

Annual cost in use of Insulation Regimes

CASE	INSULATION REGIME FLOOR	WALL	ROOF	COST IN USE 9% $	12% $	15% $
A1	nil	nil	nil	130-53	130-53	130-53
A2	nil	nil	foil	109-54	112-96	116-45
A3	nil	nil	25	99-86	102-97	106-14
A4	nil	nil	150	100-21	110-06	120-09
A5	nil	foil	foil	103-00	107-50	112-09
A6	nil	foil	25	90-42	94-60	98-87
A7	nil	foil	150	87-39	98-32	109-45
A8	nil	25	25	95-53	101-19	106-96
A9	nil	25	150	91-94	104-35	116-99
A10	nil	100	150	89-49	105-19	121-19
A11	foil	foil	foil	112-30	120-00	127-84
A12	nil	50	150	88-10	101-61	115-37
A13	nil	50	100	83-78	94-71	130-53
A14	nil	50	75	81-33	90-63	100-11
A15	nil	50	50	83-10	91-14	99-32
A16	nil	foil	150	87-39	98-32	109-45
A17	nil	foil	100	82-85	91-21	99-72
A18	nil	foil	75	80-77	87-50	94-35
A19	nil	foil	50	82-21	87-67	93-23
A20	nil	75	150	88-22	102-82	117-68
A21	nil	75	100	83-46	95-46	107-68
A22	nil	75	75	81-42	91-82	102-40
A23	nil	75	50	82-93	92-05	101-35

Table 6.2-c

Annual Cost in Use 9% interest rate Rank Ordering

CASE	INSULATION REGIME FLOOR	WALL	ROOF	COST IN USE $	% DIFF No 1	RANK	CAPITAL COST RANK
A18	nil	foil	75	80-77	-	1	2
A14	nil	50	75	81-33	0.7	2	6
A22	nil	75	75	81-42	0.8	3	7
A19	nil	foil	50	82-21	1.8	4	1
A17	nil	foil	100	82-85	2.6	5	4
A23	nil	75	50	82-93	2.7	6	5
A15	nil	50	50	83-10	2.9	7	3
A21	nil	75	100	83-46	3.3	8	10
A13	nil	50	100	83-78	3.7	9	8=
A16	nil	foil	150	87-39	8.3	10	8=

Table 6.2-d

Annual Cost in Use 12% interest rate Rank Ordering

CASE	INSULATION REGIME FLOOR	WALL	ROOF	COST IN USE $	% DIFF No 1	RANK	CAPITAL COST RANK
A18	nil	foil	75	87-50	-	1	3
A19	nil	foil	50	87-67	0.2	2	2
A14	nil	50	75	90-63	3.6	3	7
A15	nil	50	50	91-14	4.2	4	4
A17	nil	foil	100	91-21	4.2	5	5
A22	nil	75	75	91-82	4.9	6	8
A23	nil	75	50	92-05	5.2	7	6
A6	nil	foil	25	94-60	8.1	8	1
A13	nil	50	100	94-71	8.2	9	9
A21	nil	75	100	95-46	9.1	10	10

Table 6.2-e

Annual Cost in Use 15% interest rate Rank Ordering

CASE	INSULATION REGIME FLOOR	WALL	ROOF	COST IN USE $	% DIFF No 1	RANK	CAPITAL COST RANK
A19	nil	foil	50	93-23	-	1	2
A18	nil	foil	75	94-35	1.2	2	3
A6	nil	foil	25	98-87	6.1	3	1
A15	nil	50	50	99-32	6.5	4	4
A17	nil	foil	100	99-72	7.0	5	5
A14	nil	50	75	100-11	7.4	6	7
A23	nil	75	50	101-35	8.7	7	6
A22	nil	75	75	102-40	9.8	8	8
A21	nil	75	100	107-68	15.5	9	10
A16	nil	foil	150	109-45	17.4	10	9

7. NET PRESENT VALUE

7.1 EXPLANATION OF THE METHOD

This method involves discounting to present value at a selected rate the cash flow of the various Energy Conservation Techniques (ECT'S) alternatives and picking the ECT with the highest nett present value (that is the excess of present value of cash inflows over cash outflows at this given rate of interest). The rate of discount used is the cost of capital or the alternative investment rate (sometimes called opportunity cost).

