An Energy Conservation Architectural Design Tool for Warm Climate (LTV):
The tool development and testing.

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The use of design tools in architectural design is common place. Yet, in recent years the need has arisen to provide design tools to assist with the evaluating the energy usage of buildings. A number of tools are available for this type of work. Unfortunately, many of these tools are inappropriate for integration in the architectural design process. The research described here reports development work on a lighting, thermal and ventilation tool for use at the conceptual stage in the design process. The main contention is that this type of tool is crucial to effective passive low-energy design as it is difficult to integrate energy saving feature at later stages in the design process. Part of this work has necessitated a critique of the concept of the passive strategies for non-domestic buildings; this is an important element in assessing the energy contribution of the external environment to the building.

INTRODUCTION

Research work has been underway to develop a design tool for assessing the environmental impacts of non-domestic buildings. In this case energy -use is taken as an indicator of environmental impact.

This tool is called the Lighting Thermal and Ventilation (LTV) architectural design tool (1). It models the energy consequences of using climate responsive design strategies in the building design. Yet the question arises as to the form this tool should take for it to be most effective for giving architects feedback of the consequences of the building design on energy consumption. It is argued here that the key to this question lies in the design process. It is widely acknowledged that ‘the best opportunity for improving a building’s energy performance occurs early in the design process when basic decisions are made (2).’

Moreover, the penalty for not addressing climatic responsive design issues early in the process is that ‘opportunity will be lost to make significant savings by relatively simple adjustments to the design. Increasingly sophisticated or costly efforts are needed to save energy (2).

A number of phases can be determined, the phase that is of most interest is the conceptual design stage where basic climatic responsive strategies are used. In large commercial non-domestic buildings this involves the conceptual layout and thermal zoning of the building.

Thermal zoning is a key concept in assessing the thermal response of the building. It is the relation of the spatial organization of the building to the exposure to environmental factors. Thermal zoning is the subdivision of spaces inside the building that have varying thermal temperatures. Zones vary with orientation and with exposure to environmental conditions. A common nomenclature in cool climates is to use two main zones, the passive and non-passive (active) zone. ‘Passive zones can be day lit and naturally ventilated and make use of solar gain for heating. Non-passive zones have to be artificially lit and ventilated (3). The importance of this description is that passive zones use less energy due the use of natural energy than non-passive zones, which use man-made energy ie, electrical energy. Therefore a basic climate responsive planning stage at the conceptual stage is to make this passive zone as large as possible to reduce energy consumption.

The extent of the passive zone is deemed to be twice the ceiling height for cool climates and gives a depth of 6m as seen in Figure 1 (3).

At present little work has been carried out to determine the nature of the passive and non-passive zone for warm climates. It may be larger for warm climates due to higher levels of day lighting (4).

This is further complicated by the need for shading which can reduce day lighting to minimize thermal gains for direct sunlight. This paper examines these issues from a theoretically and experimentally stand point. The first part includes a theoretical discussion of climate responsive design strategies to determine the concepts for zoning in warm climates, the second describes experimental work to establish the dimensions of the passive zone.

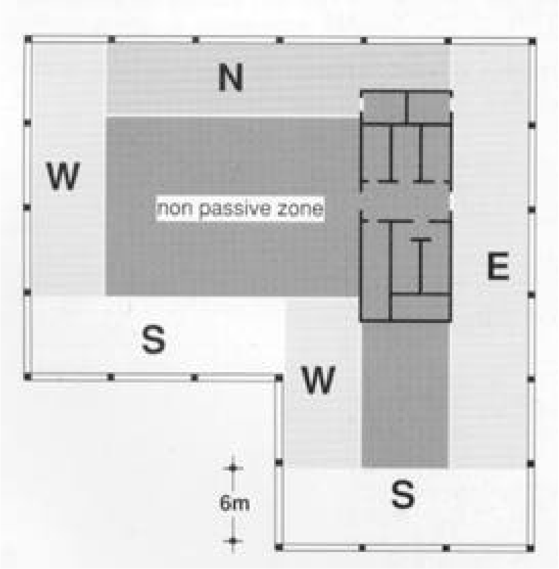

Figure 1 Passive active zone concept

Part 1: Climate responsive design strategies

A review of the passive, low energy design principles used in non-domestic buildings revealed the following factors important in warm climates. These are framed as design strategies that can be used by architects to reduce energy consumption. .

