Problems of house energy rating (HERS) in warm-humid climates

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ABSTRACT: A building thermal response simulation method was developed in Australia by the CSIRO, starting in the 1950s and released as CHEETAH in 1986. This became the 'engine' of the NatHERS (National House Energy Rating Scheme) by 1995. NatHERS works well in the southern states of the country, where the primary use of energy is for heating. The paper first explores the problems of using this scheme for energy rating in the warm-humid climates of northern Australia. The contradictory requirements of air conditioned and open, ventilated 'free-running' houses are examined. Then the recent modifications to the program are outlined and the new version re-named AccuRate is described. The continued hostility to any such rating or regulation relating to thermal performance is discussed and the problem is illustrated by an actual example.

Keywords: comfort, energy, rating, air flow

1. INTRODUCTION

In Australia the practice of house-building was woefully lagging behind existing knowledge of climatic design and passive thermal controls. Until 1998 persuasion and information were the only tools to promote energy conservation. As the response from industry was very poor, it has been decided to introduce compulsion: the BCA (Building Code of Australia) was extended to include energy provisions, which came into force in January 2003. Compliance with Code requirements can be shown by following the 'deemed to satisfy' prescriptions, or using the NatHERS (National House Energy Rating Scheme) program to show a minimum of 3.5 stars performance (out of 5 stars).

The basis of simulation is the assumption of a closed box, for which the heat flows in and out are calculated in hourly time steps for the given climate. NatHERS works quite well for the southern temperate climates, where the main problem is underheating. It can also be used for inland hot-dry areas, where buildings are closed during the day (ventilated at night). Not so for the northern (warm-humid) part of the country, where houses are mostly used in the 'open' mode: with windows and doors wide open, to maximise cross-ventilation. In the best houses there is no sharp boundary between inside and outside.

North of Brisbane (lat.-27.5°) there is no need for any energy use for heating or cooling in a well-designed house. There was a contention that "we are concerned with energy rating, not comfort rating, non-conditioned houses are not our concern". However we argued that there is a frightening increase in air conditioning installations and consequent increase in energy use, that is largely due to the poor thermal qualities of houses. Better houses would not only reduce air conditioning load, but also avoid the need for air conditioning, thus achieve energy conservation.

It was agreed that the basis for rating would be a notional air conditioning load, even if the house has no such installation.

2. THE SIMULATION TOOL

The program NatHERS is based on the theoretical work done by Muncey [1] at the CSIRO (Commonwealth Scientific and Industrial Research Organisation). The program STEP (early 1960s) used a building response factor method, based on a frequency response analysis of the building's thermal network. Later a routine for the calculation of incident solar radiation was added, thus it became SUSTEP. Walsh [2] modified the program in 1977, to analyse multi-zone buildings and it was renamed ZSTEP. Delsante [3] modified the input-output routines and included a data-base of materials and elements. All these were main-frame programs, but Delsante [4] adapted it for PCs, under 'Windows' and made it more user-friendly. It became known as CHEETAH.

In 1982 the GMI project (Glass, Mass and Insulation) supported by the glass, brick, concrete and insulation industry developed the "5-star design rating" system, using a HERS (House Energy Rating Scheme) program, [5] based on CHEETAH. This was a voluntary scheme and did not have much effect. In 1993 the Nationwide House Energy Rating Scheme (NatHERS) was launched, managed by the University of NSW and funded by the federal Government through EMTF (Energy Management Task Force). CHEETAH was adopted as the simulation engine, the modified version becoming CheeNath. This was released in 1995 and in 1997 EMTF announced the completion of NatHERS.

The output of the program is the annual specific energy requirement for heating and cooling in kWh/m^2y (or MJ/m^2y), and a rating of 1 to 5 stars. The 'star-bands' vary with the climate.

The program was generally welcomed, but objections were raised by some northern states. In response to these, in Aug. 1999 EMTF called a workshop meeting of interested parties in Brisbane to examine this problem (which I was asked to chair).

3. TROPICAL PROBLEMS

The workshop identified three problem areas: the setting of comfort limits, the inclusion of the cooling effect of air movement and the design of houses suitable for dual mode of operation: both for air conditioning and for free-running.

