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QuickTEMP—A Thermal Analysis Program for Designers of Naturally Ventilated Buildings

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A microcomputer implementation of a simplified thermal simulation model of a naturally ventilated building is presented. One of the main features of the model is the ability to predict the indoor environment of a building with open windows. It can also account, amongst other things, for internal heat generation, solar penetration, exterior surface colour, ground contact and the position of mass and insulation in the building shell. A good agreement between predictions and measurements was found and four validation studies are presented. The program is fast, highly interactive and extremely easy to use. It is ideal as a design tool for building designers.

NOMENCLATURE

- ΣA area of the exposed building shell (m^2)
- ΣC total active thermal capacity of a building per unit shell area (kJ $°C^{-1}m^{-2}$)
- C_p thermal capacity value based on the properties of the indoor air volume and the convective air-conditioning plant (kJ $°C^{-1}$)
- q_a heat transfer rate to the indoor air volume (W)
- q_s heat transfer rate to the building structure (W)
- R_h convective resistance of the building (°C W^{-1})
- R_N internal resistance of the non-ideal capacitor (°C W^{-1})
- R_s thermal resistance of the building shell (m^2 °C W^{-1})
- R_v ventilation resistance of the building (°C W^{-1})
- T_{ff} forcing air temperature (°C)
- T_g constant ground temperature (°C)
- T_i indoor air temperature (°C)
- T_o outdoor air temperature (°C)
- T_{sa} sol–air temperature (°C)
- τ_s thermal time constant for the structure (h)
- τ_a thermal time constant for convective heating (h)
- $*$ convolution

INTRODUCTION

ONE OF THE primary objectives in the construction of a building is to provide a shelter against the extremities of the outdoor environment. The designer of a building is therefore responsible for the microclimate created within the space enclosed by the structural shell.

It is possible to assess the thermal performance of a proposed building by various means such as full-scale field experiments, laboratory tests or simulation models. Computer simulation, however, is the most widely used method because of the high costs of the other methods and their restrictive nature [1].

The physical behaviour of a building structure, subjected to an outdoor environment and internal heat sinks or sources, can be simulated by means of an abstract model. Any simulation model is consequently an approximation of reality. The relative merit of each model should therefore be judged according to its specific objectives and the relevant field validations.

At the design stage, the building designer needs an inexpensive and fast method of predicting the thermal performance of the proposed structure. The available input data are usually limited and the configuration not fully defined. At this stage, it is therefore not practical or economical to employ a comprehensive simulation program to predict the thermal performance of the future building [1, 2].

In the case of natural ventilation, most simulation models require measured or assumed values for the expected ventilation rate of the air volume enclosed by the structure [3]. At the design stage measured values are normally not available, which makes it difficult to evaluate alternative design strategies quantitatively [4]. It seems, however, as though a subtle interplay between empirical and theroretical considerations will result in the most effective predictive method [5].

It is from this point of view that a simplified model of a naturally ventilated building was developed [6–8]. The thermal simulation model is based on sound theoretical considerations, but empirical constants account for the typical natural ventilation rates expected in conventional South African buildings. The method is therefore eminently suitable, at the design stage of a proposed building, for the prediction of the indoor environment resulting from natural ventilation.

A highly interactive microcomputer program named QuickTEMP was developed to implement the prediction method and to validate the solutions against measured data for a wide range of buildings and building zones [6].

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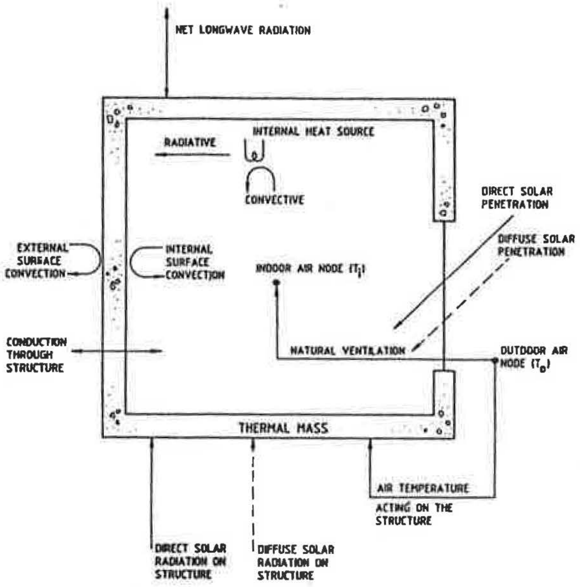

Fig. 1. Building energy flow paths (plan view).

