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A NEW THERMAL DESIGN GUIDE FOR NEW ZEALAND HOUSES

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A new thermal design guide for New Zealand houses

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This paper presents a new thermal design guide for New Zealand houses. The guide is an extension of the existing ALF (Annual Loss Factor) method. The paper introduces a new version of the method with the flexibility to calculate the annual home heating energy demand for house designs in a variety of climates and heating schedules.

1. Introduction

The beginnings of ALF reach back more than 18 Years [1]. At that time (the oil shock years) BRANZ could see a need for a simple thermal design guide for houses that would demonstrate the effect of varying insulation, the location and size of windows, and thermal storage effects. During that period and later on a number of other thermal design tools were developed [2,3,4]. However, the strength of the BRANZ ALF calculation was that it was simple, transparent and easy to use. These features were also important criteria when the BIA adopted ALF as a compliance method for the new thermal efficiency performance targets in the Clause H1 (Energy Efficiency) in the NZBC [5]. ALF was first revised in 1990 [6] to include an air infiltration calculation and an allowance for thermal storage. The method was still based on a steady indoor temperature of 20°C and lacked any way of adjusting for heating different schedules or alternative heating season lengths.

In recent years BRANZ has investigated a number of limitations in the current ALF calculation procedure, and worked steadily towards an update of ALF. Although the new ALF (referred to as ALF 3 in this paper) is a ground-up redevelopment, much of the simplicity and transparency of the current ALF has been retained. The procedure can still be completed with a hand calculator and it follows the same intuitive steps of balancing heat losses against heat gains. As always with simplified procedures, there comes a point where simple pad and pencil tools have to be abandoned for more sophisticated computer based methods. This point is thought to occur when the building is divided into different thermal zones, or where temperatures and energy requirements must be modelled over shorter time periods of hours and days.

1.1 Criteria for a new ALF thermal design guide

Energy assessment: The current ALF calculation method was designed to estimate the energy performance of residential buildings rather than comfort, moisture or other characteristics of the building. Similarly, the ALF 3 procedure does not attempt to evaluate benefits other than in terms of heating energy efficiency. One obvious advantage of effective thermal design is improved moisture control. Prolonged heat release from heavy thermal floors in late can increase temperatures outside the periods where thermostats are set for heating. This increases the moisture carrying capacity of air ventilated from the building, bringing advantages not reflected in purchased heating savings.

Simplicity: There are a large number of sophisticated thermal building design tools available in New Zealand and overseas but this sophistication tends to limit their application to users with specialist computing skills. Ultimately, though, the greater part of sensible thermal design can be carried out with much simpler calculations which are accessible to anyone involved in building design. The ALF procedure fills this role. Although the ALF procedures have been developed using the SUNCODE thermal simulation programme [7] and many other experimental and theoretical results, the scope of the calculations has been limited where necessary to retain simplicity.

Transparency: The steps in an ALF calculation align with the heat flow processes in houses and contain very little “black box” calculation where the process is not obvious. Almost all of the intermediate steps in an ALF calculation produce physically real terms, eg the heat loss through windows or the air infiltration rate. The advantage of this is that performing an ALF calculation is instructive and interactive with the process of refining a building thermal design.

Flexibility: The ALF 3 procedure is more flexible than any previous version of ALF, in that it can account for a greater range of indoor heating patterns. Previous versions of ALF restricted indoor temperatures to a steady 20°C throughout the building.

2. New features in ALF 3

2.1 Selection of heating schedules

Experience has shown that industry and government require tools which supply them with information on annual heating energy use. While the current ALF provides a robust method to evaluate different thermal building designs against each other, it is not able to make annual heating energy calculations. The existing ALF assumes a fixed heating schedule of 20°C over a twenty four hour period. Since this heating level is uncommon in New Zealand the calculated annual heating energy can not be directly compared with actual heating energy consumption.