3.1 Comfort limits

For indoor comfort or thermostat set-point temperature a constant value had been used, following the ASHRAE 55 recommendation of 26.1°C. Many research workers, e.g. Busch [6], Karyono [7] or the definitive work by De Dear et al. [8], had shown that this is not applicable to tropical climates. The workshop recognised the 'adaptability model' and recommended the adoption of the Auliciems expression [9] for thermal neutrality:

$$\mathbf{Tn = 17.6 + 0.31 \times Tav} \quad \text{….. eq.1)}$$

(Tav is the average temperature of the month). The comfort band (for 90% acceptability) is taken as 5 K wide, thus the upper limit of acceptable temperature is to be set as Tu = Tn+2.5. This will obviously be different for each location and each month.

This in itself would result in a substantial reduction of the calculated cooling load.

3.2 Air movement cooling

Air movement generated by a breeze, with cross-ventilation or by a ceiling fan can be recognised for cooling up to 1.5 m/s. The workshop accepted the expression for apparent cooling effect (dT) proposed by Szokolay [10] of

$$\mathbf{dT = 6 \times (v-0.2) - 1.6 \times (v-0.2)^2} \quad \text{….. eq.2)}$$

(v is air velocity at or near the body surface of occupants, in m/s). Accordingly, the maximum such cooling effect may be 5 K.

Table 1 shows the resulting temperature values for Brisbane (lat. -27.5°) and Townsville (lat. -19.2°).

Table 1: Critical temperatures for the hottest month)

January:	Brisbane	Townsville
Tav (outdoor mean)	25°C	27.6°C
Tn (neutrality)	25.4	26.1
Tu (upper limit)	27.9	28.6
with 1.5 m/s air velocity	32.9	33.6

Our problem is that if a house is designed for open, free-running operation and gets top rating, but later air conditioning is installed, it will be very inefficient in energy use. Can we design a house that is good in open operation, possibly using ceiling fans and also in air conditioned mode. If so, then how can we predict its performance and provide a rating for such a 'dual mode' operation.

A scheme for this has been formulated and a computational algorithm proposed that consists of 7 main steps:

- find Tn and upper limit Tu as above

then for each hour

- if Ti < Tu then there is no cooling load
- find indoor v based on wind data (windows open)
- if Ti > Tu and To < (Ti+4) and indoor v > 0.2 m/s then cooling effect dT is found as above and added to Tu. if Ti <= (Tu+dT) then no cooling load
- if same conditions, but no wind available (v < 0.2 m/s) then fan(-s) switched on and fan energy use is added to cooling load
- if Ti > (Tu+dT) then windows taken as closed and start air conditioning, calculate load
- star rating is then based on the annual cumulative load per unit floor area

The open question is how to predict indoor air speeds that can be expected from either source. The workshop requested EMTF to commission CSIRO to produce an indoor air flow model as an addition to the NatHERS program.

3.3 'Dual mode' operation

For air conditioned operation all that is required is a sealed box, with well shaded windows and an evelope with good insulation and a vapour barrier near the outer surface of elements.

However, houses in these areas are usually designed for 'open' operation, for full cross ventilation, often with large windows of glass louvres, and lightweight construction, without air conditioning. If a packaged air conditioner is subsequently installed, it will have to cope with a very large cooling load. The infiltration is large through the louvres and the building is lacking insulation as well as thermal mass. In a free-running building the indoor temperature will always be a little higher than the outdoors. A good house is one that keeps the indoor temperature as close to the outdoors as possible. If To ≈ Ti, there is no need to insulate the walls (if shaded), but on the roof the sol-air temperature can exceed 60°C and cause a large heat flow. Roof insulation is very important.

In spite of this, some architects would argue that roof insulation is a double-edged weapon. It is generally accepted that the evening, when people want to go to sleep, is the most critical time for having overheated conditions, so quick cooling down would be an advantage. Such insulation may reduce heat gain during the day, but it would prevent heat dissipation at night.

Some advocate the use of reflective foil laminates (RFL, under the roof cover, face down into the attic) which would act almost as thermal diodes: preventing (reducing) downward heat gain (which is dominantly radiant) but offering little resistance to upward heat transfer (by convection).

This may be true, but such benefits of reflective foils claimed by the industry are grossly exaggerated. Furthermore, only a detailed study could determine which benefit is greater: the reduction in heat gain or the promotion of heat dissipation.