This paper briefly describes the theoretical development of the thermal predictive method, its extensive validation and the computer implementation.

THERMAL SIMULATION MODEL

The thermal interactions of a single zone or complete building can be schematically represented (Fig. 1). The roof and walls can be either exposed to the outdoor environment or to adjacent zones. The floor can be suspended, for example as a division between upper and lower zones, or it can be in direct contact with the ground. The outdoor and indoor air temperatures are depicted, as well as solar radiation, penetration and internal heat sources.

The proposed thermal network model of the single zone is shown in Fig. 2. The indoor air temperature (T_i) of the zone is the response of the thermophysical properties associated with the enclosure to the outdoor air temperature (T_o), the sol–air temperature (T_{sa}) and the internal convective and radiative heat sources (q_a and q_s).

The sol–air temperature T_{sa} used in the thermal network is the surface-averaged value of the different

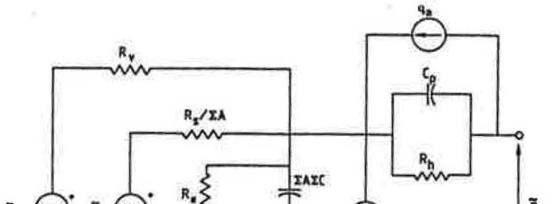

Fig. 2. Thermal network of a building zone.

exterior surfaces of the building. The effect of solar radiation and absorption on the opaque building elements is therefore accounted for in the model.

The thermal properties of the zone are lumped to a very high degree in the thermal network and single values describe the shell resistance per unit shell area ($R_s/\Sigma A$), the ventilation resistance (R_v), the total active capacity (ΣC) and the convective heat resistance (R_h).

The resistor (R_N) accounts for the fact that the total active capacity is represented by a non-ideal capacitor and that leakage flow across the capacitor is inevitable. The magnitude of R_N, however, will be much larger than that of the other resistances in the network and will therefore be neglected in the derivations for periodic forcing temperatures [7].

The active capacity of the floor is calculated to a depth of 300 mm where the temperature has a negligible diurnal swing [9]. The lower node of the capacitor (ΣC) is therefore at a constant ground temperature which is described by the constant voltage source (T_g).

The thermal network in Fig. 2 can be further simplified by combining the outdoor air temperature (T_o) and the sol–air temperature (T_{sa}) into a single forcing temperature (T_{ff}). For very high rates of ventilation, the outdoor air temperature will usually be the predominant forcing temperature and for no ventilation the sol–air temperature will be the prevailing forcing temperature acting on the building shell. Most naturally ventilated buildings, however, will lie between these two extremes and it can be shown that the forcing function can successfully be approximated by the average of the two temperatures [8].

The convective resistance (R_h) is the average convective heat transfer coefficient between the internal air volume and all the interior surfaces of the enclosing zone.

The capacitance (C_p) accounts for the initial non-uniform distribution of heated air at the start of convective heating. The value of the time constant of the RC-circuit formed by R_h and C_p is therefore basically related to the time required for the air volume to reach the uniform temperature distribution assumed under steady-state conditions of convective heating. The capacitance also accounts for the geometrical features of the zone, as well as for the heat transfer properties of the convective plant [10].

The convolution equation for the total response of the building zone represented by the thermal model in Fig. 2, subject to any arbitrary outdoor environment, as well as to any internal heat sources acting on the structure or air volume, can be written as follows [6]:

$$T_i(t) = 1/\tau_s(\exp(-t/\tau_s)) * T_{ff}(t) + 1/(0.28\Sigma C\Sigma A)(\exp(-t/\tau_s)) * q_s(t) + 1/C_p(\exp(-t/\tau_a)) * q_a(t). \quad (1)$$

The time constants are defined by:

$$\tau_s = (24/2\pi)[(\Sigma C/\text{system constant})^2 - 1]^{1/2}, \quad (2)$$

and:

$$\tau_a = 0.28 C_p R_h. \quad (3)$$

The factor 0.28 in Equations (1) and (3) converts the relevant units to hours, which are the time-step used in the convolution.

