CONFORTO NO AMBIENTE CONSTRUIDO
III ENCONTRO NACIONAL
I ENCONTRO LATINO-AMERICANO
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BIOCLIMATIC DESIGN: STRATEGY TO DETAILS

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Introduction

The term 'bioclimatic design' was coined by Victor Olgyay (1953), when he was still at the MIT, but it is more widely used in the Latin countries than in English-speaking parts of the world. Hence I often find it necessary to define its meaning:

Bioclimatic design in architecture is to ensure the existence and wellbeing of **bio**logical organisms within the given **climatic** conditions, (primarily of humans, but protecting bio-diversity). Bioclimatic architecture relies heavily on architectural science, especially architectural energetics, but goes well beyond that. It rejects energywasteful and inhuman environments, the ubiquitous glass boxes and skyscraper machines. It rejects fashion-dominated architecture, it returns to basic human needs and values, it encourages regionalism.

Bioclimatic design employs appropriate technologies, as dictated by the particular task, by the given socio-economic conditions, but it avoids the trap of romantic neo-primitivism. It does not reject high technology, but it is based on an ecological moral imperative: *take least from and dump least into the environment.*

One could say that bioclimatic architecture is a way of thinking about architecture, a way of doing architectural design. Bioclimatic thinking has to penetrate all levels, all stages of the design process, from pre-design analysis to final details. And this is what I wish to examine in this paper.

Pre-design analysis

The big hype about the 'information super-highway' makes me rather suspicious, but there is no doubt that computers are very useful tools in design. I am not concerned with CAD systems, rather with the use of analytical and performance-predictive programs. Most such analyses and calculations are possible by manual methods, but are far too time-consuming, hence rarely used by practising architects. There is a hope that they may become more widely used as computerised tools become available.

When a design task is given, especially if it is in an unfamiliar climate, the first task is a climate analysis and the selection of the most appropriate design strategies, before pencil is put to paper.

Olgyay, over 40 years ago, developed a bioclimatic analysis method, which is often followed today, sometimes in a rather mechanistic and servile manner. Since his time computers were developed and our knowledge and understanding has increased tremendously. Some of his methodology has been transferred to a more exacting base, the psychrometric chart, but some of his concerns are today relegated to a lesser importance. Wind is one such factor, for three reasons:

1 his wind considerations are quite valid for an open site, but with suburban densities wind can rarely be relied on
2 orientation towards the wind is not critical, as simple wing walls or similar features can create pressure zones which will produce air flows through the building, even with grazing incidence.
3 physiological cooling effect can be produced by quite low powered ceiling fans, which may be cheaper and more effective than the effort to get cross ventilation.

In one available computer package – for example – if the climatic data are 'on file', this kind of analysis gives instantaneous answers on the screen. A hard-copy output may take a few minutes, depending on the kind of printer available.

A climatic data file can be created for any location in less than 10 minutes, provided the necessary data are available. These should include monthly values of the mean minimum and mean maximum temperatures, an early morning and an afternoon relative humidity value, monthly total precipitation and an average day's horizontal total solar irradiation. The only problem may be the availability of standard deviation values for minima, maxima and means of the temperature. In Australia such values are readily available. Where unavailable, it would necessitate an exercise of processing any available temperature data, preferably by the Bureau of Meteorology.

In the ARCHIPAK package the climate analysis output may include the following:

1 Numerical printout of the climatic data file (Fig. 1), – this is in fact the complete data set used by the package.

Climatic data for CANBERRA
Latitude = -35.3

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
TMax :	27.8	27.0	24.3	20.0	15.0	12.4	11.1	12.6	15.8	19.6	22.9	25.4	degC
sdMax:	5.1	4.5	3.7	3.6	3.1	2.3	2.1	2.4	3.4	4.1	4.9	4.9	K
TMin :	12.7	12.7	10.3	6.4	2.1	0.2	-0.5	1.0	2.6	5.9	8.1	10.9	degC
sdMin:	3.3	3.2	3.6	4.4	4.4	4.6	4.2	3.9	3.8	3.9	3.9	3.5	K
Tsd :	3.6	3.3	3.1	3.3	3.1	3.0	2.7	2.7	3.0	3.4	3.7	3.5	K
RHam :	57	64	68	75	81	86	84	79	72	66	58	55	%
RHpm :	36	38	40	44	52	58	58	53	48	47	40	37	%
Rain :	60	58	53	48	51	39	39	47	47	70	64	57	mm
Irad :	7667	6750	5389	3861	2778	2472	2389	3194	4528	5778	6972	7417	Wh/m2