Therefore it was decided that the revised ALF procedure should give a choice of heating schedules (time of day) and heating set points (temperature level). The ALF 3 provides the following selection of schedules and temperatures:

		Heating Level		
		16°C	18°C	20°C
Heating Schedule	1. Evening only (5:00 pm - 11:00 pm)	x	x	x
	2. Morning and evening (7:00 am - 9:00 am & 5:00 pm - 11:00 pm)	x	x	x
	3. Morning to evening (7:00 am to 11:00 pm)	x	x	x
	4. Continuous (24 hours)	x	x	x

Table 1: Heating schedules and levels available in ALF 3

This gives the opportunity to calculate more realistic heating energy results, along with the possibility of adding even more flexibility with the processes of interpolation and extrapolation.

The thermal performance of a particular design depends to a large degree on the behaviour and requirements of its occupants. A particular building design might have benefits in the case of intermittent heating whereas it has disadvantages in the case of all day heating schedules. Particularly the benefits of thermal mass are largely dependent on the applied heating schedule. Intermittent heating generally favours light weight buildings whereas continuous heating favours heavy thermal mass buildings [8]. The provision of different heating schedules in the ALF 3 method allows to evaluate designs in correspondence with the assumed usage of the building.

These features allow the use of ALF 3 as an energy calculation tool for a large number of applications: The new ALF 3 algorithm provides realistic New Zealand heating habits and could therefore be applied for heating energy estimations required for future developments of the New Zealand Building Code. The Energy Saver Fund [9,10], a $18M program by the Energy Efficiency and Conservation Authority aims to reduce the energy consumption of NZ households. The bidding process requires the estimation of energy saving through the proposed measures. The new ALF 3 will allow bidders to run simple calculations to estimate the heating energy benefits of their proposals. The use of realistic heating schedules allows building designers to provide their clients with realistic estimates of heating energy savings in kWh or $ of specific designs. Also the heating energy estimates of Home Energy Rating Schemes such as the ECNZ supported EnergyAssist scheme [11] could be improved through the flexibility and realism of the heating schedules and levels in ALF 3.

2.2 Mass heat up energy

The second significant extension of the current ALF procedure is the modified treatment of thermal mass. The current method was based on a fixed 24 hour heating schedule. This meant that it was sufficient to consider only the benefits of thermal mass as a heat sink which can supply free heat in the early evening hours. The introduction of intermittent heating schedules required to take account also of the disadvantages of high thermal mass. In the case of insufficient free heat (small windows, unsuitable climate, etc) the thermal mass absorbs heat which is supplied through purchased heating and thus increases the amount of required heating.

The consideration of both aspects of mass, the “mass heat up” energy as well as the thermal storage of free heat in the ALF 3 calculation allow a rather specific evaluation of disadvantages and benefits of thermal mass as a function of building design and heating habits. The method allows to decide what is an appropriate amount of mass.

3. Other changes

3.1 Climate specific heating seasons

One of the main requirements for the new calculation method was the ability to provide realistic annual heating energy requirements. The current ALF procedure uses a heating season which was the same for all climate and locations in New Zealand. This was sufficient since the main application of the current ALF procedure was the comparison of different designs at one location. There were rarely applications where designs in different climates had to be compared. ALF offered a modified monthly calculation process if the user required so, however, the transparency and user-friendliness of the process was somewhat limited.

The extended focus of the new ALF 3 procedure required a more climate linked approach. It was therefore decided to define the winter season climate on the basis of long term average monthly temperatures. The threshold temperature was decided through a heating habit survey conducted with BRANZ staff. The subjects were asked during which months of the year they usually apply heating. The results were then compared with long term average monthly temperatures from the National Institute of Water and Atmospheric Research Ltd. [12]. This comparison lead to a threshold average monthly temperature of 11.5°C. Thus the winter season in the ALF 3 calculation procedure is defined as all the months with a long term average monthly temperature of 11.5°C or less. This heating season is fixed, rather than user selective winter months.

3.2 Infiltration calculation method

The ventilation component of building heat loss has always been difficult to calculate because it depends on the air-tightness of the building (leading to infiltration) and the occupant management of windows and other ventilation devices. All of these factors are unknown at the design stage so that certain realistic assumptions have to be made about infiltration and occupant provided ventilation . The approach taken in the current ALF is to use the larger of 0.5 ACH (minimum building averaged ventilation rate required to comply with NZS4303) or an estimated infiltration rate for heat loss calculations. The ventilation heat loss is therefore a minimum which may often be exceeded.