The system constant in Equation (2) is empirically related to the ventilation resistance (R_v), shell resistance (R_s) and the exposed shell area (ΣA) for conventional buildings subject to natural ventilation or infiltration. It was determined from measurements for 39 case studies [6–8]. A system constant value of 150 is therefore used for buildings with open windows and a value of 90 in the case of closed windows. These values account for the thermal effect of both natural ventilation and infiltration respectively.

The time constant (τ_a) in Equation (3) was empirically determined from measurements in buildings with typical convective heating systems acting on the indoor air volume [6]. A value of one hour was consequently chosen as the time constant.

Although it is obvious that certain simplifications and approximations are intrinsic in the proposed simplified thermal model, the salient thermal parameters of a building are modelled within a sound mathematical and thermal framework.

NUMERICAL SOLUTION

It is not always easy to calculate the convolution Equation (1) analytically, but it can be shown that a numerical approximation is possible in the case of arbitrary functions. However, even such a method is extremely laborious because of the vast amount of computations required [11].

The derivation of Equation (1) was done for a linear system in the time-domain. The time-domain description of the system can also be transformed to another domain. One important consequence of the transform-domain description of a linear system is that the convolution operation of the time-domain is converted to a simple multiplication in the transform-domain [12]. This process was applied to Equation (1) in order to make it feasible to implement the solution on a microcomputer.

The complex frequency spectrum of a continuous time-domain function can be described in the frequency-domain by the Fourier transformation of the function.

The Fourier transform can be approximated by analysing a sampled sequence of the function at a sufficient number of points. The complex frequency spectrum of a sampled function is then described by the discrete Fourier transform (DFT). Two properties of the DFT are of importance in the application of convolution in the frequency-domain namely, periodicity and sampling rate.

Periodicity

Periodicity is an intrinsic property of the DFT. The periodic property of the DFT can be a distinct advantage in the solution of the thermal networks for a design day. The prediction will be based on the assumed periodicity of the specified design day. It is therefore not necessary to provide initial conditions or to repeat the simulation for several days in order to eliminate the effect thereof. The same will apply for predictions of a design week, month or year. It should also be noted that the property of periodicity does not limit the method to the prediction of the steady-state behaviour of the building.

Sampling rate

The rate at which the time-domain waveform is sampled determines how well it is defined and how close the discrete representation is to the analog original. Insufficient sampling of a high-frequency component results in a low-frequency alias. Sampling rate is governed by the Nyquist sampling theorem [13].

Aliasing is, however, inevitable when analog waveforms, such as a design day, are windowed and sampled. It is however important to ensure that the high-frequency components have dropped to an insignificant level at the cutoff frequency.

It was shown that the magnitude of the high-frequency components is negligible above the Nyquist frequency dictated by the hourly sampling rate [6]. The hourly values of a design day can therefore by used with confidence in the numerical prediction of the thermal performance of buildings.

Fast Fourier transform

The number of multiplications required to solve the DFT is directly related to the square of the number N of samples used to define the function. It is obvious that implementation of the DFT on a large number of samples on a microcomputer will result in very long running times.

A method for the computation of the DFT of a time series of discrete data samples, which require much less computational effort, was reported by Cooley and Tukey [14]. The method is commonly referred to as the "Fast Fourier Transform" (FFT). It should be noted that the FFT is not an approximation of the DFT, but an exact computation [15].

Most algorithms are restricted in the number of samples (N) to the $N = 2^k$ case (where $k = 1, 2, 3 \ldots$) due to the simpler derivation and programming involved than for the general case. In the specific case of climatic data pertaining to the prediction of the thermal behaviour of a building, the choice of N will usually be dictated by the interval of samples and the period of interest. The sampling interval chosen in this case was an hour. This corresponds to the sampling interval of the design day data [16], as well as the climatic data gathered by the Weather Bureau. The value of N will therefore be an integer of $24n$, where n is the number of days of interest.

In order to meet the condition of $N = 24n$, the in-order and in-place prime factor FFT algorithm with a separate output pointer [17] was implemented. A comparison proved the algorithm also to be faster than both the Cooley–Tukey and nested Winograd algorithms [18]. The only prerequisite of the algorithm is that the number of samples N has M relative prime factors which can be described by the array $NI(K)$, such that $N = NI(1), NI(2), \ldots, NI(M)$.