Fig. 1
A typical climatic data file: full printout

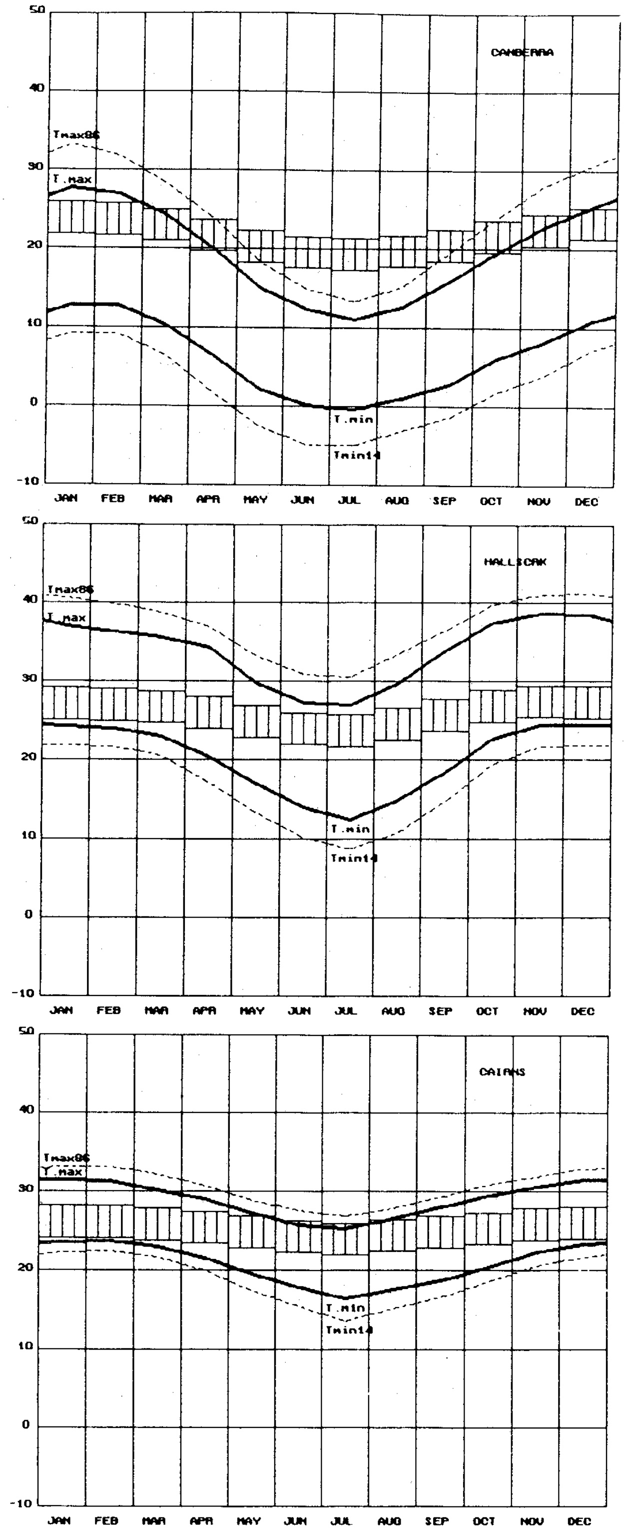


Fig. 2
Temperature plots: ***a) for a cool climate: Canberra***
b) a hot-dry climate: Halls Creek (Western Australia)
c) a warm-humid climate: Cairns (northern Queensland)
Note both the width and annual swing of the temperature band and its relationship to the comfort band.

2 An annual temperature graph (Fig. 2), plotting the comfort zone as a band, with limits calculated on a monthly basis, the mean maximum and minimum temperatures, plus the 14th %-ile values of the minima and the 86th %-ile values of the maxima. These values are chosen, as one day per week is 1/7, approx 14% of the week, thus conditions may be – on average – outside these limits one day a week. In other words, temperatures will probably remain within these limits five days a week.

3 A plot of 12 monthly temperature lines on the psychrometric chart, drawn between two points:
– the mean maximum temperature with afternoon humidity
– the mean minimum temperature with the morning humidity.
The lines indicate the range of mean conditions for the 12 months.

The comfort zones are plotted for the coolest and the warmest month (Fig. 3). This gives an instant visual indication of the nature of the climatic problem, i.e. the relationship between the given and the desirable conditions. This is however supplemented by three numbers, all three having the same denominator: the aggregate length of the 12 lines:

fuT *fraction under-temperature*, the length of lines below the lower boundary of the comfort zone for the coolest month, with the above denominator

foT *fraction over-temperature*, the length of lines above the upper comfort limit of the warmest month, divided by the same denominator