Air infiltration rates were calculated in the previous version of ALF from a measure of the complexity of the building and local climate factors. The algorithms for this were developed from field studies showing that more architecturally complex buildings to be less airtight than those of simple design [13]. While this was a useful way of estimating the air-tightness of conventional timber framed residential buildings, the relationship, although not proven for other types of construction eg. concrete block and panel construction, was frequently used by ALF users well outside its range of application. In this version of ALF a simpler approach is offered:

Different base infiltration rates are calculated for houses built before and after 1960 [13,14]. Although 1960 is a somewhat arbitrary date, it does mark the replacement of strip flooring with particle board and the earliest examples of aluminium window frames. New homes are allocated a base infiltration rate according to their floor area and complexity of design. The base infiltration rate is then modified to reflect specific design features. This leads to a specific infiltration rate which must then be adjusted for the local climate and for the wind exposure appropriate to the building.

3.3 R-Values from the BRANZ House Insulation Guide

In May 1995 BRANZ published a revised version of its Home Insulation Guide [15]. The guide provides R-values for wall, ceiling, floors and windows for most of the common construction materials and methods in New Zealand houses. It was decided that instead of repeating a similar data base in the new ALF 3 manual, to refer directly to the BRANZ Home Insulation Guide. This will lead to an increased consistency of R-values used in various applications. The reference also provides a multitude of materials and construction types in respect to the current manual ALF

3.4 Slab floor R-Values

BRANZ has spent considerable effort over the last three years to research the thermal performance of slab on ground floors [16]. These efforts have in recent times lead to a revision of the calculation of the thermal performance of slab on ground floors. The new formula takes account of the geometric outline of the floor, the insulation level of the floor, the thickness of the external walls and the ground water table. The revised formula is currently being published [16] and will eventually be implemented in ALF 3. For the time being the existing calculation method which does not account for wall thickness and ground water table is retained.

3.5 Gain utilisability based on gain/loss ratio, mass and conductance

The most important feature which distinguishes the ALF calculation procedures from other simple degree day calculation methods, is the accounting for solar and internal gains. ALF is designed to be an energy calculation method. Therefore only the gains which reduce the required amount of purchased heat can be taken into account in the energy balance. The useful fraction of solar and internal gains depends on several factors.

Significant effort was invested into the development of an appropriate utilisability function for the new ALF 3 calculation method. The provision of a set of different heating schedules required the development of different utilisability function for each schedule because the amount of replaced purchased heating depends on the time of day when the heating is applied. It was found for each of the four heating schedules that the three heating levels can be dealt with by one function.

3.6 ALFs for walls independent of orientation

The current ALF calculation procedure considers the orientation of the walls for their heat loss performance. It was decided to drop this distinction and to treat all wall orientations in the same way in terms of their heat losses. This simplification is justified by results from thermal simulations which showed only marginal differences between the two methods. It is believed that the main reason is that the wall areas facing in each orientation are of similar size, thus if an average wall Annual Loss Factor (*ALF)* value is applied the orientation effects of all the building walls cancel each other largely out. It was found that the difference in thermal performance between walls oriented in different directions is between 5% and 20% depending on the climate region.

4. The ALF 3 calculation steps

The new ALF 3 calculation method has a very similar structure as the current ALF method. Figure 1 provides a flow chart depicting the calculation steps. First the total heat demand and the total free heat are calculated, and then the useful fraction of the gains is subtracted from the total heat demand. This provides a very clear structure which reflects as far as possible actual heat flows in the building. There are, however, a number of changes to the calculation of the various heat flows.

4.1 Heat demand

The total heat demand is composed of three different processes: conductive heat losses through the building envelope, convection of warm air due to infiltration and the heat required to heat up thermal mass in the building after the building has cooled down. First the building characteristics are determined for each of the three mechanisms. The thermal building performance is then multiplied with the climate and heating specific *ALF* value to give the total heat demand.

Conductance through the envelope: The conductive heat losses through the building envelope are calculated using the R-values and areas of the building components (walls, roof, floor and windows). The heat conductance of each of these components is calculated by dividing the areas by the R-values. All the conductances are then added up to give the building conductance (also called UA-value).