The thermal performance of a building can now be predicted by a numerical solution of the convolution Equation (1) of the thermal network, which represents the building. The FFT algorithm is used to transform both the response function, and the climatic forcing function to which the building is exposed, into the frequency-domain. The resulting indoor air temperature is simply the product of the two functions and the inverse transformation back into the time-domain.

Although it is now possible to implement the thermal prediction method on a computer, two important properties directly related to the thermal modelling of the building zone have to be highlighted.

Mean correction

The original solution of the thermal model was based on an analytic forcing function defined by a single sinusoid [7, 8]. The arithmetic mean and the mean of the minimum and maximum values of an integral number of cycles of the forcing function will therefore be equivalent. It can also be shown that the mean of the predicted sinusoid of the thermal model is approximately the same as the mean of the forcing sinusoid [7].

Consider two cycles of a forcing function $x(t)$ that consist of the sum of two sinusoids 2 sin (t) and sin $(2t-45°)$. The arithmetic mean of the function will not be equivalent to the mean of the minimum and maximum values of the function. The difference between the two values will be defined as the mean correction.

The two mean values will be subject to a difference in value over any period of interest for an arbitrary forcing function as in the case of the numerical implementation. The mean correction is therefore applied to meet the conditions imposed by the original derivation of the thermal model which was subject only to a single sinusoidal forcing function [6].

Phase correction

Due to the single forcing function and the very high degree of lumping employed in the thermal network as shown in Fig. 2, the time lag between the forcing temperature and the indoor air temperature is not predicted with sufficient accuracy. This time lag is defined as the phase difference between the two functions.

A phase correction was therefore derived from the measured and predicted data of the 39 different case studies [6]. The phase correction is calculated from an empirical equation, related to the phase equation of the thermal network, fitted on the data:

$$\text{Phase Correction} = \arctan(3\Sigma C/\text{System Constant}) - 4. \quad (4)$$

It should be noted that the same equation is used for simulations with the windows open or closed.

VALIDATION

Ultimately, the usefulness of a simulation model as a design tool to predict the thermal performance of a building can only be ascertained by comparing the predictions with experimental results from actual buildings [19]. Although this task is fraught with difficulties due to inherent problems encountered [19], from a design point of view these are often the exact same problems that the designer is faced with in the early design phase. Some of the problems include: lack of adequate climatic data, the accurate determination of the thermophysical properties of the building elements and the difficulties of measuring certain variables such as air movement or user actions including the opening of windows.

The purpose of the experimental validation was therefore aimed at determining whether the simplified simulation model, with the limited input data it requires, will adequately predict the indoor air temperature of a naturally ventilated building. The prediction of the indoor air temperatures were verified for 39 separate cases [6].

Although any period of time can be simulated by the thermal analysis method, it was decided to calculate an average 24 h period from the available experimental data. This 24 h period can be seen as a design day representation of the actual measurements. The advantage of an average day is that the high-frequency components of small magnitude due to digitalization are reduced [20] and the model is evaluated for the exact input data normally available to a building designer.

The average day was calculated, in the majority of cases, over a period of five to seven consecutive days. In the case of large variations in the outdoor environment due to influences such as overcast skies, the average day was calculated from a selection of days over a period of two weeks or less.

The predicted thermal performance of four buildings compared with their actual recorded temperature measurements is presented [6]. The different buildings were selected in order to demonstrate the validity of the method for a range of designs.

Factory building

The factory is situated in an exposed position on a slope. Except for an adjoining factory, there are no buildings near the factory that can shade any part of the structure. The factory, covering nearly 10 000 m^2, is naturally ventilated by means of roll doors at ground level and roof-mounted ventilators. The total area openable for ventilation was calculated from the throat area of the ventilators and the door openings.

The factory was used for assembly of mechanical components and storage and no internal heat was generated during the period that measurements were recorded.

The structure of the building consists of lightweight metal IBR-profiled steel cladding that is well insulated with flexible glasswool. The floor of the factory is a massive reinforced concrete slab directly in contact with the ground. The roof and walls of the building are exposed to the outdoor environment, except for the south wall which is a partition between the two factories. The exterior vertical surfaces of the factory are painted different shades of brown. The roof was left unpainted and has a weathered galvanized finish. The calculated active thermal capacity of the factory is 504 kJ $°C^{-1}m^{-2}$.

