EDT: An expert adviser for energy design of passive and conventional buildings at the sketch design phase

J W Hand and F S Higgs

Energy in Building Division
National Building Research Institute
Council for Scientific and Industrial Research
P O Box 395, Pretoria, 0001, Republic of South Africa

Keywords: Computer aided design, thermal design tools, passive solar heating and cooling, Southern Africa

Summary

The use of comprehensive thermal simulation tools in the early architectural design process is limited by economics and the demand for a full geometric description which does not reflect the generally limited data and budget available at that time. Simplified methods tend, by definition, to lack the sophistication which would promote the widespread use of passive heating and cooling techniques. The Energy Design Technique (EDT), written for a 16 bit microprocessor by the authors and undergoing validation at the NBRI, offers a novel approach for design professionals and is described in the paper. A building typology consisting of interrelationships, materials (including passive solar technologies), areas, orientations, and temperature/weather profiles is arrived at via a menu-driven program. A five volume design can typically be described in less than 15 minutes, need not be complete, and may be readily altered to explore 'what if' questions. EDT accesses an hourly energy flow database developed via massive parametric studies conducted with DEROB, and with minimal computation time outputs hourly energy balances for each component and space. The expert adviser capabilities of EDT are extended with a background program which uses hill-climbing techniques to search the design elements for sub-optimal thermal solutions.

EDT: Un conseillé authorisé, au stade du croquis, pour l'etude d'energie dans les batiments passifs et traditionnels

J W Hand et F S Higgs

National Building Research Institute
Council for Scientific and Industrial Research
P O Box 395, Pretoria, 0001, South Africa

Mots clef: Conception assistee par ordinateur, outils pour conception thermique, chauffage et refroidissement solaire passif, Afrique due Sud

Résumé

L'utilisation d'outils de simulation thermique complète dans les premiers stades de la conception architecturale est limitée par des raisons économiques et par la nécéssité d'une description géométrique complète. Ceci ne correspond généralement pas aux données limitées et au budget disponibles à ce stade. Les méthodes simlifiées manquent par définition du raffinement qui inciterait à une large utilisation des techniques de chauffage et de refroidissement passifs. L'EDT (Energy Design Technique - Technique d'étude d'énergie) est un programme écrit pour un micro-processeur à 16 bits par les auteurs et est en cours de validation au NBRI; il offre une approche originale pour les concepteurs professionnels et est décrit dans le rapport. Via une série de menus, on définit un bâtiment type, constitué d'interactions, matériaux (y compris les technologies solaires passives), surfaces, orientations et profils température/climat. Un projet contenu dans cinq volumes peut généralement être décrit en moins d'un quart d'heure, ne doit pas être terminé et peut être aisément modifié pour répondre à des questions "et si?". L'EDT se réferre à une banque de données de flots horaires d'énergies, développée via une étude massive de paramètres au moyen de DEROB et, avec un minimum de temps de calcul, produit des balances energétiques horaires pour chaque composant et volume. Les capacités de conseillé autorisé de l'EDT sont étendues par un programme secondaire qui utilise les techniques d'alpinisme afin de rechercher les éléments de conception pour des solutions thermiques sous-optimales.

Introduction

The application of thermal simulation tools in the architectural design process is all too often delayed by scheduling and economic factors until the design is so fixed that thermal optimisation is difficult to accomplish. It is in the early design stage that the visual, structural, and thermal characteristics of a building are decided. Unfortunately, the thermal implications of these decisions remain largely hidden.

An Energy Design Technique (EDT) developed by the authors and currently undergoing validation at the NBRI offers a novel 'expert adviser' approach which can provide the user with an indication of the dynamic thermal qualities of a building throughout the design process and including the schematic phases. Besides allowing for rapid manual editing of a design to appraise the thermal implications of design decisions, EDT will search through the building description and via hill-climbing techniques find suboptimal thermal solutions and present them for the designer's consideration. A figure of merit equation which appraises design changes can be modified by the user to help in the search for design variations which, for example, reduce peak electrical demand or shift loads to off-peak hours. The program can even recommend a balance between direct gain windows and Trombe-Michel walls.

