


DESCRIPTIVE GUIDE FOR PROGRAM

 **ZSTEP**

P.J. WALSH · J.W. SPENCER · T.A. GURR

**THERMAL PERFORMANCE
OF
BUILDINGS**

CSIRO - DIVISION OF BUILDING RESEARCH

DESCRIPTIVE GUIDE FOR PROGRAM "ZSTEP"

THERMAL PERFORMANCE OF BUILDINGS

by

P.J. WALSH
J.W. SPENCER
T.A. GURR

COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANIZATION

DIVISION OF BUILDING RESEARCH

CSIRO
Division of Building Research
P.O. Box 56
Highett, Victoria, 3190
AUSTRALIA

© CSIRO, 1980

ISBN 0 643 02640 1

Printed by BUILDRESEARCH Melbourne

CSIRO DISCLAIMER

This program was developed by CSIRO as part of its research effort, and while the program is believed to be reliable, no warranty is made on this score by the authors or CSIRO. The material is therefore released on the understanding that it is not republished without CSIRO permission, and that recipients will not hold the authors or CSIRO liable for any loss or damage resulting from its use.

PREFACE

Program ZSTEP has been developed over the past two years. It is a zonal version of the program STEP which was developed at the Division of Building Research about fifteen years ago. Program ZSTEP and its predecessor have always been regarded primarily as research tools. Consequently they were not written with the uninitiated user in mind, and such features as ease of portability and input coding are absent. Nevertheless there has been an increasing demand for information about program ZSTEP and its capabilities, and this descriptive guide is written to meet that demand. Although its format is largely that of a user manual, it should be stressed that this guide is not a user manual. Such a manual awaits further developmental work which the program is expected to undergo in the next two years and so any comments would be most welcome. Acknowledgement should be made to Mr. Chris Wharton who played a large part in developing the data preparation forms contained in Appendix A.

CONTENTS

Preface

Contents

1. General Description
 - 1.1 Purpose
 - 1.2 Development
 - 1.3 Program Language
 - 1.4 Mathematical Basis
 - 1.5 Results
 - 1.6 Program Accessibility
 - 1.7 Program Portability
 - 1.8 Program Flexibility
 - 1.9 Special Editions
2. Program Structure
 - 2.1 Description of subroutines
 - 2.2 Flow Diagram
3. Program Input
 - 3.1 Data Requirements
 - 3.2 Data Availability
 - 3.3 Data Preparation and Layout
4. Program Operation
 - 4.1 Usage
 - 4.2 Costs
5. Program Output
 - 5.1 Form and Options
6. Applications
 - 6.1 Evaluations
 - 6.2 Applications to Date
 - 6.3 Planned Developments
7. References

1. GENERAL DESCRIPTION

1.1 Purpose

ZSTEP is a program for simultaneous calculation of the thermal performance of up to ten zones in a building, i.e. for a given building in a given location the program calculates indoor temperatures and as an option may calculate sensible heating or cooling loads over as long a time period as required. Either real or theoretical climatic data may be used.

1.2 Development

The program was originally developed at the CSIRO Division of Building Research in the early 1960s as Program STEP by R.W. Muncey and subsequently refined by J.W. Spencer. It was then modified by P.J. Walsh in 1977 to enable different zones within a building to be handled and was renamed ZSTEP.

1.3 Program Language

The language used in the latest version of the program is Control Data Corporation FORTRAN EXTENDED, Version 4.

1.4 Mathematical Basis

1.4.1 A response factor technique is the basis of the calculation. It differs from the well-known technique promulgated by the American Society for Heating, Refrigerating and Air Conditioning Engineers.