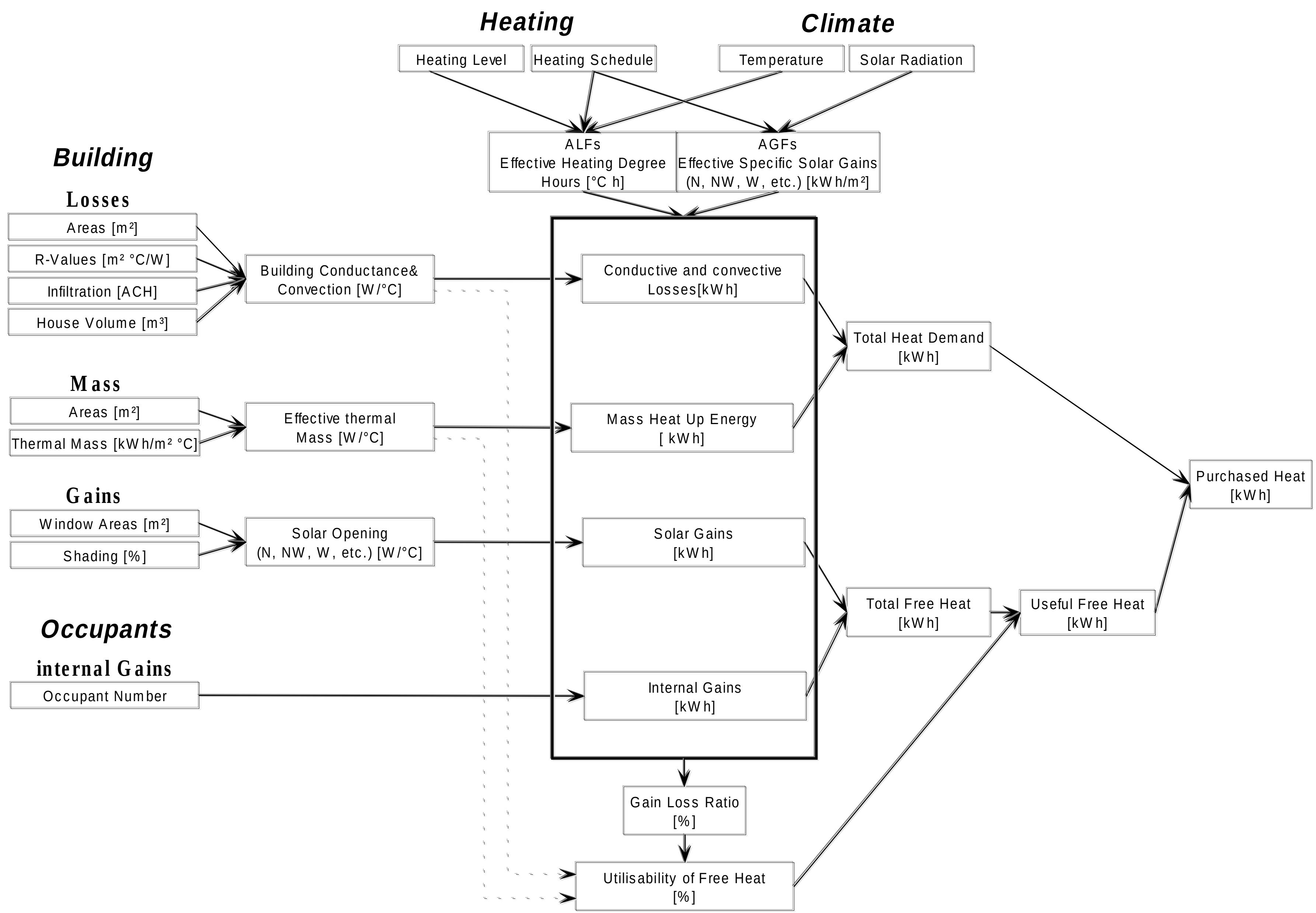

Figure 1: Structure diagram of the ALF 3 calculation steps

Infiltration loss: The heat loss due to convection of warm air caused by infiltration is calculated by first determining the number of air chances per hour. This calculation takes account of building design features, of the regional wind conditions (Air Leakage Zone) and the local building sheltering (Site Exposure). First a base air change rate is determined based on a general description of the house type. There are four categories provided:

Base air change rate	**[Air changes per hour]**	**typical example**
airtight	0.25 ACH	post 1960, simple small rectangular design, airtight joinery, all windows with gaskets
average	0.50 ACH	post 1960, larger than 120 m²
leaky	0.75 ACH	post 1960, complex shape, some feature strip lining materials, generally larger than 200 m² or pre 1960, sheet lining and retro-fit aluminium windows
draughty	1.00 ACH	pre 1960, strip lining, strip flooring, often high stud

Table 2: Base air change rates with typical construction examples

This base air change rate is then modified according to design features like number of open fires, number of solid fuel heaters with flue restrictors, areas of large openings (i.e. gap under front door), retro-fit air-tightening of old wooden windows and retro-fit air-tightening of leaky linings. The resulting air change rate is finally multiplied with factors taking account of the Air Leakage Zone and the Site Exposure. The Air Leakage Zone Factor is chosen from a map of New Zealand containing data which reflect regional variation in average wind speed and temperature in the proportions in which that they drive infiltration. The Site Exposure Factor is chosen from a chart according to the extent of shielding by local terrain and buildings etc. The result is multiplied with the house volume and the specific heat capacity of the air. This gives the specific infiltration loss.

Thermal mass heat up energy: The heat required to heat up thermal mass in the building after the building was let to cool down is considered in the following way: The thermal mass of the building is determined as a function of construction material and component areas. Table 3 provides specific thermal mass values. The units amounts are provided in units of kWh/m² °C because component areas are easer to determine for the user than volumes.

Material	**Specific Heat [kWh/m² °C]**
Floor	
Slab on ground floor without insulation	0.3
Slab on ground with full insulation beneath	
Cast Concrete (50mm)	0.028
Cast Concrete (100mm)	0.056
Cast Concrete (150mm)	0.083
Suspended Floors	
Timber flooring	0.004
Walls	
Concrete Blocks (every other core filled)	0.042
Concrete Blocks (lightweight) (every other core filled)	0.013
Brick (100mm)	0.038
Timber framed Wall	0.009
Solid Timber Wall (64mm)	0.010
Ceiling	
GibBoard	0.003

Table 3: Specific thermal mass of the most common construction elements

Some construction materials possess large amounts of thermal mass. Not all of this mass takes part in the diurnal energy flows. Therefore the total thermal mass per m² floor area is then modified using the chart in Figure 2 to provide the effective thermal mass of the building. The dimension of the effective thermal mass was chosen to be compatible with the UA-value and the specific infiltration loss (W/°C). This allows the combination of the three mechanisms into one building performance number.

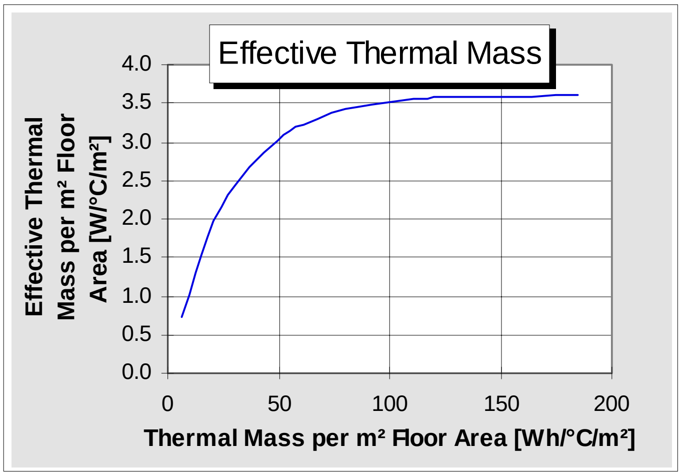

Figure 2: Effective thermal mass as a function of total thermal mass

ALF values: The building performance number is then multiplied with the Annual Loss Factor (*ALF*), an index describing the coldness of the climate, the applied heating schedule and the heating level. A subset of the *ALF* data are shown in Table 4 for Schedule 1 ("Evening Heating Only"). The result is the Total Heat Demand in kWh per year.