For the purpose of the study these strategies are used as variables that can be manipulated in a work-back process. This involves generating a number of possible design scenarios an architect may take and find the energy consequences. Architects tend to evaluate design concepts in terms of the plan and section of the building.

A hierarchy is found in the decision making process which relates to priorities designers have in the design process. For convenience, first order decisions are those that relate more to the planning decisions whilst second order are those in the section.

Planning strategies:	*Façade strategies:*	*Service strategies*:
plan/ room depth	ceiling height	air conditioning
service spaces zoning	orientation	electric lighting
functional zoning	window area and position	natural ventilation
thermal zoning	thermal defense	
	solar shading and light guiding	
	natural lighting	

Table 1: The climate responsive design strategies

Second order decisions examine relationship between solar shading lighting and energy consumption was examined. This is called the **solar design strategy**. It is common practice for buildings in warm climates to apply this strategy in favour of reducing thermal loads through the façade by over shading. Yet this can mean higher electrical lighting consumption. The loss of natural light is also a reduction of amenity to users.

Earlier models have recognized the significance of the effect of natural light on reducing electrical consumption (5, 6) but there has been little work into examining this relationship for subtropical and tropical climates. The outcomes of this work show optimum shading and window wall ratios for these design variables (7).

In the study reported here the first order involved study of the **planning strategies** used to improve energy efficiencies. Previous work has established that considerable savings in energy use can be achieved by planning the building to achieve optimum plan depths, environmental zoning of spaces, ceiling height and orientation. This is an important area for saving energy, 30% savings inenergy use can be achieved by using this strategy alone (Hyde R.A. 1997).

To assist architects in assessing the energy consequences of planning decisions the concept of the **passive zone** has been developed (Baker and Steemers 1996). This concept has been developed for warm climates but not related to tropical or subtropical climates. Work on this deficiency has led to a more complex model to acknowledge the need for shading to buildings to accommodate high solar gain in these climates (Hyde 1999 forthcoming). In this model a variety of zones can be established both inside and outside the building from the line of enclosure to control the external climate. These are:

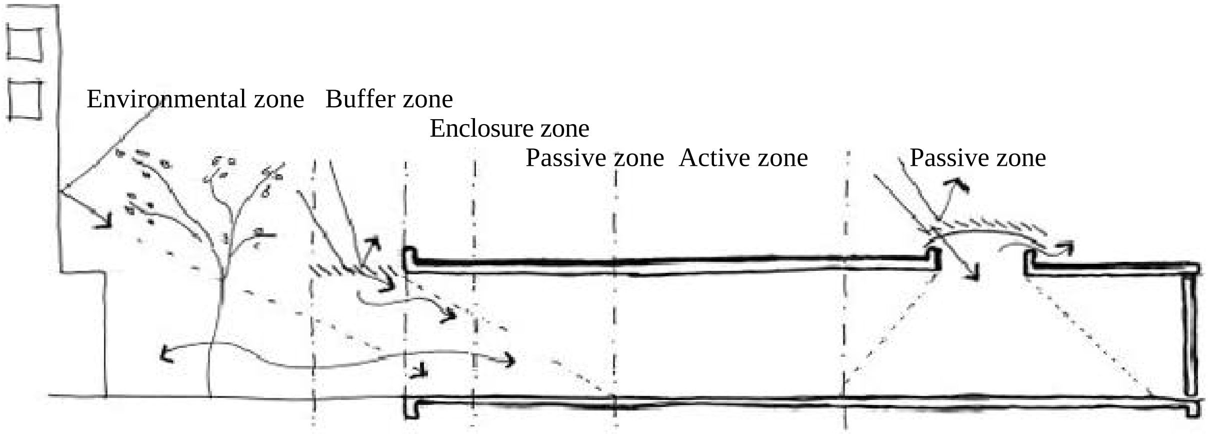

Figure 2: Thermal zoning in section

External zones:

1. Environmental zone: micro climate of the site

2. Buffer zone: microclimate created by the building

Internal zones:

1. Enclosure zone: internal climate, immediately adjacent to the line of enclosure

2. Passive zone: the area defined in plan to receive a significant contribution from the external environment for heating, lighting and ventilation. The convention is to use a dimension equal to twice the ceiling height to define the extent of this zone from the façade

3. Non-passive zone: the area defined in plan and which receives an insignificant contribution from the external environment for heating, lighting and ventilation.