EDT was developed to bridge the gap between comprehensive thermal simulation tools which demand massive input and computation, and simplified methods which tend by definition, to lack the sophistication needed to promote the widespread use of alternative building techniques such as passive solar heating.

Because EDT does not require a full geometric description of a building, a five volume design can typically be described in less than 15 minutes. A building typology consisting of interrelationships, materials (from a library of typical building sections which includes both conventional and passive solar technologies), areas, orientations, and site data is derived via a menu-driven program.

EDT accesses a database derived from massive parametric studies conducted with the DEROB-IUA building thermal simulation system. [1,2] For each building membrane in the EDT library the database contains hourly thermal fluxes (ß) in W/m^2 for each possible combination of weather pattern, location, orientation, and interior temperature profile in the EDT menu. Figure 1 is a plot of a portion of the ß values for a single glazed window facing the cardinal directions in Johannesburg with 2,5% winter weather and an interior temperature profile of 10°C from 00h00 to 08h00, 17°C from 08h00 to 21h00, and 10°C from 21h00 to 24h00. Positive ß-values imply an excess of energy within the space in relation to what is required to maintain the temperature profile. Note that the relationship between solar radiation and orientation is quite pronounced.

Expert adviser possibilities

EDT is computationally fast so the user can explore a broad range of possibilities within the time constraints of the building design process. the technique is especially adept at modelling the dynamic behaviour of highmass construction which is prevalent in both southern Africa and the third world. It does not merely answer questions about specific design options but indicates directions the user can take to improve thermal performance.

EDT uses two stages of hill-climbing techniques to search the building description and randomly alter elements of the design, scoring the change in building thermal performance by a figure of merit equation. Each change judged to be an improvement thus becomes a part of the latest optimum design until such time as no change is found that increases the score, whereupon a suboptimal solution has been found. Given the complexity of most buildings, there will be many suboptimal solutions produced by EDT. The user can then select which changes to include.

The EDT figure-of-merit equation is based on the peak energy demand in each space, its time of occurrence, and the overall energy demand. The relative importance, or weighting factor (WF) of each, is set by the user. In southern Africa overall building energy use is moderate (WF=1.0), but peak energy demand is high and determines generating capacity (WF=3.0). If off-peak rates were used then an hourly weighting factor could also be included in the equation. The figure-of-merit equation can also be used to search for other design objectives such as to limit the size of heating and cooling equipment, or to minimise the afternoon heat gains.

During the design process the user may wish to include only specific building elements in the optimisation. EDT allows the user to select or exclude elements by both location and material type. Chosen elements can be further restricted by setting upper and lower area boundaries. This allows non-thermal constraints, such as building code requirements and visual criteria, to be included in the optimisation process.

In the schematic phase, where there is considerable design latitude, the user might instruct EDT to do a global search of the design for possible optimisation paths. As the design becomes progressively fixed, the number of variable elements can be decreased and the optimisation process delivers more specific suggestions for design improvement.

Program structure

After the elements to be tested and the weighting factors have been specified EDT archives figure-of-merit scores for each design parameter. EDT loops through the building description and selects elements for adjustment and stores their attributes.

In the first stage of hill-climbing the program selects elements at random and tests to see whether an increment or decrement in area produces an improvement in thermal performance, whereupon it saves a directional flag for each element in a vector. If two elements are related, such as a window and a wall, both are adjusted before the thermal performance is scored. If the adjusted areas fall outside acceptable limits then the directional flag is set to zero and another element is tested. When all the elements have been checked the whole vector is scored by the figure-of-merit equation, and, if this is better than the archive score, it becomes the optimum version and the second stage of hillclimbing begins.

Second stage hillclimbing

The probability that previous successful adjustments can be repeated is exploited in the second stage of hillclimbing by repeating the adjustments embodied in the vector and rescoring the whole. Although no scoring is done for individual elements, if they are not within area limits, they are tagged and their area is fixed during subsequent passes. The second stage is repeated until no improvement occurs, whereupon the program returns to the first stage and constructs a new vector. If the new vector does not produce an improvement then a sub-optimal solution has been found.