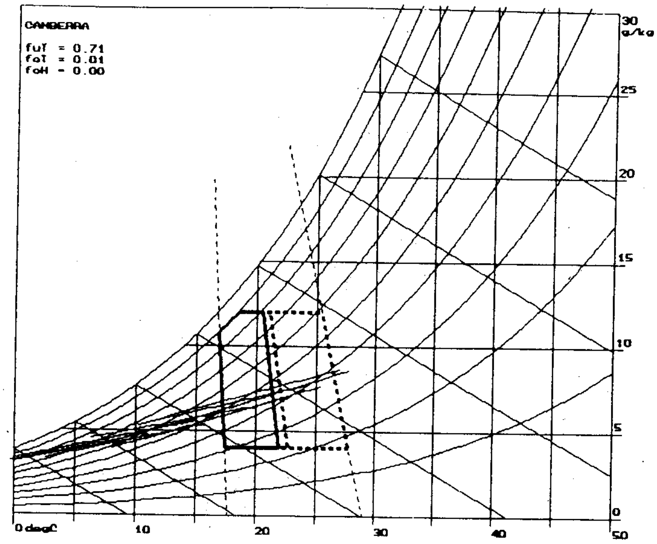
foH *fraction over-humid*, the length of lines above the 1.9 kPa vapour pressure (12 g/kg moisture content) level, again with the same denominator.

These would indicate the nature of the climatic problem in simple numerical terms (a monthly breakdown of these is optional).

4 A series of CPZ-s (control potential zones) can then be produced, – hence the name of the technique: *the CPZ method* (Szokolay, 1986) – indicating the potential effect of the various control strategies, i.e. the extent of outdoor conditions under which indoor comfort can be achieved by the particular passive control technique. The main thermal design strategies are taken as the following:

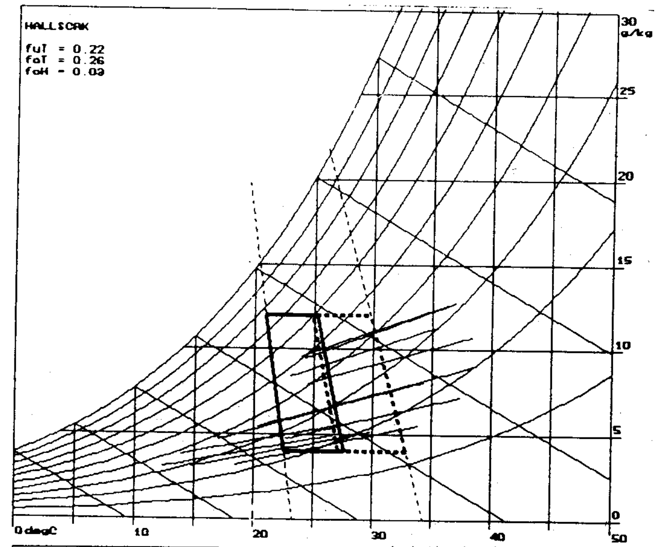
- *passive solar heating* (direct gain), with 0.5 and 0.7 utilisation factors (Fig. 4),
- *mass effect*, i.e. reducing in the interior the swings of exterior temperatures by the thermal mass of the building fabric, with or without night ventilation (Fig. 5),
- *physiological cooling* effect of air movement at the body surface (Fig. 6)
- *evaporative cooling*: direct and indirect (Fig. 7).

These CPZs can be called up to see which covers best the climate lines produced above.



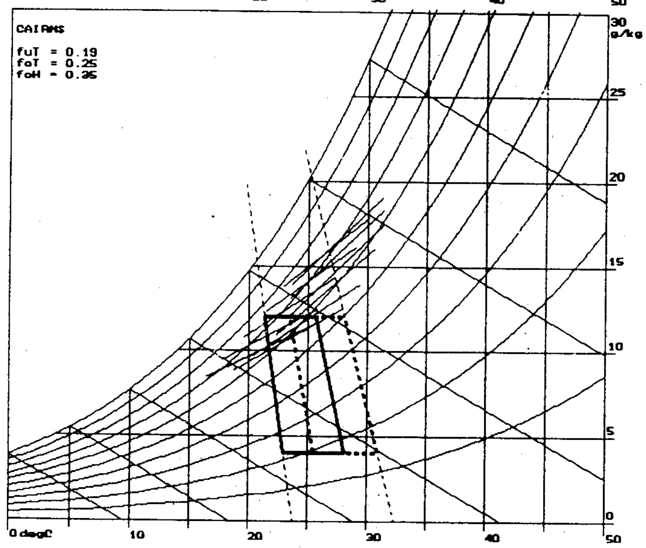
CANBERRA

	fuT	foT	foH
1	31 %	8 %	0 %
2	32 %	4 %	0 %
3	50 %	0 %	0 %
4	80 %	0 %	0 %
5	100 %	0 %	0 %
6	100 %	0 %	0 %
7	100 %	0 %	0 %
8	100 %	0 %	0 %
9	100 %	0 %	0 %
10	83 %	0 %	0 %
11	62 %	0 %	0 %
12	44 %	0 %	0 %
Yr:	71 %	1 %	0 %