For quantitative assessment the crucial design variables can be related to the passive zone and therefore to this end a study using series of computer simulation exercises were carried out using DOE 2. It is acknowledged that the qualitative variables concerning lighting or other factors are not addressed in this study i.e. factors such as glare.

The main aim of the study was to examine the extent of the passive zone for warm climates. A ‘rule of thumb’ has been established for cool climates. The extent of the passive zone is function of room depth and the ceiling height, where the passive zone is seen as twice the ceiling height. Thus for a ceiling height of 3meters, the passive zone extends 6 meters to towards the interior, at 90 degrees from the façade.

Part 2: Discussion

The extent of the passive zone is controlled by two main sets of factors:

1. the room depth, that is the depth from facade
2. the solar design strategy, the level of transparency in the facade to provide daylighting

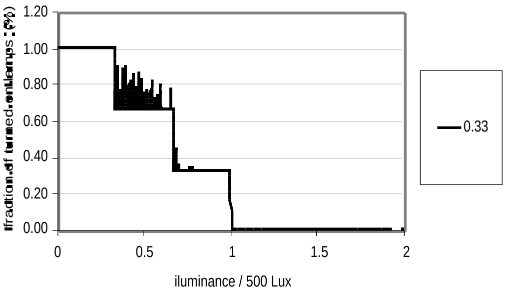

Figure 1: Daylighting control

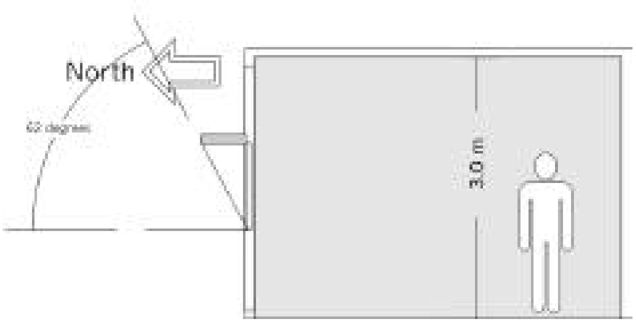

Figure 2: Shadow angle definition.

The main goal in the study was to identify parameters to define an optimum room depth. The analysis consisted of varying the room depth and different amounts of transparency in the envelope. A test cell was developed to examine this relationship. This was used to simulate energy performance by using a computer simulation tool.

Shadow angle	Overhang width in meters
5	11.43
10	5.67
20	2.75
30	1.73
40	1.19
50	0.84
60	0.58
70	0.36
80	0.18
90	0.00

Table 2: Values for overhang depths for different angles

Test cell

For the study the test cell was set up in DOE 2 (9). The following characteristics are used in the cell:

1. room size of 10 x 20 m
2. floor to ceiling height 3 meter
3. insulation is used in the wall, floor and ceiling to prevent heat gain

4. cooling loads from people and equipment are not included
5. windows are constructed with clear glass, sill height 1.0 m, width 10 m, height 1 m.

Solar shading

The first variable to be considered was solar shading .As shown in Figure 2 supposed the variable in this study is the angle between a horizontal plane and the line that links the base of window and the extreme of the shading overhang.

The shading overhang width for the different shadow angles are shown is the Table 2. Note that this is a theoretical study, small shadow angles give impractical overhang widths.

The designer has a number of choices in the design of façade, one is the location of the window another is the window to wall ratio (WWR), that is the percentage of transparency to solidity. A number of additional assumptions were made regarding nature of the test cell used for the study with regard to these choices..