Heat flow by conduction through building elements is calculated using simple frequency response analysis (Van Gorcum 1950; Muncey 1953). Denoting by subscript a the building interior, and by subscript b the building exterior, then $T_a \exp(j\omega t)$ is the building internal temperature when the climatic drivers $T_b \exp(j\omega t)$ are acting on the various external building elements, where t is time, $j = \sqrt{-1}$ and ω is a specified angular frequency. Furthermore, if $W \exp(j\omega t)$ is the heat input generated from sources inside the building (e.g. lighting, cooking), we may show (Muncey 1953) that

$$T_a = \frac{\sum_b r_b T_b - W}{\sum_b R_b + \sum_c S_c} \quad (1)$$

where \sum_b denotes summation over all external paths, \sum_c denotes summation over all internal paths (e.g., internal partitions, furniture), r_b is the product of path area and the so-called *transfer parameter* for the particular path, and R_b , S_c are each the product of path area and the so-called *admittance parameter* for the particular path. Further work has shown how particular cases such as heat flow paths with parallel branches or heat flow to the fabric of the building (Muncey and Spencer 1969) and radiation effects within rooms (Muncey and Spencer 1966) may be incorporated into this model. Both the transfer and admittance

parameters are complex numbers so T_a is also complex. However for $\omega = 0$, both transfer and admittance parameters (for external paths) are equal to minus the so-called U-value (overall coefficient of heat transfer) for the given building element. The above equation provides the contribution of the various paths to the overall harmonic internal temperature response. To obtain a transient response, i.e. the response of the internal temperature to a unit step pulse on each of the drivers, use is made of the known relation between the harmonic and step responses of a linear system (Muncey 1963, Muncey *et al.* 1970). For each path the step response, $a(t)$, is given by

$$a(t) = B_0 + \sum_{n=1}^N B_n \exp(-b_n t) \quad (2)$$

where the coefficients B_n , b_n are real. In practice, the series may be truncated to 18 terms with good accuracy. Then by evaluating each portion of the harmonic response (1) at each of 18 frequencies ω_n ($n = 1, 2, \dots, 18$) and the steady state ($\omega = 0$) and setting $b_n = \omega_n$, the coefficients B_n and hence the response of the indoor temperature to a step pulse on the given path may be determined. It has been found that angular frequencies

$$\omega_n = \left(\frac{2\pi}{24}\right) \times 2^{n-9} \text{ radians per hour } (n = 1, 2, \dots, 18)$$

cover the time scale of interest in building thermal behaviour.

In practice the step response is not very useful. A triangular or inclined step pulse is preferred for climatic drivers and a square wave pulse for heat flows. The appropriate response is determined from (2) by the inclusion of known factors in the truncated series (Muncey *et al.* 1970).

In order to calculate building thermal behaviour, such responses must be calculated for time points long after the pulse has ceased. The response factors (2) are calculated at 25 chosen times, viz.

$$1, 2, 3, 4, 5, 6 \text{ hours and } 2^{\left(\frac{m}{2} - 3\right)} \text{ days } (m = 1, 2, \dots, 20),$$

i.e. at 25 times ranging from 1 hour up to 128 days. Note that these are *total building response factors*, relating the indoor temperature for the whole building to each of the drivers in turn. For each path in the building there are 25 such response factors. Now each driver may be synthesized as a series of pulses of the required form. Then for each path in turn and at each of the 25 times indicated above, the product

$$(\text{response factor at } t) \times (\text{pulse size})$$

is accumulated into an array FUTTMP(I), $I = 1, 2, \dots, 26$. The internal temperature at the end of the current hour is then simply FUTTMP(1). The array FUTTMP is then "moved on" by 1 hour and the process repeated.

1.4.2 Zoning is accounted for at the frequency response stage (Walsh 1978). Therefore the user may restrict the actual calculating to the zone(s) of interest, whilst still correctly accounting for all the zones.

1.4.3 The nature of the temperature thus calculated depends on the choice of the combined (convective and radiative) internal film coefficients for the room or zone (Muncey and Spencer 1966). In general it will be a linear combination of air and mean radiant temperatures though in many cases these temperatures differ little from one another.