The predicted and measured indoor air temperatures of the factory are in reasonable agreement as shown in Fig. 3. The proposed thermal model is therefore capable of predicting the thermal performance of a well-insulated lightweight structure that is in direct contact with the ground.

Shop no. 10

The vacant shop is located in a shopping mall. In contrast to the other buildings evaluated, the two exposed facades of the shop are oriented in a south-easterly and south-westerly direction. The south-easterly facade consists mainly of glazing, but is well protected by the build-

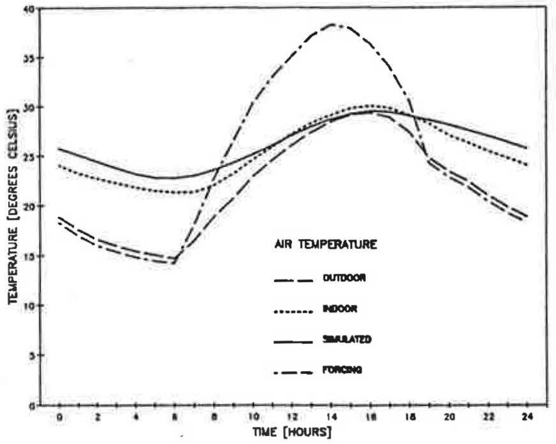

Fig. 3. Comparison of the simulated and measured indoor air temperatures of the naturally ventilated factory for a design day. Period of measures: 11–24 November 1985.

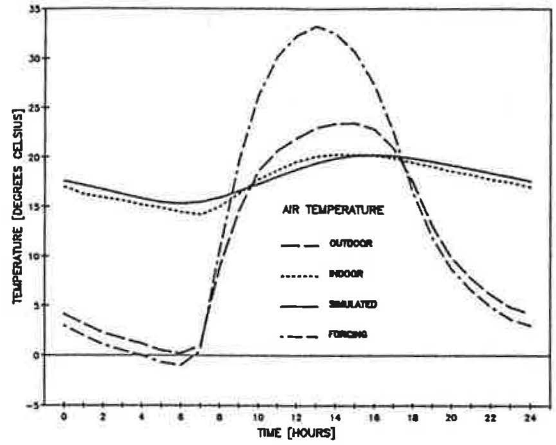

Fig. 5. Comparison of the simulated and measured indoor air temperatures of the bedroom with solar penetration and closed windows. Period of measurements: 4–10 August 1986.

ing eaves. The interior walls are shaded by an adjoining restaurant and a loading zone.

The shop of nearly 100 m^2 has a high ceiling of acoustic panels and the floor is covered with PVC tiles. The roof consists of dark red Fibercem roofing slates and insulated with Sisalation 420 aluminium foil. The exterior walls are constructed of medium coloured face bricks and the interior of the building is plastered. The windows of both facades were opened during measurements to assess the effect of natural ventilation. The total active thermal capacity of the building with open windows is 758 kJ °C^{-1}m^{-2}.

To validate the internal heat source modelling capabilities of the model, heat was generated from 0800 to 1700 in the shop by means of convective heaters capable of delivering a total output of 7000 W.

Figure 4 depicts the comparisons between the predicted and measured indoor air temperatures of the shop, with convective heating loads imposed on the interior air volume of the building. The predicted rise in air temperature of the shop is in fair agreement with the measured values.

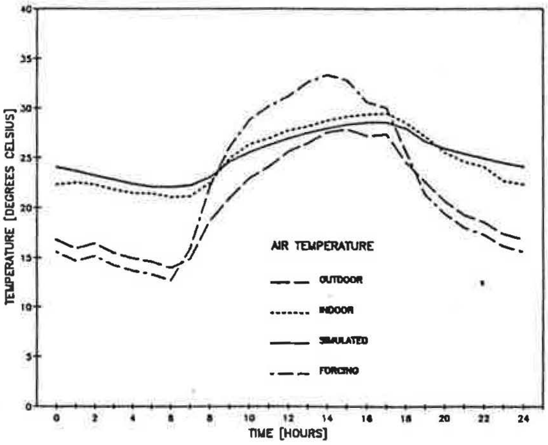

Fig. 4. Comparison of the simulated and measured indoor air temperatures of shop no. 10 with open windows and 7000 W convective heat generated from 0800 to 1700. Period of measurements: 2 January–16 February 1986.