1. The window was designed as a strip window, which has the same width of the facade. This gives a greater uniformity of the light distribution for a given distance from the facade.
2. A working plane of 0.8 meters was used as this is common practice for office buildings
3. The optimum windowsill height was set at 0.8 meters. The lighting gain below this height is not significant. Yet, the heat gain is significant and would increase the thermal gains to the space.
4. The window wall ratio varies not in height but in width. Thus with small window wall ratios the window geometry will be narrow and thin

One problem emerged from these assumptions, the location of small windows of say 0.3m with a sill height of 0.8m can be problematic. The window location should be as high as possible to optimize the daylighting. In the Figure 3 a comparison of the performance of the window with a sill height equal to 0.8m and with the highest window height is shown.

The results confirm the above problem, height windows is more efficient than any other position. The difference in performance is almost 20%.

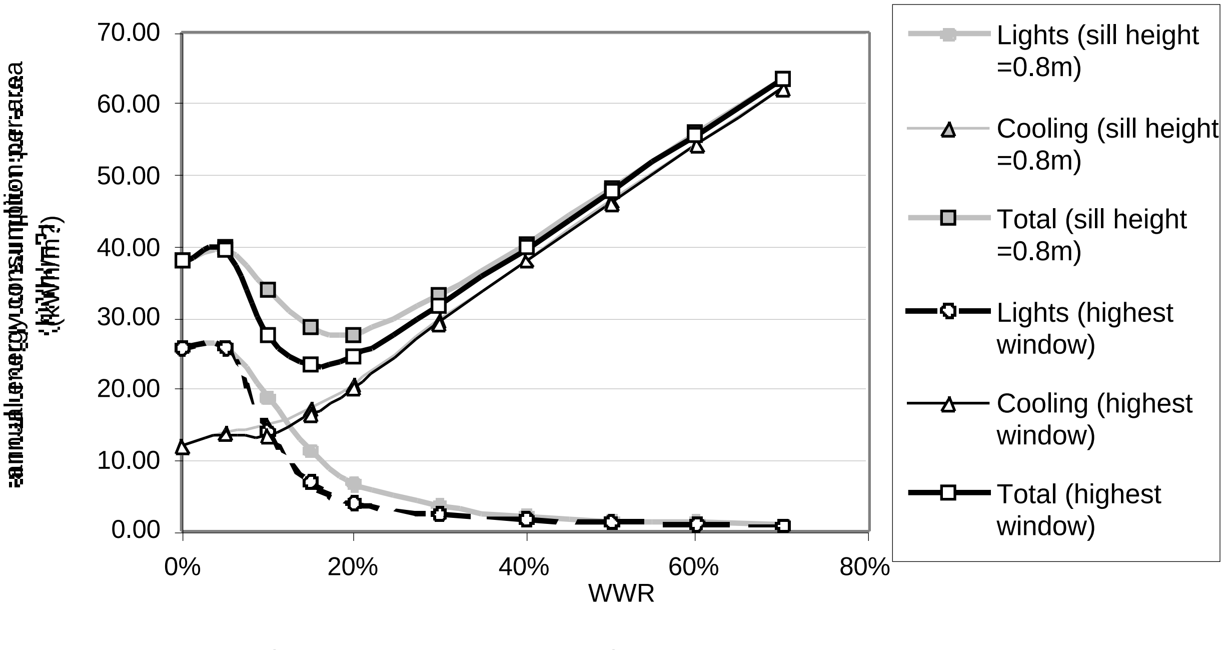

Figure 3 – Analysis of the window location on facade

The defaults for the test cell are shown below

Characteristics	**Value**
Size	Dimensions: width = 10m, ceiling height = 3m, variable depth
Orientation	North
Weather	Brisbane TRY
Operational schedule	Lights and air conditioning working between 8 am and 6 pm
Lights	320 Lux in work plane, with light power density equal 10 W/m
Daylight control	electric lights are either off, one third-on, two third on or fully-on
Work plane height	Height from floor: 0.765m
Reflectance	Wall: 0.5; floor: 0.2; ceiling: 0.8
Window,	Window width = 10m (frame width 0.051m), single clear glazing 3mm, light transmission 0.898, U-factor (center of glass) = 6.31 W/m/°C; window front facade: 10 m. No shading was provided to the window
Envelope properties	Walls, floor and roof thermally insulated
Air conditioning	Packaged, EER (energy efficiency ratio) = 2.638 W (cooling)/W (consumption); cooling set-point: 22°C

Table 1 - Characteristics of the test cell

Results

The results of this test cell are plotted in Figure 4. Energy optimum consumption is shown for varying room depths, also the optimum window wall ratio.