Station Name	Winter	Annual Gain Factors (AGF)									Internal Gain Factor	Annual Loss Factors (ALF)		
		N	NE	E	SE	S	SW	W	NW	H		16 °C	18 °C	20 °C
Rotorua	May to Sep	137	63	39	39	39	40	97	154	97	0.91	5594	7387	9184
Napier	Jun to Aug	161	78	51	51	51	58	125	186	125	0.55	2857	4057	5261
Wanganui	Jun to Aug	165	81	53	53	53	61	130	192	130	0.55	2772	3953	5138
Wellington	May to Sep	183	92	62	62	62	74	150	216	150	0.91	5086	6769	8456
Nelson	May to Sep	189	96	65	65	65	78	157	224	157	0.91	6073	7970	9871
Dunedin	May to Oct	254	136	98	98	98	127	231	311	231	1.10	7479	9681	11887
Queenstown	Apr to Oct	262	141	101	101	101	132	240	321	240	1.28	9778	12478	15183
Invercargill	Apr to Nov	298	164	120	120	120	160	282	370	282	1.46	10557	13426	16299

Table 4: Table of the AGFs*, Internal Gain Factors and* ALFs *for a sample of the available climate locations*

Heat gains: Heat gains consist of solar gains and internal gains caused by the excess heat of appliances in the building.

The solar gains are calculated by firstly calculating the effective solar opening area of all the windows facing in each of the eight primary orientations. Under consideration of the shading factors of the window areas the solar gains are calculated by multiplying the areas with the Annual Gain Factors (*AGF*) which are provided in Table 4. The Annual Gain Factors are calculated for the whole winter heating season, which is defined in respect to the severity of the climate. This leads to Annual Gain Factors being higher in colder location than in warmer ones.

Internal gains are calculated taking account of the number of occupants and the floor area of the house. The Internal Gain Factors from Table 4 are used to adjust the size of the internal gains according to heating season and heating schedule.

Utilisable gains: Heat gains provided either through solar radiation or through internal heat releases can generally not all be utilised in terms of heating energy reduction, because they may occur at times when no specific temperature level is demanded by the occupants. Large solar gains can for example occur in the early afternoon hours through North facing windows. If, however, the applied heating schedule requires a specific temperature level only in the evening (i.e. Schedule 1) most of the gains can not be utilised immediately. A fraction of the gains, however, can be stored in the thermal mass of the building and be released later during the scheduled heating time. The fraction of utilisable gains depends on the ration of heat gains and heat losses, the effective thermal mass of the building and the building conductance. The utilisability of gains can be determined in ALF 3 using a diagram as displayed in Figure 3.

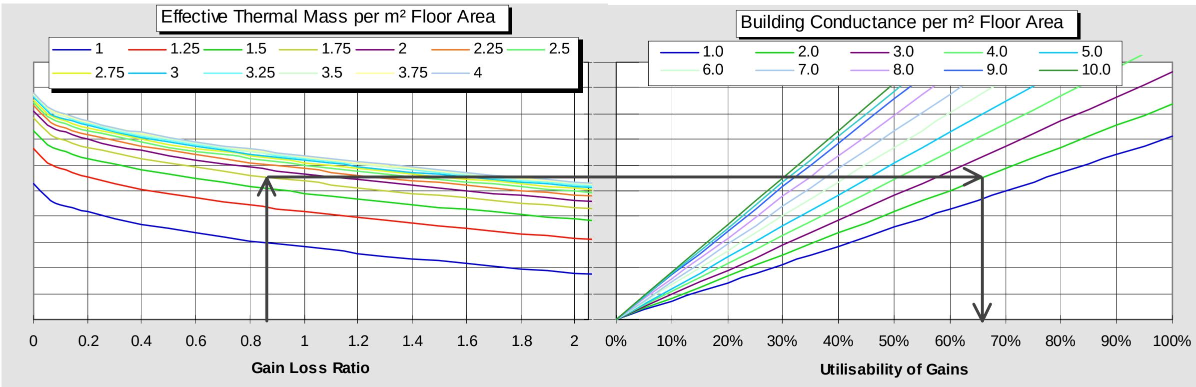

Figure 3: Determination of the utilisability of heat gains: 1. Calculate and select Gain/Loss Ratio (left graph), 2. Determine vertical intersection with Effective Thermal Mass (left graph), 3. Determine horizontal intersection with Building Conductance (right graph), 4. The resulting ordinate value of the right graph is the utilisability of the gains

5. Development of ALF 3

The new calculation method was developed using heating energy simulation results from SUNCODE simulations. SUNCODE is a thermal simulation program which was used widely in the for heating energy use calculations by New Zealand government and designers [9, 17].