HALLSCRK

	fuT	foT	foH
1	0 %	54 %	21 %
2	0 %	50 %	19 %
3	0 %	40 %	0 %
4	13 %	20 %	0 %
5	41 %	0 %	0 %
6	63 %	0 %	0 %
7	69 %	0 %	0 %
8	51 %	0 %	0 %
9	26 %	10 %	0 %
10	0 %	37 %	0 %
11	0 %	50 %	0 %
12	0 %	54 %	0 %
Yr:	22 %	26 %	3 %



CAIRNS

	fuT	foT	foH
1	0 %	56 %	56 %
2	0 %	59 %	59 %
3	0 %	47 %	47 %
4	0 %	26 %	26 %
5	24 %	0 %	0 %
6	47 %	0 %	0 %
7	59 %	0 %	0 %
8	46 %	0 %	0 %
9	32 %	0 %	0 %
10	14 %	18 %	45 %
11	0 %	38 %	79 %
12	0 %	51 %	98 %
Yr:	19 %	25 %	35 %

Fig. 3

Plots of climate lines and comfort zones for the coolest and warmest moths, on the psychrometric chart for the same three locations as in Fig. 2

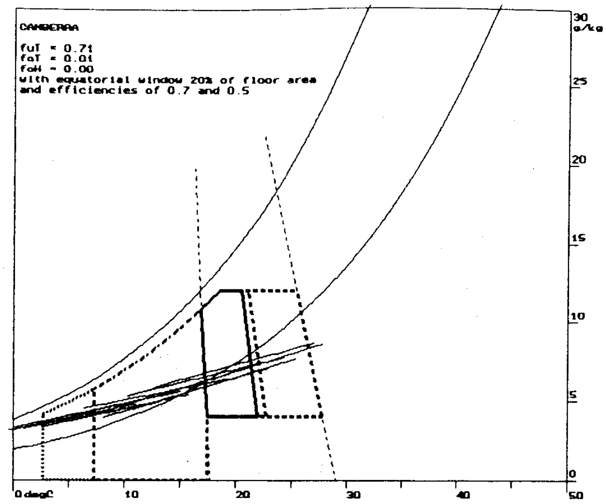


Fig. 4
Control potential zone for passive solar heating, Canberra

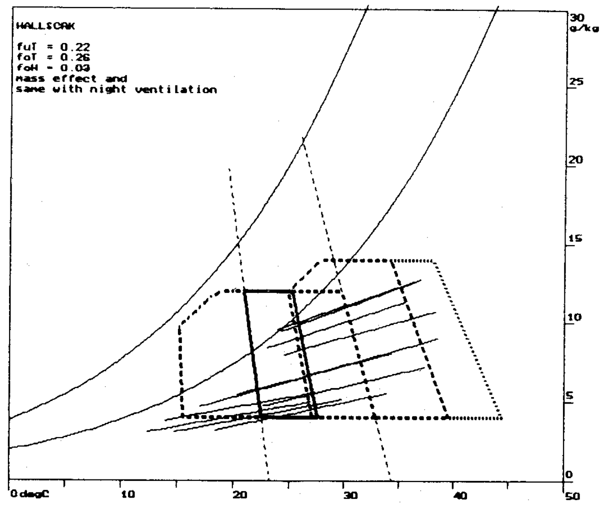


Fig. 5
Control potential zone for mass effect: Halls Creek

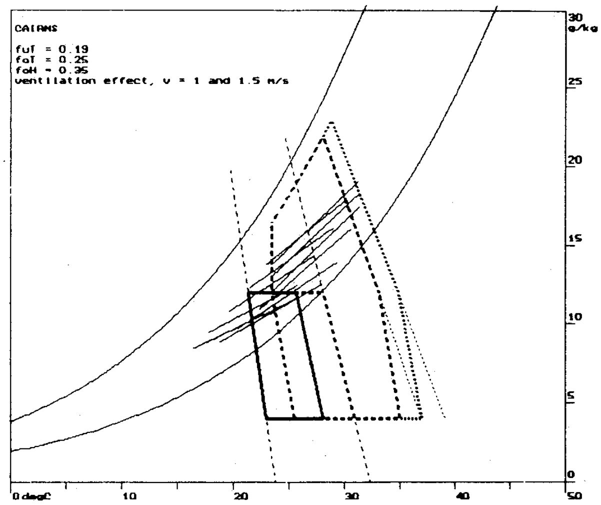


Fig. 6
Control potential zone for air movement effect: Cairns

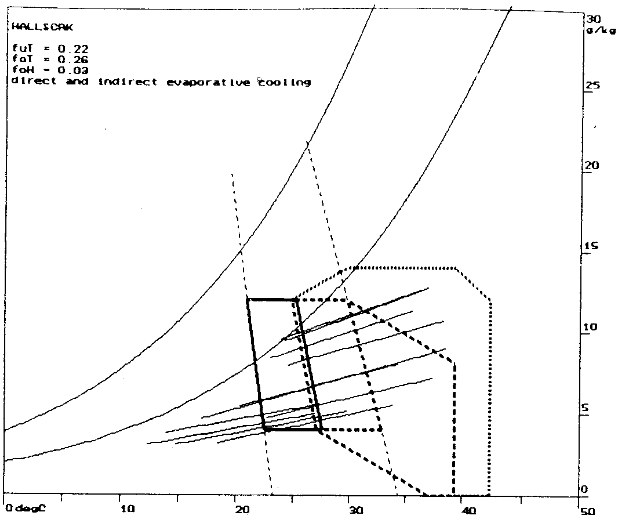


Fig. 7
Control potential zone for evaporative cooling: Halls Creek

Sketch design

The CPZ method only states that it is possible to achieve comfort by the selected strategy within the boundaries indicated, but it does not specify 'how'. The task at this stage is to translate the selected strategic principles into an actual building solution.

Architects tend to collect all kinds of information relevant to the design problem, attempt to internalise this information, so that the creative leap: the very first design idea is produced with all the factors, perhaps sub-consciously, kept in mind. Whilst acknowledging that at this point the architect must consider a multitude of factors and often must reach a compromise between conflicting requirements, I suggest that **bioclimatic considerations must never be compromised.**

Bioclimatic design, which incorporates energy conservation and greenhouse issues, is a question of survival. Quite basic and essential in terms of Maslow's (1948 and 1971) 'hierarchy of needs'.

> (Maslow distinguished five levels of human needs: physical/biological, safety/survival, affection/belongingness, esteem (by self and others), self-actualisation and suggested that the higher level needs arise only when the more basic ones are satisfied.)

Many of the 'normal' architectural considerations are often of secondary importance, embellishments or luxury, possibly desirable, but of no serious consequence if not fully satisfied. Many are much higher up in Maslow's hierarchy. Furthermore, here we are dealing with very subtle thermal processes and even apparently 'small' compromises can render some of these passive systems quite ineffective.

The first idea can then be tested and modified, in a cyclic process, until the solution satisfies all the requirements to the best possible extent. As so many different issues are involved at this stage, mostly only qualitative testing or evaluation methods are used. The individual architect's understanding, knowledge and experience will largely determine success or otherwise.

Design development and details