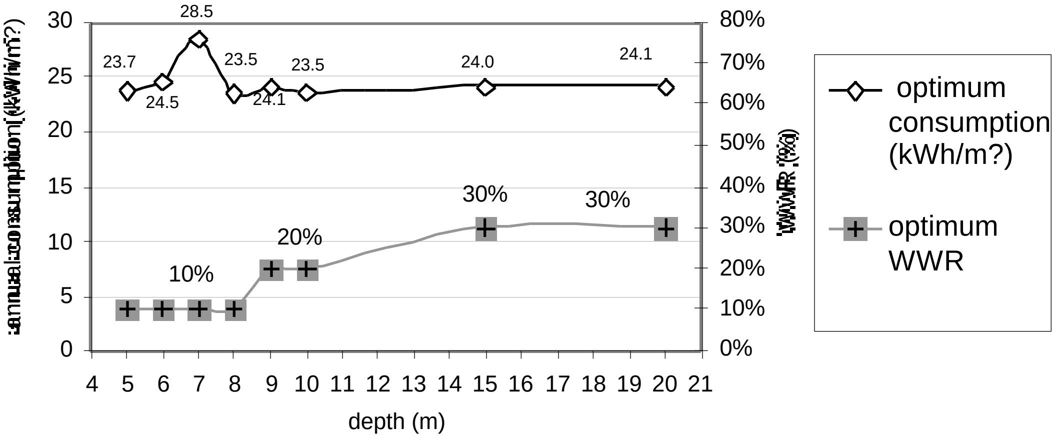

Figure 4 Optimum energy consumption and window wall ratios (WWR) for different room depths

The following observations can be made:

1. Without shading to the windows the optimum WWR is between 10 to 30 percent. Thus, for a northerly facade, small windows between 3 and 9m2 in area for every 10 meters of linear length are appropriate.

2. As the room depth is increased, the larger window wall ratio of 30 percent is appropriate, as the depth is reduced a smaller ratio of 10 percent is appropriate.