The development was conducted in mainly three stages: at first the *ALF* values for conductive and infiltration heat losses were calculated, second the energy for heating up the thermal mass of the building was determined and at last the utilisability function of solar and internal gains was developed. All three steps were performed for all four heating schedules and three heating set-points, as well as for between 4 and 10 New Zealand climate regions. The calculated *ALF* and Annual Gain Factors (*AGF*) were then extrapolated to approximately 80 other New Zealand locations.

1. In order to determine the *ALF* values due to conductance and infiltration, simulation runs were conducted using buildings with no thermal mass and no solar and internal gains. The building heat conductance was calculated according to the simulation model description (Areas, R-values, Volume, Infiltration rate). The ratio of simulated heating energy and building conductance gave the *ALF* values for each heating schedule, heating level and location.

2. The same buildings were then simulated again, this time including a range of different thermal mass levels (again without internal and solar gains). The resulting heating energy was compared to the mass less buildings and the functional relation between additional energy requirement and increased mass level was determined.

   The following two graphs in Figure 4 show the effect of taking account of the mass heat up energy.

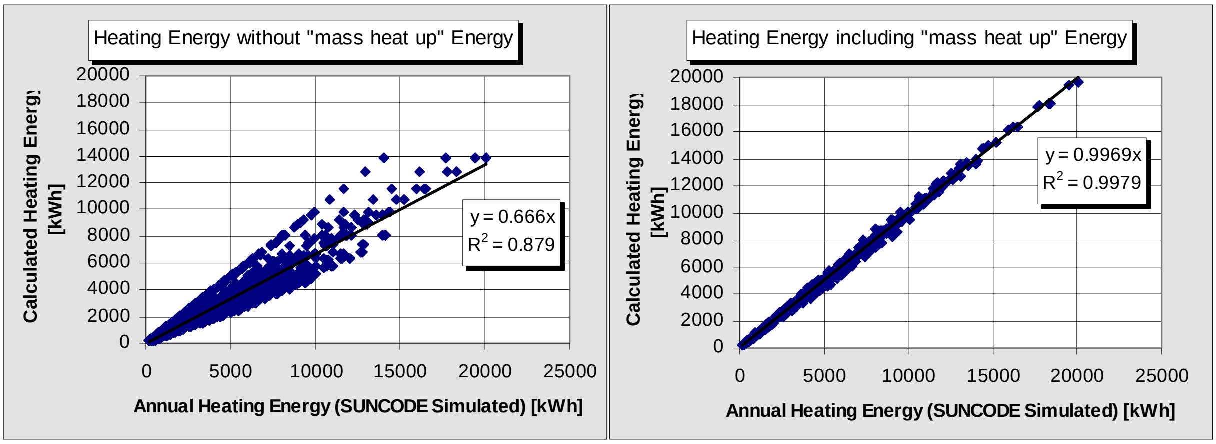

Figure 4: Calculated heating energy versus SUNCODE simulated energy. The left graph shows the comparison without taking account of the energy required to heat up thermal mass in the building, the right graph shows the comparison of the calculation which does account for mass heat up energy.

3. Subsequently the buildings were simulated again, this time including a range of mass and solar gain levels (expressed as Solar Gain Factors). The results were compared with the ones without solar gains. The heating energy reduction was then compared to the total solar gains, which were derived from weather data input files. The ratio of the heating energy reduction and the total solar gains are the utilisability of the gains. These utilisabilities were analysed and functional relations between them and the gain/loss ratio, the thermal mass level and the building conductance were established.