1.4.4 Only sensible heating and/or cooling loads may be calculated. Thermostat paths are modelled as heat flows direct to the internal temperature point. Plant capacity (i.e. maximum flow rate of heat) is specified together with a thermostat differential, ΔT . For an optimum (prescribed thermostat setting) temperature, T_o , the thermostat "switch on" temperature is $T_t = T_o - \Delta T$ for heating and $T_t = T_o + \Delta T$ for cooling. In general, heating (say) is not applied until the indoor temperature is below T_t . More specifically, at the *beginning* of a given hour, the internal temperature at the end of the hour *without* heat being supplied is calculated. If this temperature is above the cut-in temperature, T_t , no heat is supplied; if below T_t , sufficient heat if possible is supplied to raise the internal temperature to the required level at the end of the hour (i.e. the thermostat setting). If not possible, then heat is supplied at the maximum rate as determined by the plant capacity and the temperature at the end of the hour is calculated. Only once during the hour is a calculation made of the amount of heat to be supplied.

1.4.5 An optional starting condition incorporated into the program is for the first day of the calculation to be repeated ten times for each zone of interest. This ensures that a condition approaching steady-state is achieved prior to the commencement of the actual calculation. The alternative is for all temperatures to be initially set to a preassigned starting temperature.

1.4.6 There is no solar radiation model incorporated into ZSTEP, i.e. the program will not generate its own solar radiation data. However certain concepts used to describe the interaction between solar radiation and the building are incorporated into the program. These are the sol-air temperature concept, used to indicate the effects of incident solar radiation on heat flow conducted through building surfaces and the solar heat gain concept, used to calculate the amount of radiation transmitted through transparent building surfaces. These are dealt with in turn below.

The method used for calculating low temperature radiation is based on Høglund *et al.* (1967), that for calculating solar altitude and azimuth on Spencer (1965) whilst the calculation of radiation on surfaces with horizontal sunbreaks is based on Ballantyne and Spencer (1969). Both the method used for calculating transmission and absorption of 3 mm thick flat glass and the use of the shading coefficient concept are taken from ASHRAE (1977), ch. 26.

1.4.6.1 Sol-air temperature for horizontal surfaces

The sol-air temperature, t_{sa} , at each hour is calculated as

$$t_{sa} = t_{oa} + \gamma [N \sin(h) + d_H] R - 4\sigma\epsilon R (t_{oa} + 273.15)^3 (14 - 0.2t_{oa}) (1 - m/9) \quad (3)$$

where t_{oa} = outdoor air temperature ($^{\circ}\text{C}$)

γ = solar absorptance of the surface

- N = direct solar irradiance on a surface normal to the solar beam (W/m²).
- h = solar altitude
- d_H = diffuse solar irradiance on a horizontal surface (W/m²)
- R = outdoor film resistance (m² K/W)
- σ = Stefan-Boltzmann constant (5.6697 x 10⁻⁸ W/m² K⁴)
- ε = emittance of the surface for long wave radiation
- m = total cloud amount in oktas.

The outdoor film resistance R can be related to instantaneous wind speed v (m/s) by

$$r = 1/(11.3 + 3.31v) \quad (4)$$

though this formula is not present in the program.

1.4.6.2 Sol-air temperature for vertical surfaces

At each hour the calculation proceeds as follows:

- (i) The cosine of the solar angle of incidence, i, on the surface is calculated from

$$\cos(i) = \cos(A - \alpha) \cos(h) \quad (5)$$

where h, A are solar altitude and azimuth respectively and α is the bearing of the surface. If this delivers a negative answer, cos(i) is set to zero and the direct solar irradiance incident on the surface, D_v, is set to zero. Otherwise the tangent of the vertical shadow angle, η, is calculated from

$$\tan(\eta) = \sin(h)/\cos(i) \quad (6)$$

and D_v calculated from

$$D_v = [1 - r \tan(\eta)/100] N \cos(i) \quad (7)$$

where r is the horizontal sunbreak rating for the surface (%). If this delivers a negative answer, D_v is set to zero.