The effect of the time required to reach a uniform air temperature, as well as that of the transient cooling of the air after the heaters are switched off, are clearly demonstrated by the predicted and measured values of the indoor air temperature.

Room in a townhouse

An unoccupied room in a townhouse was used to measure temperatures with the windows open and closed, as well as the effect of solar penetration.

Only one wall is exposed to the outdoor environment and the adjacent rooms are the study and dining-room. The door and the window were left open during measurements to ensure adequate cross-ventilation. The floor of the room is covered by a carpet of medium thickness and a layer of glasswool on the gypsum board ceiling insulates the galvanized steel roof.

The walls of the townhouse are solid brick, plastered on both sides. The paint on the exterior wall is a yellow-beige and the colour of the steel roof is dark brown. The total active thermal capacity of the room with open and closed windows respectively, was calculated at 758 kJ °C^{-1} m^{-2} and 541 kJ °C^{-1} m^{-2}.

Solar penetration of the building enclosure is modelled as a radiative heat source. A typical winter period was used to validate the modelling of solar penetration for the room with the windows both closed and open. The results are shown in Figs 5 and 6. The predicted and measured indoor air temperatures are in fair agreement and within experimental accuracy. It should be noted that both the direct and diffuse solar radiation incident on the interior enclosure were calculated at each time-step. Although no attempt was made to model the shading of the windows, the effect of a completely shaded or unshaded window on the indoor environment can be predicted. This will be the boundaries of the effect of solar penetration and can be a useful indicative tool for the designer in assessing the influence of different facades.

Garage

The garage adjoining one of the townhouses described in the previous section was also used as a validation

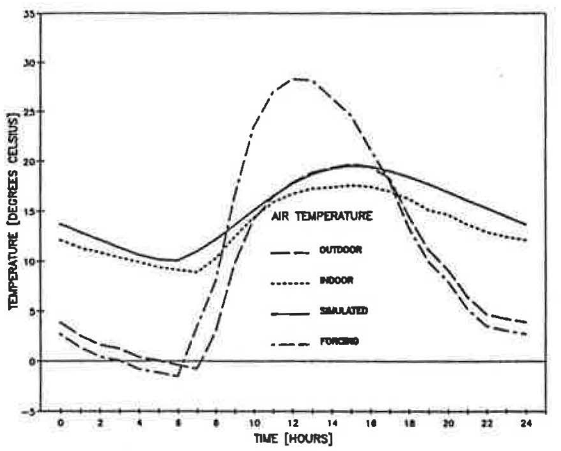

Fig. 6. Comparison of the simulated and measured indoor air temperatures of the bedroom with solar penetration and open windows. Period of measurements: 21–27 July 1986.

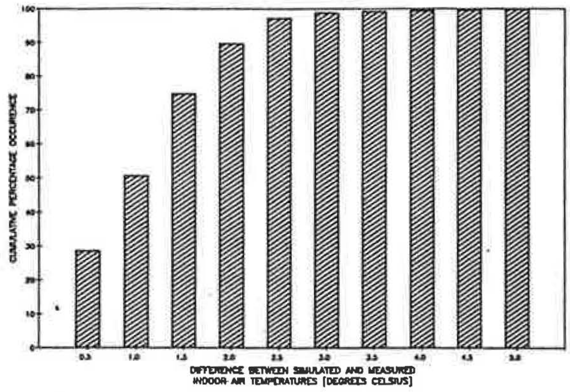

Fig. 8. Cumulative frequency distribution of the difference between the simulated and measured indoor air temperatures for 39 validation studies.

exercise. The construction of the garage is the same as that of the room, except that no ceiling is provided and the floor consists only of a poured concrete slab. The steel door of the garage faces south. It was therefore possible to evaluate the sensitivity of the prediction to distribute building elements in different positions with a large variation in thermal mass and resistance. The garage has an active thermal capacity of 367 kJ $°C^{-1}$ m^{-2}.

The predicted and measured indoor air temperatures for the garage with the window open, are plotted in Fig. 7. The differences between the predicted and the measured data are within the accuracy range obtained in the previous cases. It seems as if the model can reliably predict the thermal performance of a building with large variations in, and a distribution of, the thermal mass and the resistance of the different building elements. It is noteworthy that the maximum indoor air temperature exceeds the corresponding outdoor air temperature. This is due to the high solar absorptivity and low heat resistance of the roof.