This is the stage of the design process when quantitative evaluation and performance prediction techniques can and must be used. At the sketch design stage creativity was the main issue and decisions could be made on the basis of 'gut feeling'; here competence and responsibility are the key terms. Some of these quantitative tasks can be handed over to various consulting engineers, but the thermal performance of the building itself, daylighting, essential aspects of noise control and ergonomics are the architect's responsibility.

Checks should be carried out at this stage to answer three questions:

1) Were the 'gut reactions', the earlier qualitative decisions correct?
2) Does the building's performance satisfy the legal, regulatory or advisory code requirements?
3) Beyond these, does the building measure up to expectations based on ecological ethics?

In terms of comfort/discomfort effects and energy use (or saving) the thermal performance of the building is the most important. Some regulations specify acceptable standards, such as maximum U-values, or window sizes, etc. Others embody performance specifications, such as the highest acceptable annual energy use. The latter must normally be estimated by some prescribed method. In many situations advisory energy targets are available, sometimes at different levels, such as minimum acceptable standards, good practice or excellent. In many states 'house energy rating' schemes are in operation. Some use a star-rating system, e.g. a 5-star house being the best and 3-star is the legal minimum. In my view, any method which prescribes thermal characteristics of individual components, or gives a number of points for certain features, which are then added up to produce an energy rating must be wrong and would often give erroneous results. It is the interaction of all its components that determines the thermal behaviour of a building, – what I referred to in an earlier paper (Szokolay, 1991) as the '*thermal Gestalt*'.

Quantitative methods that may be used at this stage include 'back of the envelope' type heat loss calculations, perhaps combined with a degree-day method of seasonal heating requirement calculation, or a slightly more sophisticated 'variable base' degree-hour method. I suggest that these should only be used as a first approximation. The simplest dynamic response calculation, the 'admittance procedure' constitutes – in my view – the minimum acceptable calculation method. For major jobs one may use more detailed and accurate methods, of the finite difference type (e.g. ESP, which solves up to 10 000 simultaneous differential equations) or the response factor type (e.g. Cheetah). These usually require a much more detailed description of the building, thus will take much longer to use.

The important issue at this stage is not so much the absolute accuracy of the predictions, rather the relative validity of the results. Whatever tool is used, it should allow quick modifications of the design, so that the designer can examine a large number of alternatives and get the correct answer as to which of the variants is better than the other.