Specifically, we are concerned with finding the present value of a stream of annual energy savings valued at (S) at today's energy prices, occuring over the lifetime (L) of the ECT. These energy savings while constant in kWh terms, are growing in dollar terms because of price rises at some average annual rate (P). But at the same time these savings must be discounted to present value using an appropriate discount rate (D)

Thus present value can be expressed in terms of nominal (Actual) price increases and discount rates as

$$P.V. = \sum_{t=1}^{L} \left(\frac{1+P}{1+D} \right)^{t} . S$$

However, both price rises and discount rates are a function of two forces: a real rate of change (P' and D') and the rate of inflation (I). Real energy price rises are due to those resources becoming scarcer relative to other resources, not inflation, which raises the nominal price of all resources. Real discount rates here refer to that rate of return required to attract an investment, apart from the need to recover purchasing power lost by inflation. Because the I term appears (implicitly) in both the numerator and the denominator of the above equation, its effects cancel out leaving only the real terms to be estimated.

ie: When discrete (vs. continuous) compounding is used

$P = I + P' + I.P'$ and $D = I + D' + I.D'$

Then

$$\frac{1+P}{1+D} \qquad \frac{1+I+P' + I.P'}{1+I+D' + I.D'} \qquad \frac{(1+P')(1+I)}{(1+D')(1+I)} \qquad \frac{1+P'}{1+D'}$$

This is of considerable value to us because the need to estimate the rate of inflation has been eliminated. Throughout the remainder of this section we will refer only to these real components P' and D'.

So now

$$P.V. = \sum_{t=1}^{L} \left(\frac{1+P'}{1+D'}\right)^t .S$$

For ease of computation this can be expressed as :-

$$P.V. = \frac{1+P'}{D'-P'} \left[1 - \left(\frac{1+P'}{1+D'}\right)^L\right].S \qquad D' \neq P'$$

$$P.V. = L.S \qquad D' = P'$$

Some discussion as to appropriate values for P', D' and L is now needed.

1) Although some energy prices, particularly those for electricity have historically declined in real terms up until a few years ago, it is unlikely that such a pattern will continue before the end of the century for several reasons. Firstly, environmental controls are growing stricter; second, more intensive extraction methods are now being used; third many new oil fields are located in remote areas; and fourth, generating, equipment and refining processes have been developed to the point where increasing their scale may no longer lower average costs significantly.

Mr M. King Hubbard of the U.S. Geological Survey has worked in the area of world oil production projections and estimates that if world oil productions were to increase at the same rate that it has in the past two decades, output would peak about 1995, and then drop sharply.

This would have a dramatic effect on the real rate of change of oil prices and would affect the prices of other energy sources as well. Estimates of projected rates of energy price increases for fossil fuels and electricity are available from several sources. Most of these are based on different sets of assumptions, however, and the estimates vary accordingly. While it is improbable that natural gas, fuel, oil, and electricity will all increase in price at the same rate it is difficult to predict relative changes with any accuracy. A real rate of increases (over and above the rate of general inflation) of 1% for all energy sources is used in the NBS proposal for "Design and Evaluation Criteria for Energy Conservation in New Buildings". This may be considered conservative by some because of recent price increases many times this rate in some cases. This rate is meant to be representative of the long run rate of real prices for the next 20 years, however, and in this respect it reflects price increases determined by long run market forces.

2) Before estimating an "appropriate" discount rate for the "typical" homeowner some insight into discount rates is needed.

In order that energy conservation investments be considered in their proper economic priority, they must be compared with the next most profitable alternative investment available to homeowners after adjusting for risk, tax liabilities, and the preference for short - over long-term investments. An appropriate discount rate will then reflect an "opportunity cost", ie, the cost of foregone profit from the next best alternative. In this study the discount rate may also be viewed as the minimum rate of return to induce further investment in energy conservation.

It is quite important to note that returns on investment in ECT'S are not subject to income taxation for - homeowners as they arise from reduced expenditure of after-tax disposable income. Therefore, for homeowners, alternative after tax rates of return should be used in determining an appropriate discount rate for investments in energy conservation.

At the present rate of inflation it is quite difficult for the average homeowner to realize a positive rate of return after taxes. It is for this reason that a 1% real rate of return on investment may be sufficient to induce further homeowner investment into energy conservation. However, one must clearly understand that this is the potential rate of return to be realized at the margin, ie, for the last increment of investment. The average annual rate of return on the total investment will be considerably higher. For example, the addition of 75mm of fibreglass to the wall and roof may pay back its costs in 4 - 7 years, but continues generating savings over its entire lifetime and one can see that the actual rate of return on the total investment is quite high.