3. The optimum room depth is 8 meters with lowest consumption using a 10 percent WWR.

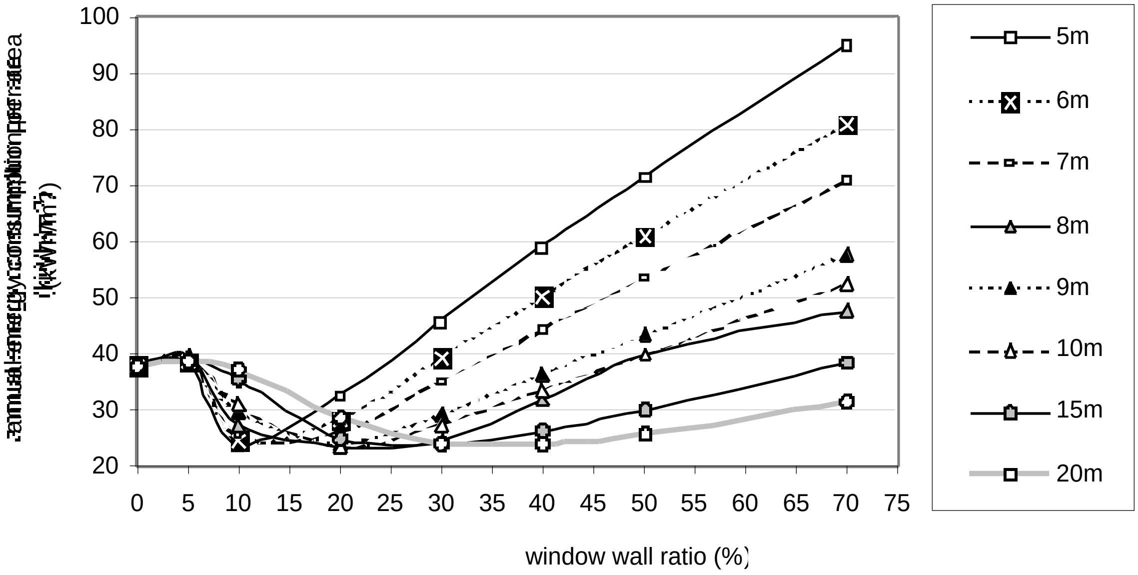

Figure 5 – Annual consumption per area for different room depths

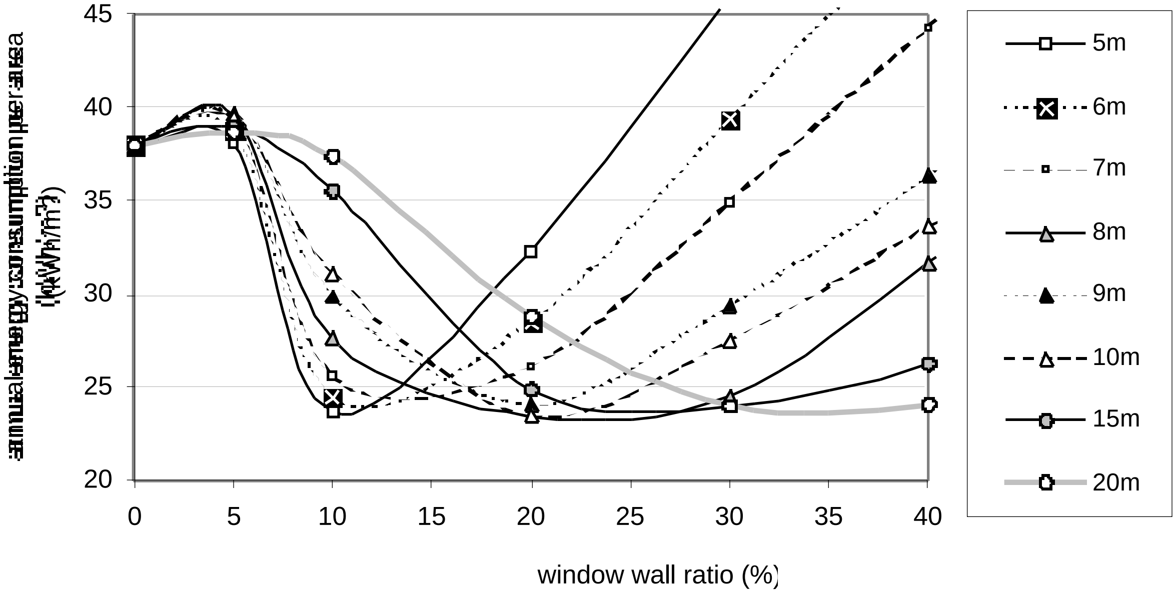

Figure 6 – Annual consumption per area for different room depths

Clearer evidence of this is seen in Figure 5 and Figure 6. In these graphs the relationship to WWR to energy consumption is shown for different room depths.

If the worst optimum performance is ranked, the most problematic is the room with a depth 7m and with a WWR 20%. The second worst is the room with a depth of 6m. The best performances are the rooms with 8m and WWR 10% and the room with 10m and WWR 20%.

If these results will be used to identify a reasonable optimum depth for passive zones the choice would be 8m.

Part 2 Discussion

From these results it is clear that the assumptions concerning the size of the passive zone found in European climates is different for subtropical climates such as Brisbane. The higher levels of solar gain and availability of daylighting means that the optimum plan depth can be increase to 8 meters with a lower wall to window glazing ratio. In this study shading was not considered although the method for assessing this has been developed. Further work has been carried out to assess optimum shading, window wall ratios and plan depth (8).

Further more a more subtle definition of the passive zone emerges which is more dynamic, related to sectional information rather than plan information. In this conception rather than try and make hard definitions of zoning, it seems appropriate to use this type of information for making strategic design decisions.