In the ARCHIPAK package there are two modules used for thermal performance prediction:

- QBALANCE, based on steady-state heat flow calculation methods and
- HARMON, which predicts the dynamic thermal behaviour of the building, using the 'admittance procedure' of the British Building Research Establishment.

The building must be described by stating the number of envelope elements and the orientation and dimensions of each. The construction is described by a 3-digit element code number, by which the relevant thermal properties will be picked up from the ELEMENTS.DAT file. This contains some 500 building envelope elements, but new entries can be created by specifying the number of layers, the thickness and a 2-digit material code for each. This code will locate the relevant material properties (conductivity, density, specific heat capacity) from the MATERIAL.DAT file. This building description can be stored on a file, which will have the .BLD suffix and which can be used for both predictive programs.

QBALANCE calculates the area * U-value products for each element and the sum of these, the *envelope conductance* (in W/K). The *ventilation conductance* is found from the input of the building volume and the number of air changes per hour. The sum of these two is q, the *specific conductance* of the building. The 24-hour average solar irradiance on each surface is calculated (from climatic data), the average solar gain is found for each element and summarised for the whole envelope. The 24-hour average internal heat gain is an input and will be added to the solar gain to get the Q_{s+i} (in W).

The output summarises the input data in tabulated form as well as the intermediate steps of calculations, together with the final results (Fig. 8). One of the outputs is the 'heat flow balance' graph (hence the name of the module), as shown in Fig. 9. The Y axis is the absolute value of heat flow (W) and the X-axis is the outdoor temperature (T_o). The sloping line is the heat loss rate (Q); zero at the point where the T_o equals the indoor design temperature (T_i) and

$Q = q * dT$ for any lesser outdoor temperature, where $dT = T_i - T_o$

The value of Q_{s+i} is taken as a constant, i.e. independent of T_o, hence it is represented by a horizontal line. The intersection of the two lines will indicate the outdoor temperature at which the heat loss equals the heat gain. This is the 'balance point' temperature (T_b), which will be taken as the base temperature for the degree-hour calculation. It can also be found numerically as

$$T_b = T_i - (Q_{s+i}/q)$$

The number of degree-hours (Kh) for the month (or for each of the 12 months) is then calculated to this base temperature and the heating requirement will be found as H = q * Kh. This assumes continuous heating but adjustments are available for intermittent operation.

Job: HOUSEY. - Location: CANBERRA month: JUL.

	No	ORI	Len	W/H	A	grp.code		U	A.U	sgf	Rso	abs	Gav	Qs
	1	2	3	4	5	6	7	8	9	10	11	12	18	19
1:	10	-1	8.00	5.00	40.00	4	21	0.99	39.6	-	-	-	0	0
2:	20	360	8.00	2.40	12.90	2	80	5.23	67.5	-	0.06	0.50	138	279
3:	21	360	3.00	2.10	6.30	1	30	6.00	37.8	0.76	-	-	138	660
4:	30	90	5.00	2.40	12.00	2	80	5.23	62.8	-	0.06	0.50	61	116
5:	40	180	8.00	2.40	19.20	2	80	5.23	100.5	-	0.06	0.50	30	90
6:	50	270	5.00	2.40	12.00	2	80	5.23	62.8	-	0.06	0.50	61	116
7:	60	-1	8.00	5.00	40.00	3	30	6.76	270.3	-	0.04	0.60	100	-111

volume = 96.0 m3 (W/K) qc = 641.3 (W) 1150
air ch.= 3.0 qv = 96.0 Qi = 100

q = 737.3 Qs+i = 1250

Outdoor mean minimum temperature	=	-0.5 degC
Indoor design temperature	=	19.2 degC
Heating capacity required	=	13270 W
Balance-point (base-) temperature	=	17.5 degC
Degree hours in month	=	9112 K.h
Heating req.ment for month JUL	=	6718.5 kWh