The marginal investment (that for the last increment) may also be viewed as requiring its full expected lifetime to be repaid (including interest at the discount rate). Each previous increment will take less and less time to be repaid, however, andthe first increment eg: 25mm may be paid back within a few months. The average length of payback will then be considerably shorter than the expected lifetime.

Because the marginal investment does require the full expected lifetime to be repaid, this may be considered a relatively long -term and illiquid investment (unless the house is sold before the last increment iscompletely amortized). For this reason such a marginal investment may not be as attractive to the homeowner as a short-term investment yielding the same rate of return. While the additional rate of return needed to induce such long term investments may be somewhat higher than for short-term investment, this difference is overshadowed by other considerations, especially the effect of high inflation rates on actual investment opportunities and the somewhat conservative estimate in estimating the rate of fuel price increase.

3) Since the real rate of fuel price increase has been considered equivalent to the homeowner's discount rate of 1%, the present value of future energy savings is simply the sum of these savings, at current prices, over the life of the specific ECT, considered. This of course leaves the estimated lifetime as a critical variable in the assessment of marginal savings generated by the various ECT'S.

For this reason we must now consider the appropriate lifetime over which energy conservation methods might be amortized. This is especially relevant to homeowners or prospective homeowners who do not foresee occupying their houses long enough for the marginal investments (ie; the cost of last increments of the various techniques) to be completely paid back in the form of energy savings. As energy costs increase relative to other costs, however, energy consumers will become more conscious of the economic desirability of energy conservation and the market value of buildings will better reflect their energy, usage (as reflected in fuel bills). In this respect a well-insulated house will be more likely to sell quickly and command a price higher than that of a poorly insulated home, making it considerably easier for a homeowner to recoup the unamortized portion of his investment if he is not intending to occupy the house throughout the lifetime of the ECT'S.

While the expected useful lifetime of some ECT'S may extend to the life of the building, any lifetime assumption over 20 years is likely to be unrealistic in view of large-scale uncertainties as to economic conditions beyond that time period, especially for energy prices. For this reason 20 years has been chosen as the appropriate time period for use in estimating the present value of future energy savings.[6,9]

This section 7.1 is a modified explanation of Net Present Value taken from Stephen Peterson's " Retrofitting existing Housing for Energy Conservation: An Economic Analysis ".

7.2 RESULTS

Table 7.2 -a gives the Net Present Value of the insulation regimes with a 1% real rate of energy price increase and 1% real discount rate taken over 20 years.

Table 7.2 -b gives, the rank orderings of net present value, the highest value being ranked first. The capital cost of each insulation regime is ranked in order of highest capital cost while the energy savings is ranked in order of greatest savings.

Increasing energy costs tend to favour the insulation alternatives which can produce a greater savings in energy. In the study, using the sizings of fibreglass insulation available on the market, there are few exceptions where a larger capital outlay in fibreglass does not result in a larger energy savings. Because Case A22 has a more optimally balanced combination of fibreglass insulation than Case A13 this is one exception where a smaller capital outlay results in higher energy savings. Foil insulation in the walls is a more cost efficient form of insulation than fibreglass because each dollar invested in foil produces more savings than a dollar invested in fibreglass. However at higher energy costs it is more preferable to invest more to save more and existing methods of foil insulation prevent this. So although foil is more cost efficient, it is not necessarily more cost effective at all energy cost levels. Case A18 which ranked first at the energy cost level of 2.33c/kWh now ranks 7th.

Case A22 and A18 are the exceptions that a larger capital outlay in insulation produces greater savings. A correlation test for the group of insulation requires which produce the ten highest net present values shows that there is a high correlation of 0.976 between capital expenditure and savings. And yet a correlation test for savings versus net present value gives a correlation co-efficient of 0.636. The highest savings cases do not rank among the highest nett present value cases. At the 1% real rate of energy price increases there is still a balancing of capital costs and energy savings.

At a higher real rate of energy price increases there would be a one - one correspondence between nett present value and energy savings or capital cost.

The difference between the first 5 ranked nett present value and the first is 2.6%. Whether one combination of insulation levels in the roof and walls is a closer optimum combination than another is not significant at this order of difference. Any higher level of insulation above 75mm fibreglass in the walls and 100mm fibreglass in the roof does not give any cost advantage at 2.33c/kWh it was found that foil in the walls and 75mm fibreglass in the roof was the optimum combination and that 50mm or 75mm fibreglass could be substitued for foil insulation in the walls and that either 50mm or 100mm fibreglass could be substituted for 75mm fibreglass in the roof without too much loss in cost effectiveness.