Tenorio [7] carried out a detailed examination of such 'dual mode' of operation and found that there is no simple categorical answer. She concluded that the results depend very much on use-pattern. Generally: a house design to ensure comfort and minimise energy consumption with both forms of operation is possible. Conflicts may arise with multi-use spaces, in ventilation, fenestration and building mass, but can be resolved. She produced a series of tables of recommended solutions for different use-patterns, e.g. for rooms used during the day or at night.

4. BUILDING REGULATIONS

Building regulations in Australia are the responsibility of States, but a consultative body, ABCB (Australian Building Codes Board) has been established in the early 1970s to produce a unified BCA (Building Code of Australia). This was then adopted by the states. The development of energy-related items were first included in the Code in 2002.

Most states have adopted these additions to the BCA, some with minor modifications, but some did not endorse the use of NatHERS for showing compliance.

In the meantime, the new air flow module has been completed and added to the program, which has been re-named AccuRate. It includes practically all recommendations of the 1999 Brisbane workshop. Parallel with this effort there was some pressure to increase the limit of acceptance from 3.5 to 5 stars. This has also been done, but the maximum has been increased to 10 stars. The effect of fans has also been allowed for, (see Appendix 1) affecting the star rating. The latest version of AccuRate (v.99-7-3) was released for testing in December 2005.

In tropical / subtropical areas the housing industry as well as architects are extremely hostile to legislative compulsion, especially to the use of the NatHERS rating system. Some of this criticism is justified, but it often degenerates into politicking. It has been agreed that the system should be revised, but that architects and builders should be educated.

It was decided to test the problem of one particular house in Townsville (lat.-19.2°) designed by one of the most fashionable local architects. We refer to it as 'P-house'. It consists of three 'pavilions', each with a pyramid-shaped roof, connected by open covered ways. It is an interesting and in many ways clever and successful design. Fig. 1 is a picture of the house from the street, Fig. 2 is the overall plan and Fig. 3 is a view into the living block from the verandah on the east. It was visited on a hot day (in February). No measurement was taken but the impression in the living room was cool and pleasant. When asked about air conditioning, the lady of the house replied "I wouldn't touch it with a barge-pole". The architect was quite bitter that the house received a very low rating by AccuRate.

Details of the house were obtained and a series of simulations were carried out for the living pavilion, results of which are summarised in Table 2. This received initially a 1.5 star rating (out of 10), with a notional cooling load of 93 kWh/m^{2}y. This is the result if the wind exposure is taken as 'suburban'.

Fig. 1 View from the street (S/W)

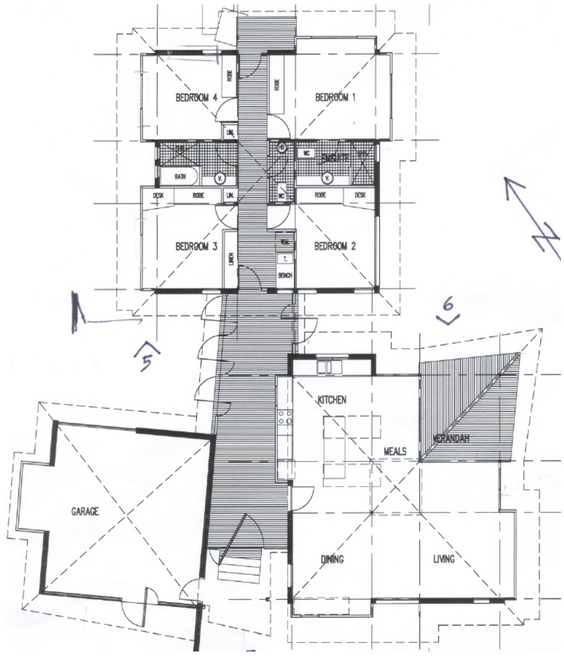

Fig. 2 Plan: the three pavilions

Fig. 3 View into living area from the east verandah

The exposure scale is 'sheltered-suburban-open-exposed'. If it is taken as 'open', the rating goes up to 3.5 stars (67 kWh/m^{2}y) and with three ceiling fans added, it gets 5 stars (with 59 kWh/m^{2}y). At present 5 stars would be the minimum to get a building approval/permit.