Fig. 8
Output of QBALANCE for a simple building in Canberra

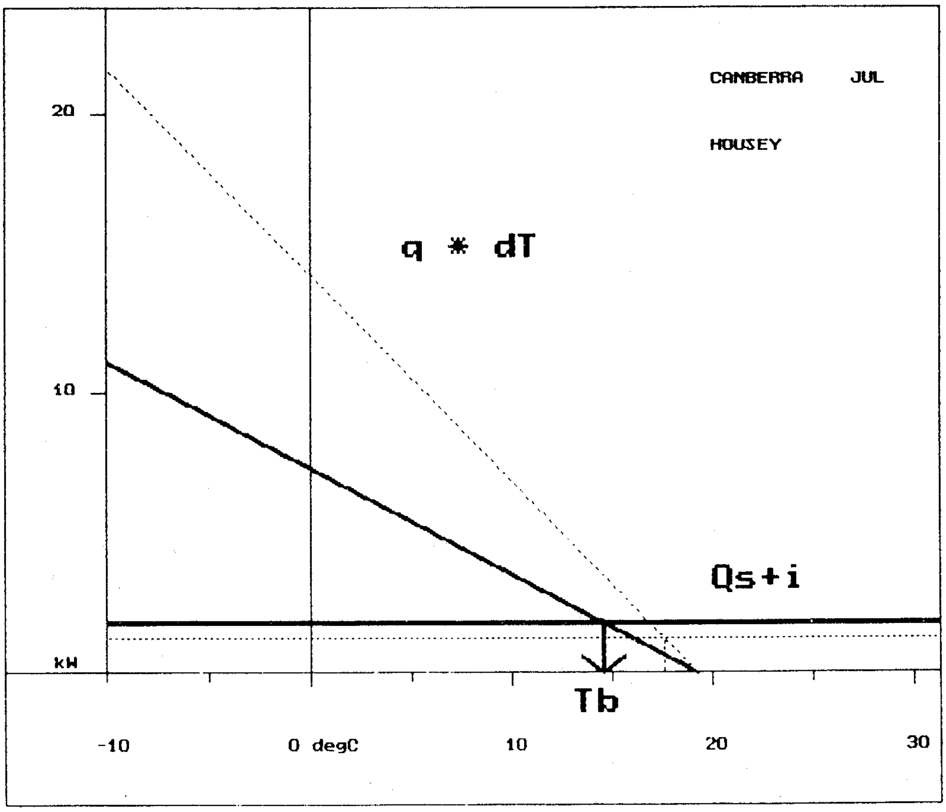


Fig. 9
Heat flow balance graph for the same building: note the dotted line indication of the previous variant (numbered 1 in the summary table)

The calculations can then be repeated, with any of the input data modified at will. The graph will show the latest results as well as the results of the previous run in dotted line. After each run a line is added to the summary table, which allows the selection of the worthwhile modifications.

HARMON estimates the dynamic response of the building for an average day of the selected month (or each month of the year). The numerical output gives hourly values of the indoor (as well as the outdoor) temperature (Fig. 10). These can also be plotted on a graph (Fig. 11).

If the design is then modified, the results of the previous run will be shown in dotted line and after each modification a new line is added to the summary table.

The building is treated as one zone, but partitions and other internal elements can be input and their admittance will be taken into account when the temperature effects of heat flows are calculated. The program will accept the input of hourly values of ventilation and internal heat gain.

The results may be in air-, dry resultant-, or environmental temperature. One output option gives the indoor temperature response to the 14th and 86th %-ile day, producing a band on the graph, which delineates the 5-day per week probability range.

It is during this development stage of the design that aspects other than thermal must also be considered. The main problem is that in the sequential design operation many such considerations must be simultaneous, for two reasons:

1) *Performance*: when the same decision influences several (indoor) environmental factors, e.g. design of shading to exclude solar/thermal inputs, but still provide adequate daylighting.

2) *Materials*: choice, when the same material has to perform several functions, e.g. if heavy walls are necessary for the exclusion of noise, then there is no point in considering a lightweight, insulated construction. Ecological aspects of materials choice must be considered at the same time, such as

   - renewable/sustainable, abundant/scarce raw materials
   - embodied energy (input in gaining, processing, fabricating)
   - environmental consequences of the manufacturing process
   - durability, maintenance requirements
   - reusability and any final disposal problems.

In many of these instances knowledge and experience will help in making correct design decisions. Quantitative methods are available and must be used for 'fine tuning', for detail design decisions, especially in critical situations. If, for example, the brief specifies the limit of acceptable NR (noise rating) for a room, design calculations will be necessary, or if a brief for a school stipulates 2% daylight factor, then daylighting calculations cannot be avoided. Fortunately computerised tools are now available for most of these tasks.

Job: HOUSEY. - Location: HALLSCRK month: JAN.

	No	ORI	Len	W/H	A	grp.code		U	A.U	sgf	Rso	abs	asg	tlg	dcr	Y	A.Y	Gav	Qs	Qav
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1:	10	-1	8.00	5.00	40.00	4	21	0.99	39.6	-	-	-	-	0.29	1.00	3.92	157	0	0	-137
2:	20	360	8.00	2.40	12.90	2	80	5.23	67.5	-	0.06	0.50	-	0.08	1.00	5.23	68	78	157	-76
3:	21	360	3.00	2.10	6.30	1	30	6.00	37.8	0.76	-	-	0.64	-	1.00	6.00	38	78	372	242
4:	30	90	5.00	2.40	12.00	2	80	5.23	62.8	-	0.06	0.50	-	0.08	1.00	5.23	63	151	284	67
5:	40	180	8.00	2.40	19.20	2	80	5.23	100.5	-	0.06	0.50	-	0.08	1.00	5.23	100	118	355	8
6:	50	270	5.00	2.40	12.00	2	80	5.23	62.8	-	0.06	0.50	-	0.08	1.00	5.23	63	151	284	67
7:	60	-1	8.00	5.00	40.00	3	30	6.76	270.3	-	0.04	0.60	-	0.08	1.00	6.76	270	281	1068	134