Examples of optimisation

The office and meeting room illustrated on the left side of Figure 2 but excluding the interior components, the roof, and the floor, has been used to demonstrate the optimisation process. Figure 3 is a plot of the initial hourly energy balance for both rooms. The reference numbers on the lower left axis correspond to those shown in Figure 2. Note that the morning valleys and late evening peaks are artifacts of an anomaly in the database which has since been corrected. The peaks during the day relate primarily to the energy contribution of windows.

After using the EDT thermal optimisation facility with WF=1.0 for overall energy use and WF=3.0 for peak demand, the energy balance plotted in Figure 4 resulted. Note the increased mid-day energy contribution of records 2, 4, 6 and 8. Table I lists the parts of the design that were adjusted in the optimisation, the area limits set, and the areas recommended by EDT. The right side of Figure 2 shows a revision of the design following the optimisation recommendations.

Figure 5 shows the energy balance of the two rooms both before and after the thermal optimisation. While the peak demands at 08h00 and the peak contributions at 23h00 show little change, the meeting room energy balance is much improved during the day. In fact, the energy balance of the meeting room becomes positive (it is warmer than the interior temperature set point) more than two hours earlier than in the original design. The office shows much less change, in part because of the limited number of elements to be optimised and the limited range of area adjustment allowed by the designer. Table II lists the changes in the sums and peaks for each room. It is apparent that the meeting room, which included both direct gain windows and a Trombe-Michel wall, was much more conducive to optimisation than the office. The revised design comes close to having the daily energy surplus in the meeting room cover the net daily loss in the office.

Conclusion

One expert advisor facility of EDT has been demonstrated on a sample building. The thermal performance optimisation code of EDT, using two stages of the hill-climbing technique to search for sub-optimal thermal solutions to the design has produced a revised design which shows a significant improvement in thermal performance.

References

1. J. Hand and F. Higgs, A Heuristic Building Thermal Design Aid for the Sketch and Detailed Phases of the Architectural Design Process, Proceedings of INTERSOL 85 (ISES), edited by E. Bilgen and K. Hollands, (Pergamon Press, N.Y., 1986)

2. J. Hand and F. Higgs, A Technique for the Design of Building Thermal Performance in Southern Africa, Proceedings, Conference on Computers in Architecture, (Johannesburg, 1984) vol. 2, pp. 128-149.

TABLE I: Optimisation parameters

REF. NUM.	FACING	- - A R E A S - - ORIG.	MIN	MAX	OPTM	REF. NUM.	FACING	- - A R E A S - - ORIG.	MIN	MAX	OPTM
1	North	10,9	-	-	7,0	12	Roof	24,0	-	-	24,0
2	North	2,1	1,0	4,0	4,0	13	Inside	10,0	-	-	10,0
3	North	2,0	-	-	2,0	14	Inside	2,0	-	-	2,0
4	North	3,0	2,0	5,0	5,0	15	South	8,5	-	-	8,9
5	East	10,5	-	-	10,0	16	South	2,0	-	-	2,0
6	East	1,5	1,0	2,0	2,0	17	South	1,5	1,0	2,0	1,1
7	West	11,0	-	-	10,5	18	East	7,7	-	-	7,3
8	West	1,0	0,5	1,6	1,5	19	East	1,2	0,5	1,7	1,6
9	South	4,0	-	-	4,0	20	West	9,0	-	-	9,0
10	South	2,0	-	-	2,0	21	Floor	12,0	-	-	12,0
11	Floor	24,0	-	-	24,0	22	Roof	12,0	-	-	12,0

TABLE II: Changes in peak demand and energy balance

Description	Meeting Room Original	Optimised	Office Original	Optimised
Summation of contributions	18 943	25 857	8 156	7 912
Peak contribution	8 819	8 063	6 133	6 120
Summation of demand	-16 635	-14 254	-19 118	-18 636
Peak demand	-8 631	-7 468	-6 706	-6 564
Overall balance	2 308	11 603	-10 962	-10 724