1. Finally the *ALF*s and *AGF*s were extrapolated to approximately 80 other New Zealand locations. The *ALF* extrapolation was based on average monthly temperatures. The *AGF*s were calculated using monthly sunshine hours from NIWA and the geographic latitude of the locations.

The developed model was finally compared with the SUNCODE simulation results for a different, larger house design. The result of the comparison is shown in Figure 5. The figure shows a good correlation between the SUNCODE and ALF 3 heating energies.

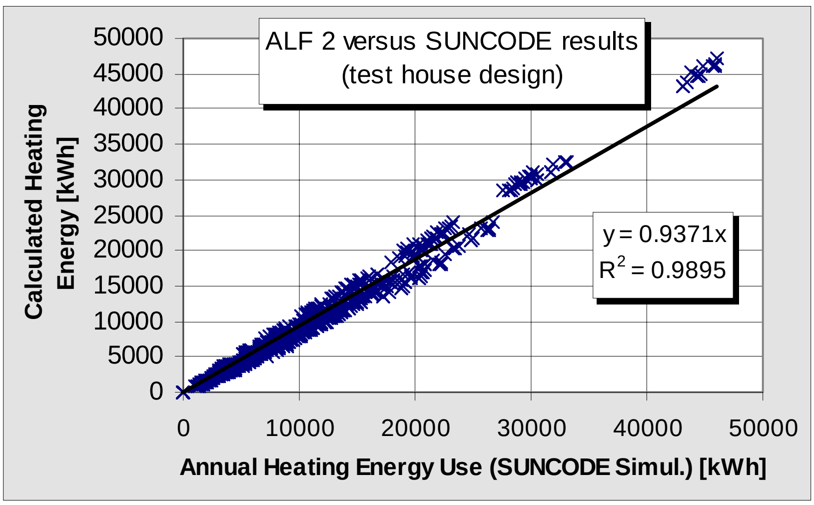

Figure 5: Comparison of SUNCODE and ALF 3 energy calculation for a test house design

6. Outlook

A number of aspects have not been dealt with in this ALF revision.

Zoning of the building can significantly change the thermal performance of the building. The new ALF 3 method provides a simple adjustment tool for houses which are not heated in all rooms. However, it seems to be useful to investigate the benefits and options of a different treatment in the future.

This ALF revision has not distinguished between different heating types. The UK BREDEM model [18] assigns different response factors to different heating systems. Most of New Zealand houses don't have central heating using fairly responsive heating systems. However, night store heaters, which have an unresponsive heating output, are becoming more common. It is therefore necessary to investigate the impact of the responsiveness of the heating system on the heating energy requirements in the future. Initial investigations have been started.

Air conditioning is becoming more and more common in the northern regions of New Zealand. A future revision of ALF should also incorporate a method to determine the cooling energy requirement of houses. This probably requires a completely new approach to the thermal building performance and will need significant development efforts.

With the envisaged alignment of New Zealand and Australian building regulations it would be desirable to be able to apply the ALF 3 calculation method also for Australian locations. For most Australian locations this would require the consideration of both cooling and heating energy.

7. Conclusion

This paper presents a new thermal building design guide, ALF 3. The guide is structured similar to the existing Annual Loss Factor method which has been in ongoing development by BRANZ for the last 18 years.

Four important features of the method were retained since the last update: it is an energy calculation tool and does not attempt to evaluate other than heating energy aspects of the building; it is simple and the calculations can be performed with a pad and pencil; it is transparent in the sense that most of the calculation steps represent actual physical heat flow processes; and it has considerably increased flexibility by including four different heating schedules and three heating set-points.

The increased flexibility of ALF 3 required that the effects of thermal mass be considered in greater detail. The method has the ability to evaluate both the increased heating demand due to heat up energy of thermal mass in intermittent heating schedules as well as the improved utilisability of solar and internal gains due to thermal mass heat storage.

Other changes to the previous version include the location specific redefinition of the winter seasons as a function of the severity of the local climate, an improved and simplified infiltration calculation method, a revision of slab floor R-values and a re-calculation of the functional relationship between the utilisability of solar and internal gains and the gain/loss ratio, the thermal mass and the building conductance.

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