Table 2: Summary of ratings of P-house 'living pavilion' under different conditions

	stars	kWh/m^2y
as built		
exposure 'suburban':		
base case, no fans	1.5	93
add 3 ceiling fans	2	82
exposure 'open':		
base case, no fans	3.5	67
add 3 ceiling fans	5	59
with R2 added to roof		
exposure 'suburban':		
base case, no fans	3	74
add 3 ceiling fans	4	65
exposure 'open':		
base case, no fans	5.5	54
add 3 ceiling fans	6.5	47
with slab-on-ground concrete floor	7.5	43

The authors of the program have been contacted to clarify the exposure categories, as the step-up due to change from suburban to open seems to be excessive.

Instinctively I would also give 5 stars (and not more) for this building, as it has many shortcomings. The roof is a metal sheet with a plasterboard ceiling, no insulation, only a reflective foil. Its U-value is some 1.3 W/m^2K. It was a deliberate decision of the architect to have no insulation. He argued that any excess heat would be removed by ventilation, especially by the rotating cowl at the apex.

If I insert an R2 glass fibre insulation, the U-value goes down to 0.36 W/m^2K and the rating goes up to 6.5 stars (with 47 kWh/m^2y). (In fact the regulations 'deemed to satisfy' clauses require an insulation of R2.3 to be added to such a roof.) If the floor is changed to concrete slab-on-ground, the rating is increased to 7.5 stars (with 43 kWh/m^2y). These results were communicated to the architects, who became very argumentative and gave me a lecture on heat transfer, which was based on total misconceptions.

This exercise prompted me to carry out a systematic parametric study**.**

5. A PARAMETRIC STUDY

In order to show clearly the effects of individual variables, a very simple 5 x 8 m and 2.4 m high building (a 'test hut') is used. Initially it is taken as having an elevated timber floor, framed and fibrous cement sheeted walls, a metal roof with only reflective foil, attic and plasterboard ceiling. It has one glazed window/door of 3 x 2.1 , size, in the north wall. The eaves project 450 mm and there is no other shading.

Results are shown in Table 3.

Table 3: Summary of simulation / rating results for 128 permutations of 6 variables the values shown indicate star rating / specific energy use (energy intensity) kWh/m^2y

Ceiling: plasterboard					+ R2.5 insulation			
Walls	**Windows closed**		**Open**		**Windows closed**		**Open**	
⇩	**no fan**	**2 fans**	**no fan**	**2 fans**	**no fan**	**2 fans**	**no fan**	**2 fans**
	Floor: elevated timber							
	shading: eaves only							
fibro	1.5 / 92	2.5 / 77	2 / 84	3.5 / 69	4 /66	5.5 /54	4.5 / 61	6 / 50
BV	2.5 / 75	4 / 64	3 / 72	5 / 58	5.5 /56	7 /44	6 / 52	7.5 / 42
revBV	3 / 74	4.5 / 60	3.5 / 70	5 / 57	5.5 /54	7 /43	6 / 51	7.5 / 41
rBV+R2	4 / 64	6 / 52	4.5 / 61	6.5 / 49	7 /46	8.5 /35	7 / 44	8.5 / 34
	full shading							
fibro	2.5 / 82	3.5 / 69	2.5 / 77	4 / 64	5 /57	6.5 /48	5.5 / 55	7 / 46
BV	3.5 / 70	5 / 59	3.5 / 67	5.5 / 55	6 /50	7.5 /44	6.5 / 48	8 / 39
revBV	3.5 / 68	5.5 / 56	4 / 66	5.5 / 54	6.5 /49	7.5 /40	6.5 / 47	8 / 38
rBV+R2	5 / 61	6.5 / 48	5 / 56	6.5 / 46	7.5 /42	8.5 /32	7.5 / 40	9 / 30
	Floor: concrete slab-on-ground							
	shading: eaves only							
fibro	2 / 82	3.5 / 68	2.5 / 77	4.5 / 62	4.5 /60	6.5 /48	5 / 57	7 / 46
BV	3 / 71	5 / 58	3.5 / 68	5.5 / 55	6 /52	7.5 /41	6 / 50	7.5 / 40
revBV	3.5 / 70	5 / 57	4 / 67	5.5 / 53	5.5 /53	8 /39	6 / 50	8 / 37
rBV+R2	4.5 / 60	6.5 / 49	5 / 57	7 / 46	7 /45	8.5 /32	7.5 / 42	9 / 30
	full shading							
fibro	3 / 75	4.5 / 63	3 / 72	5 / 59	5.5 /55	7 /44	6 / 52	7.5 / 42
BV	3.5 / 67	5.5 / 55	4 / 64	6 / 52	6.5 /49	8 /38	7 / 47	8 / 37
revBV	4 / 66	6 / 52	4.5 / 63	6 / 50	6 /50	8 /36	6.5 / 47	8.5 / 35
rBV+R2	5 / 57	7 / 45	5.5 / 54	7 / 43	7.5 /42	9 /30	8 / 39	9 / 28