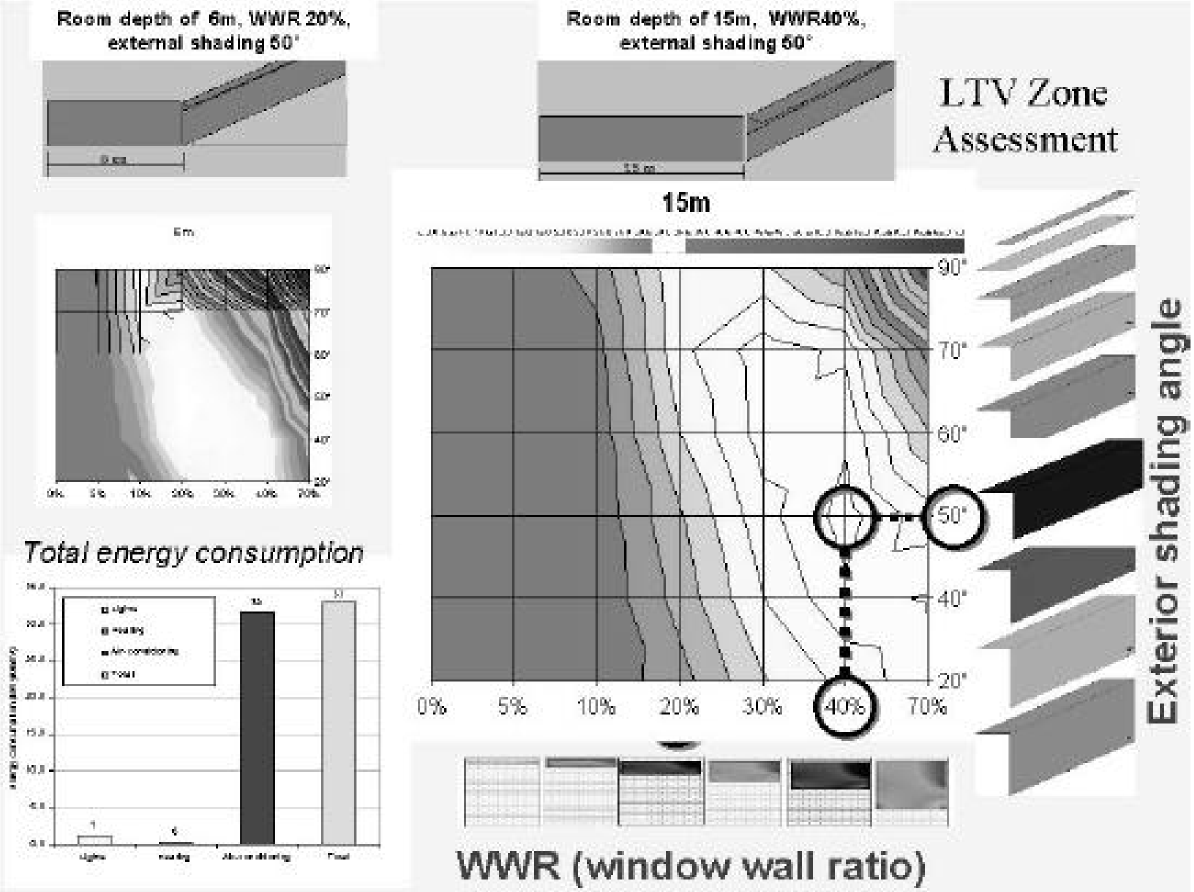

Figure 7 Graphical tool for assessing thermal zoning strategies

Further outcome of this work is that it is possible to use this information in a number of ways. The earlier definitions of the passive zone are aimed at providing a method of assessing plans to give information regarding total energy use of the design. The contention here is this information is particularly useful for bench marking purposes. Benchmark figures for building types can be set and optimum design variables selected to meet the benchmark. Thus the benchmark for northern orientated facades may be 30 kWh/m2. A range of window wall ratios and rooms are therefore available to meet this standard. This gives boundaries in which the designer can work. This flexibility can begin to intellectualize the design process so that choices available to designer can be clearly indicated and the consequences of choices articulated.

Additional information can also be obtained from the graphs, which enables the selection of optimum window wall ratios for room depths or visa versa. This assists with the design of particular zones of the buildings. Some preliminary work has been carried out with regard to this issue. It is clear that this information can be integrated into a graphical tool, which gives visual information of the consequences of selections made by designers as shown in Figure 7.

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Energy Research and Development Corporation, 1996
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