A final conclusion is that the sensitivity of cost effectiveness is so small that a range of insulation combinations can be used to satisfy cost effectiveness at present day electricity costs and future energy costs which may increase at the real rate of 1% per annum. These ranges for Auckland are as follows:-

Walls foil on gib board
or 50mm - 75mm fibreglass

roof 75mm - 100mm fibreglass

At or below 1% real rate of energy price increases, any higher level of insulation outside these ranges would be unwarranted on a cost effectiveness basis.

<u>NOTE</u> These insulation standardsrecommended for Auckland are based on:-

a) The cost effectiveness of the insulation which takes into account the cost of the insulation as well as the savings it produces.

b) A minimum inside temperature of 18^{o}c. A higher inside temperature of 20^{o}c would involve greater energy costs even if higher insulation standards were used. In raising a house from 18^{o}c to 20^{o}c there would be a greater absolute heat load involved to maintain the house at this new higher thermal comfort level. With the higher heat loss involved it would be justifiable to use a higher insulation standard on a cost effectiveness basis. But higher levels of insulation gives diminishing energy savings. This rate of diminishing returns becomes more predominant at higher insulation levels. As well as involving extra insulation costs to maintain the house at 20^{o}c the heat load would not be reduced to the previous heat load level by using insulation at the new cost effectiveness insulation level. So if absolute energy savings were the criteria then a sub-optimum insulation standard would be then required to reduce the heat load down to the previous heat load for the 18^{o}c internal temperature house.

An insulation standard which is based on economic criteria takes into account the cost of the insulation, the cost of energy, the cost of money or interest rate, and the energy savings this standard can produce. The purpose of such an insulation standard would be to save more for less. Any rise in insulation standards results in greater savings of energy. But to base insulation standards on absolute energy savings criteria alone would be uneconomic for the country and for the consumer. If insulation standards use energy savings as a criterion then these savings should not be greater than economically viable to achieve so that the consumer can make adjustments and choose the appropriate level of insulation himself.

But consumer must be "informed"

Table 7.2-a

Net present Values of Insulation Regimes

20 year period

1% real rate of energy price increase

1% real discount rate

CASE	INSULATION REGIME FLOOR	WALL	ROOF	CAPITAL COST $	ANNUAL SAVINGS $	PRESENT VALUE SAVINGS	NET PRESENT VALUE $
A10	nil	100	150	538-12	90-12	1802-40	1264-28
A12	nil	50	150	462-86	84-65	1693-00	1230-14
A13	nil	50	100	374-56	80-92	1618-40	1243-84
A14	nil	50	75	318-86	78-29	1565-80	1246-94
A15	nil	50	50	275-31	72-53	1450-60	1175-29
A16	nil	foil	150	374-56	77-31	1546-20	1171-64
A17	nil	foil	100	286-26	73-79	1475-80	1189-54
A18	nil	foil	75	230-56	73-12	1462-40	1231-84
A19	nil	foil	50	187-01	65-47	1309-40	1122-39
A20	nil	75	150	500-19	87-93	1758-60	1258-41
A21	nil	75	100	411-18	84-58	1691-60	1280-42
A22	nil	75	75	356-19	81-60	1632-00	1275-81
A23	nil	75	50	312-64	76-12	1522-40	1209-76

Table 7.2-b

Net Present Value Rank Ordering

CASE	INSULATION FLOOR	REGIME WALL	ROOF	NET PRESENT VALUE $	% DIFF No 1	RANK	CAPITAL COST RANK	SAVINGS RANK
A21	nil	75	100	1280-42	-	1	4	4
A22	nil	75	75	1275-81	0.4	2	6	5
A10	nil	100	150	1264-28	1.3	3	1	1
A20	nil	75	150	1258-41	1.7	4	2	2
A14	nil	50	75	1246-94	2.6	5	7	7
A13	nil	50	100	1243-84	2.9	6	5	6
A18	nil	foil	75	1231-84	3.8	7	10*	9
A12	nil	50	150	1230-14	3.9	8	3	3
A23	nil	75	50	1209-76	5.5	9	8	8
A15	nil	50	50	1175-29	8.2	10	9	10

Case 18 is the only foil type insulation combination in the first ten rankings.

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