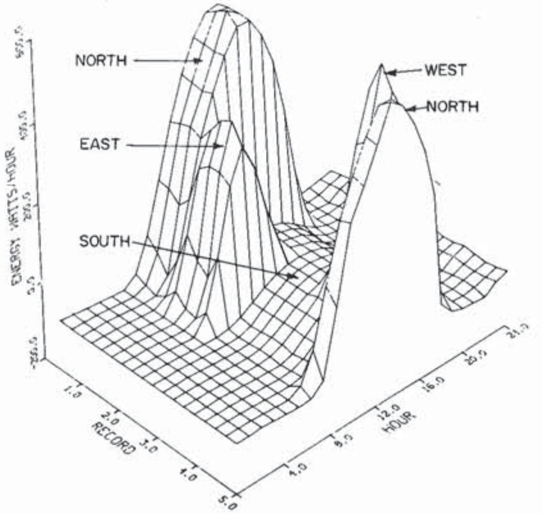

FIGURE 1: Hourly energy balance of a 1,0 m² window

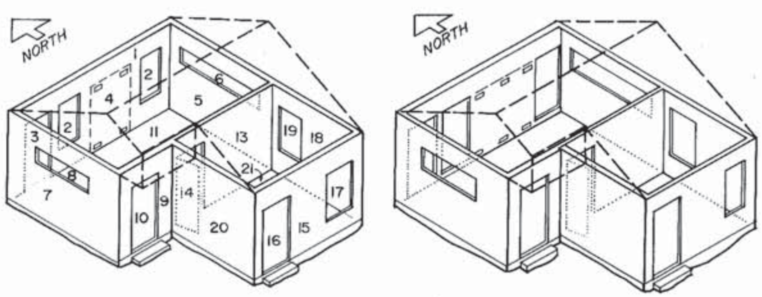

FIGURE 2: Original test building (left) and revised design (right)

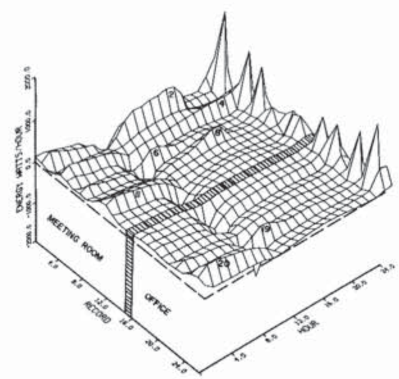

FIGURE 3: Original design: hourly energy balance

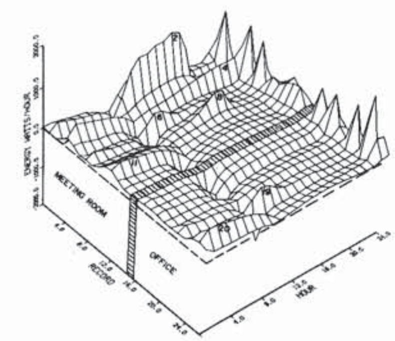

FIGURE 4: Revised design: hourly energy balance

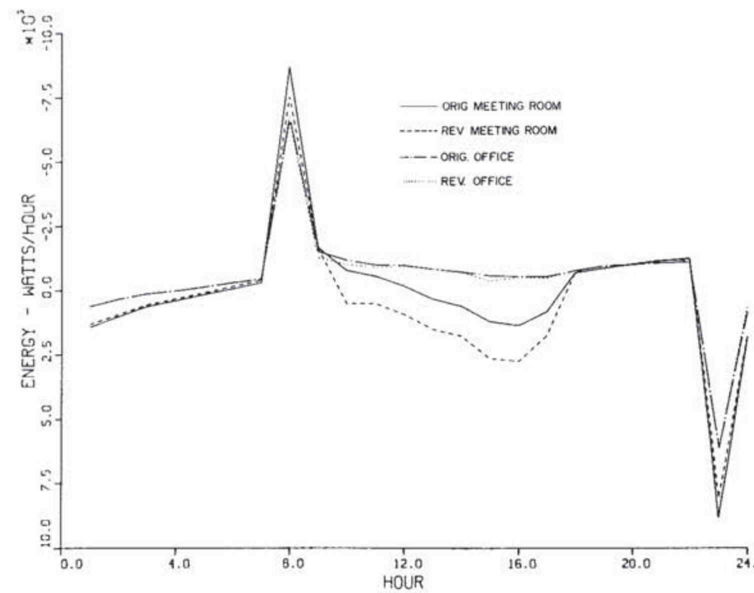

FIGURE 5: Room hourly energy balance before and after optimisation