An extension of the model to account for the forcing temperatures acting through each separate building element could result in better prediction of the maximum indoor air temperature, but it should be weighted against the added complexity and time required for the simulation.

Accuracy of the proposed thermal model

The statistical distribution of differences between the predicted and measured indoor air temperature of 39 validation studies is shown in Fig. 8 [6]. The cumulative error distribution graph shows that 50% of the predicted values are within 1°C of the measured values, while 90% of the predictions are within 2°C of the measured data. None of the differences between predicted and measured values was greater than 5°C. This compares extremely favourably with the expected accuracy of other methods, including very sophisticated and comprehensive mainframe computer programs [21].

The satisfactory agreement between predicted and measured results provides a very high level of confidence in the use of the numerical implementation of the proposed thermal model as a design tool to predict the thermal performance of naturally ventilated buildings.

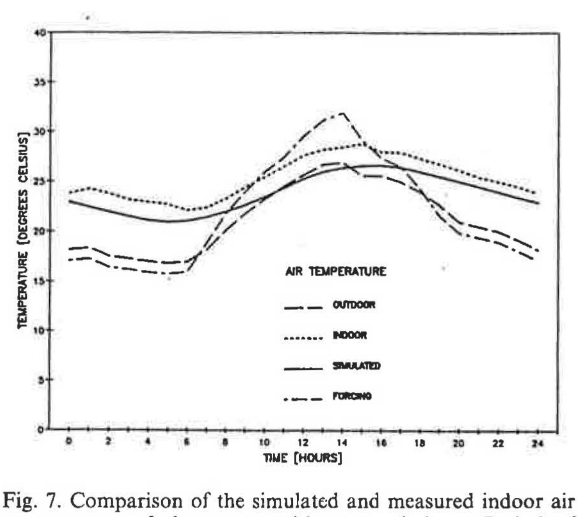

Fig. 7. Comparison of the simulated and measured indoor air temperatures of the garage with open windows. Period of measurements: 27 January–2 February 1986.

MICROCOMPUTER IMPLEMENTATION

A highly interactive microcomputer program named QuickTEMP was developed to implement the prediction method [6]. It was also employed in the validations described in the previous section. The program was written in Pascal operating under MS-DOS on IBM-compatible microcomputers and is extremely easy to use. A user can become fairly proficient with the program within an hour. The description of the building zone and the climatic data can be entered typically within 15 min. The actual simulation run is in the region of 15 s.

QuickTEMP consists basically of a series of input screens, an algorithm to compute the forcing temperature, the FFT algorithm and a graphic output of the situation which is displayed on the screen of the microcomputer.

The building zone is defined by a floor, roof and a set of enclosing surfaces in QuickTEMP. Each of these

Project : OFFICE IN SANLAM BUILDING Time: 14:50 Date: 03/01/88

Select material from data base (using F7 and F8)
Enter all surface layers from the outside to the inside

Number : 1 SURFACE DESCRIPTION

Name: NORTH WALL — Area: 6.01 [m^2]
Exposed to outdoor environment: YES — Azimuth: 0 [degrees]
Absorptance of outdoor surface: 80% — Indoor partition: NO
Indoor surface of bright metal colour: NO — Window: NO

SURFACE LAYERS

Layer no	Material description	Thick [mm]
1	BRICKWORK	114
2	AIRSPACE	30
3	BRICKWORK	114
4		0
5		0
6		0

MATERIAL DATA BASE

Material description
PRESSED ASBESTOS CEMENT
UNPRESSED ASBESTOS CEMENT
ASPHALT
ASHCRETE
BITUMEN
BRICKWORK

F1 Help F2 New F3 Next F4 Prev F7 Put F8 Sel F10 End

Fig. 9. Input screen defining an enclosing surface of the building zone.