Subsequently full shading is added, the floor is changed to slab-on-ground, the wall is changed to brick-veneer (BV), to reverse BV and the same with R2 insulation and the ceiling is insulated with R2.5 batts. Each of these variants is taken with window closed or open, with and without fans, thus we have 2 x 2 x 2 x 4 x 2 x 2 = 128 variants. The results of simulation/rating runs are shown in Table 3, in terms of "stars / (kWh/m^{2}y)" .

It would appear from studying the above Table that

1) the framed fibrous cement walls are the worst, even the ubiquitous brick-veneer (contemptuously referred to as 'brick venerial') is better by 1 to 1.5 stars
2) reversing the brick-veneer (to have the brick inside) makes very little or no difference
3) if however insulation is placed outside the mass, (the rBV+R2 variant) is substantially better, it receives a rating some 1.5 stars higher then the BV
4) the concrete floor slab is in all cases better than the elevated timber floor, by between 1 and 1.5 stars. The improvement is greater when there are fans installed. With the otherwise best construction (the rBV+R2) there is practically no improvement. This would indicate that the mass of brick, protected from the outside by insulation is sufficient, there is no need for the additional mass of the concrete slab.
5) roof insulation is the single most effective improvement, resulting in a rating at least 2 stars higher, but in some cases 3 stars higher.

The cumulative effect of variables can be illustrated, with a plausible sequence according to ease of construction or cost, starting with

the initial variant	1.5/ 92
concrete floor	2 / 82
+ reverseBV walls	3.5/ 70
+ full shading	4 / 66
+ natural ventilation	4.5/ 63
+ fans	6 / 50
+ roof insulation	8.5/ 35
+ wall insulation (rBV+R2)	9 / 28

This demonstrates that the annual energy use can be reduced from 92 to 28 kWh/m^{2}y, to less than one third of the original.

6. RATING PROBLEMS

As we now have a dual system for satisfying the building code requirements (to get a building approval or permit), namely to follow the 'deemed-to-satisfy' clauses or to get a rating of at least 5 stars, many builders discovered that it is easier to get this rating than to follow the detailed prescriptive clauses.

There are problems already with these 'deemed-to-satisfy' clauses. The worst one is the specification of shading requirements. The ABCB refused to employ shadow angles for such specification. It was claimed that builders would not understand them. It was decided to use linear dimensions, such as eaves height and projection. Unfortunately such linear dimensions would be different for any orientation and depend on the geographical latitude. The Code distinguishes only four orientations. A compromise was offered to consider e.g. 'North' as from 340° (20° west of north) to 30° east of north (our worst orientation is west), but this was considered too complicated; the four sectors are now defined by 45° lines, e.g. 'north' is from 315° to 45°, 'east' from 45° to 135°, etc. Another irrational item is that maximum permissible sizes are set for windows. This may be reasonable for cold climates, or even for air conditioned buildings in the tropics, but certainly not when the maximum possible natural ventilation is to be achieved. However, this is not our topic now, it was just an example.

Coming back to the question of rating, some suggested that too much benefit is allowed for air movement cooling by cross-ventilation and by having ceiling fans. It has been claimed that an otherwise very poorly designed house can get 5 stars this way. The 'P-house' reported above is a case-in-point. It manages to get 5 stars without any roof insulation, timber floor and half of the walls being lightweight, uninsulated. The run of the mill builders' houses are usually much worse.