volume = 96.0 m3 (W/K) qc = 641.3 (W/K) qa = 759 (W) 2521 305
air ch.= 3.0 qv = 96.0 Qi = 100

bldg.response factor = 1.2 q = 737.3 Qs+i = 2621

Hourly outdoor and indoor environmental temperatures for JAN:

h:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
To:	26.0	25.2	24.6	24.3	24.4	25.1	26.3	28.1	30.1	32.2	34.1	35.6	36.6	37.0	36.8	36.4	35.7	34.7	33.6	32.3	31.0	29.6	28.3	27.1
Ti:	26.9	26.0	25.3	24.8	24.6	25.2	27.7	30.8	34.1	37.8	41.1	43.7	45.1	46.4	45.6	43.9	41.6	38.9	36.0	33.4	31.7	30.2	29.1	27.9

Indoor design temperature = 27.1 degC
Balance-point (base-) temperature = 23.6 degC
Heating req.ment for month 1 = 0.0 kWh

Outdoor mean temperature = 30.6 degC
Indoor mean temperature = 34.1 degC
Degree hours in month = 0 K.h

Fig. 10
Output of HARMON for a simple building for Halls Creek

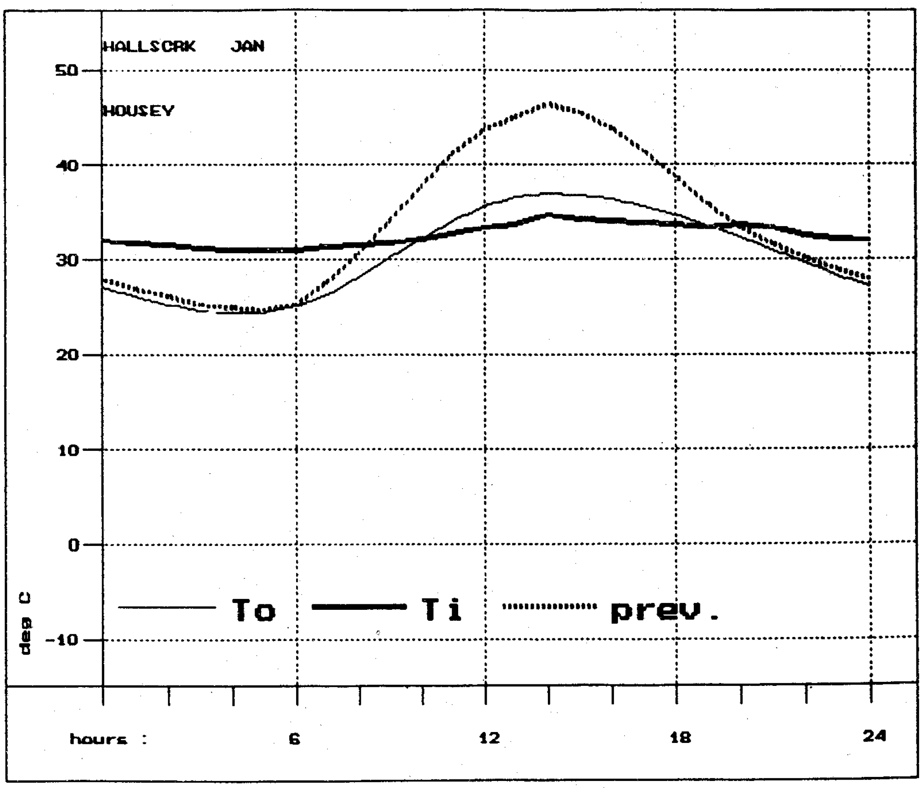


Fig. 11
The day's temperature profile: note the reduction in amplitude with the heavier construction of the modified version

vers.	Ti.av(degC).	Tmax(degC).	amplitude(K)
1	34.1	46.4	12.37
2	32.6	34.7	2.16

One word of caution, a warning I give to my students: never use a design tool unless you know what it does. Ultimately you are responsible for the results, not the author of the program.

Computer results must be mitigated by human intelligence at the best of times. Bioclimatic design is not just calculations and numbers. Numbers are to help design thinking, but are not substitutes for it. The design process can start with broad, qualitative decision-making. These decisions will then be verified, perhaps corrected by the use of numbers. At the end we must come back to qualitative considerations of human, cultural and social factors.

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