Project: OFFICE IN SANLAM BUILDING Time: 15:05 Date: 03/01/88

Enter Material data (max 29 characters)

MATERIAL DATA BASE

Material Description	Density [kg/m^3]	Conduct [W/m°C]	Spec Heat [kJ/kg°C]
PRESSED ASBESTOS CEMENT	2100	0.620	0.830
UNPRESSED ASBESTOS CEMENT	1830	0.480	0.840
ASPHALT	2243	1.230	1.670
ASHCRETE	753	0.330	1.200
BITUMEN	1050	0.160	0.840
BRICKWORK	1826	0.820	0.800
CONCRETE POURED	1986	1.500	0.880
FELT UNDERCARPET	120	0.045	1.000
FIBREBOARD	240	0.058	1.460
GLASS	2483	0.750	0.670
GLASS WOOL	25	0.040	1.000
GYSUM PLASTER BOARD	993	0.170	1.050

F1 Help F9 Scrl F10 End

Fig. 10. Input screen of the material data base which is coupled to the description of material appearing in Fig. 9. The data are stored on and retrieved from file.

elements is described by a separate screen (Fig. 9) which is filled in by the user of the program. It is important to note that the thermophysical properties of each element are specified by data imported from an open-ended material data base (Fig. 10). The material data base can be supplemented by new materials, with their associated properties entered by the user. The concept of an open-ended program was implemented throughout QuickTEMP. The advantage of this concept is that a knowledgable user can apply QuickTEMP to different situations through intelligent choices.

The climatic data required by QuickTEMP are the outdoor air temperature and the global and diffuse radiation on a horizontal surface for a period of 24 h. The design day given in reference [16] or actual measurements can be used. Once again the concept of an open-ended climatic data base was retained (Fig. 11). An example of its use is the simulation of a building that will be in the shade of a mountain for part of the day. The user can change the solar radiation specified in the climatic data base in order to get an indication of its effect on the predicted indoor environment. It should be noted that the climatic data for different locations can be stored on file. It is therefore easy to select the appropriate environmental data for a specific location.

Project : OFFICE IN SANLAM BUILDING Time: 15:02 Date: 03/01/88

Location: CAPETOWN WINGFIELD — Longtitude: 18.53 [degrees]
Season: SUMMER — Latitude: -33.90 [degrees]

Hour	Temp [°C]	Hor Rad Global	[kW/m^2] Diffuse	Hour	Temp [°C]	Hor Rad Global	[kW/m^2] Diffuse
1	17.9	0.00	0.00	13	28.4	0.98	0.13
2	17.6	0.00	0.00	14	28.6	0.99	0.13
3	17.4	0.00	0.00	15	28.1	0.92	0.13
4	17.0	0.00	0.00	16	26.9	0.78	0.12
5	16.9	0.00	0.00	17	25.4	0.60	0.11
6	16.7	0.02	0.00	18	23.6	0.38	0.09
7	17.3	0.08	0.03	19	21.7	0.18	0.06
8	19.2	0.25	0.07	20	20.2	0.04	0.00
9	21.9	0.46	0.09	21	19.5	0.00	0.00
10	24.4	0.66	0.11	22	19.1	0.00	0.00
11	26.3	0.83	0.11	23	18.6	0.00	0.00
12	27.6	0.93	0.11	24	18.3	0.00	0.00

F1 Help F10 End

Fig. 11. Input screen of the climatic data base accessed by the program. The data can be stored on file or retrieved from file.

The simulated indoor air temperature predicted by QuickTEMP is plotted on the screen as a graph of hourly temperature values (e.g. Fig. 7). The outdoor air temperature is also plotted and the user can see at a glance the comparison between the indoor and outdoor environment. Due to the quick response time of QuickTEMP, it is possible for the designer of a building to conduct sensitivity analyses economically at the early design stage of a proposed building and see the effect of changes to the building's properties.

QuickTEMP is therefore the practical implementation of the theoretical development of the simplified thermal predictive method to simulate the indoor air temperature of a naturally ventilated building described in this paper.

CONCLUSION

A highly simplified thermal model for predicting the thermal performance of a naturally ventilated building was extended, validated and implemented on a microcomputer. The objective of the program was to provide the building designer with a design tool to assist him in making a judgement of his proposed design in terms of the expected indoor climate for which he is responsible.

It has been proved that the thermal performance of a naturally ventilated building can be reliably predicted numerically by means of the proposed simplified thermal simulation model. An inexpensive, easy to use and accessible design tool in the form of the computer program QuickTEMP was developed. QuickTEMP is consequently an interactive design tool available to any designer with access to a personal computer. It is therefore possible for a building designer, at a very early stage in the design of a proposed building, to evaluate economically the influence of different design options on the indoor environment. This should also be an ideal educational aid for the prospective building designer or architect.

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