It irritates the architects of the P-house that it is 'poorly' rated. They accuse the 'bureaucrats' that they would want to force architects to do something inappropriate, which has been developed for the 'southern' states. At the same time some building control officials believe that the 2 stars achieved with 'suburban' exposure is correct (see Table 2 above) – that the house does not deserve any more. The architects are unhappy even with the 5-star rating achieved by assuming an 'open' exposure. It has been shown that the house could achieve 9 stars with roof insulation and a concrete floor slab. The architects have an almost religious belief that the use of mass and insulation is wrong in this climate. Does this not indicate that there is something wrong with our architectural education?

My problem is that the house did feel nice and cool when visited on a hot day. I do believe that this impression was – to a great extent – due to elements that are not (and cannot be) considered by the simulation program. The luscious green garden is one of these elements. Another one is the pond to the north of the kitchen, that is bridged by the walkway connecting to the bedroom block. Even in the humid climate of Townsville the evaporative cooling has some effect, but (and I am only speculating here), I think the psychological effect of water and vegetation is more important.

Similarly, whilst the tall cathedral ceiling may not reduce the radiation effect, and it certainly does not reduce the air temperature, it helps to create the impression of a spacious, airy, thus 'cool' interior.

My work always related to the physical performance of buildings. I do however think that this problem should be tackled by environmental psychology. We should not forget that even ASHRAE defines thermal comfort as "the condition of mind that expresses satisfaction with the thermal environment." This, clearly, embraces factors beyond the physical / physiological. Apparently, with the P-house the architect managed to get the owner-occupants 'on side', they are proud of the unusual and interesting building and this influences their attitude and judgement. Is this something similar to the Hawthorne-effect? (see e.g.[12]).

I do believe that any house should be climatically good in physical terms, but even at that level, as I concluded in a recent report, **the results of any computer simulation should be mitigated by human intelligence.**

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APPENDIX 1
Determine velocity produced by ceiling fans
for the purposes of eq. 2

An extensive literature survey suggests that the air flow generated by a ceiling fan is of a pattern that can be represented by Fig.4. Measurements carried out also indicate this form of distribution. Here the 'footprint' area corresponds to the swept area of the fan and the 'target area' is a circle of a radius equal to the fan diameter.

It is suggested that any definable room function (e.g. a lounge settee/armchairs, a pair of beds or a double bed, a work station) takes place within an 'activity area' not greater than some 3 x 3 m. This is the area taken as 'served' by a fan. For persons in such an area the horizontal velocity at the edges of our 'target area' would be effective. The 'work plane' is taken as the surface of a bed, or the general head-level in a seating area ($\approx$ 1 m).

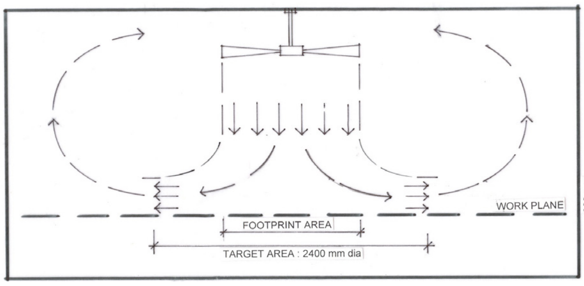

Fig. 4 Probable air flow pattern (1200 mm fan)

The 'representative velocity' of the downward vertical air flow within the footprint area can be taken as 1.33 m/s, regardless of fan diameter. This is based on literature as well as measurements.

The downward volume flow rate (vfr) will be this velocity times the footprint area (A_F), in m^3/s. We take this as distributed over the vertical surface of a ring corresponding to the perimeter (p) of the target area, taken at the work plane level and 300 mm deep (ring area, A_R), i.e. a horizontal flow (velocity v_h) in radial directions. These values are shown for the three most popular fan sizes, with the resulting apparent cooling effect (dT)

Table 4: calculation of velocity and cooling effect

fan d	A_F $r^2 x\pi$	vfr $A_F x vr$	p $2xdx\pi$	A_R px0.3	v_h vfr/A_R	dT
0.9m	0.64m^2	0.85m^3/s	5.65m	1.7m^2	0.5m/s	1.6K
1.2	1.13	1.5	7.54	2.26	0.66	2.4
1.4	1.54	2.04	8.8	2.64	0.77	2.8

These are the dT values to be used to extend the upper comfort limit in a room up to 20 m^2, served by a fan. A larger room could accommodate more than one activity (function), then two fans may be used, or if it only has one fan, then the dT will be reduced by a factor of 20/room area.