- (ii) The diffuse radiation incident on the surface, d_v, including radiation reflected from a ground of reflectance 0.2, is calculated from

$$d_v = \frac{1}{2} \left(\frac{2}{\pi} \arctan \left[\frac{100}{r} \right] d_H + 0.2 (N \sin(h) + d_H) \right). \quad (8)$$

(iii) the sol-air temperature for walls is then calculated from

$$t_{sa} = t_{oa} + \gamma (D_v + d_v)R - \frac{4\sigma\epsilon R(t_{oa} + 273.15)^3 (5 - 0.1t_{oa})}{\pi} \arctan \left[\frac{100}{r} \right] (1 - m/9). \quad (9)$$

(iv) The sol-air temperature for windows is calculated, assuming a low temperature emittance of 0.9, from

$$t_{sa} = t_{oa} - \frac{3.6\sigma R(t_{oa} + 273.15)^3 (5 - 0.1t_{oa})}{\pi} \arctan \left[\frac{100}{r} \right] (1 - m/9). \quad (10)$$

1.4.6.3 Solar heat gains for windows

The solar heat gains, ξ , through each of the windows are calculated at each hour as

$$\xi = s[(\psi + 0.267\phi) D_v + 0.81 d_v] \quad (11)$$

where ϕ is a function, dependent on angle of incidence, i , for calculating the absorption of 3 mm thick flat glass; ψ is a function, also dependent on angle of incidence, i , for calculating the transmission of 3 mm thick flat glass and s is the window shading coefficient. D_v and d_v are as calculated in (7) and (8) above. Once transmitted, this radiation may fall onto any internal surface as required and then subsequently be released by convection and radiation.

1.5 Results

There are options to produce, for each zone required, the following:

- (i) hour-by-hour internal temperatures and/or sensible heating and/or cooling loads,
- (ii) monthly mean temperatures and diurnal temperature swings,
monthly peak loads,
total load over the period considered,
peak load over the period considered.

1.6 Program accessibility

The program is currently available in Australia to users with access to CSIRONET, which has nodes in all States linked to a Cyber 76 in Canberra. It occupies about 50 000 (decimal) locations of store on the Cyber 76. Purchasing cost would be determined upon request. No detailed user manual exists.

1.7 Program portability

The program is easily transferable to machines supporting FORTRAN EXTENDED, Version 4. Thus it was at one time available on Control Data Corporation's 6600 in Sydney. Transfer to other machine types has been achieved (one version of the program was transferred to a Burroughs 6700 in Wellington, New Zealand) though at the expense of more time and effort.

1.8 Program flexibility

Up to 10 zones can be considered for one building. Thus for a detached dwelling we might typically take five zones, viz. living area, service area, bedroom area, roof space and sub-floor space. Clearly we would be generally interested only in temperatures (and loads) in the first three of these and the program offers the flexibility of being able to concentrate on just these zones whilst still correctly accounting for interaction between all five.

Plant operation may be specified in terms of a capacity, thermostat setting and thermostat differential. The thermostat setting may be varied as required *during the 24-hour day*, thus allowing the possibility of intermittent heating or night-time "setback", but it is constant for *all days* of the calculation. Both heating and cooling requirements may be simultaneously calculated in one zone, the heating and cooling plant operations being specified separately. Heating requirements may be simultaneously calculated for two zones in the building, cooling requirements in only one.

Shading of vertical building surfaces by horizontal eaves is a standard feature. Shading by trees, other buildings, vertical eaves etc. is not. Only vertical building surfaces oriented mutually at right angles (e.g. N-E-S-W) may be considered. Only a horizontal roof may be considered. A different horizontal sunbreak rating, shading coefficient, solar absorptance and low temperature emittance for each of the four orientations may be adopted but cannot be varied in time. The rate of infiltration/ventilation to each zone from external air is also constant in time, as is the rate of interzone air infiltration.

Occupant loads (lighting, cooking, people, etc) may be lumped together as a heat flow direct to the internal temperature point for each zone. The profile may be varied *during the 24-hour day*, thus allowing various living patterns to be simulated. The profile may be varied from day to day as required.

Although it is normal for calculations to be performed at hourly intervals, the possibility exists for this time interval to be greater or smaller than one hour. If, for example, half hourly calculations are specified, then response factors would be calculated at the 25 times,

$$0.5, 1, 1.5, 2, 2.5, 3 \text{ hours and } 2^{\left(\frac{m}{2} - 4\right)} \text{ days } (m = 1, 2, \dots, 20),$$

i.e. at the 25 times varying from half an hour up to 64 days. Furthermore, climatic data would need to be specified at half-hourly intervals.

1.9 Special editions

The following related programs should be noted:

CARE: A harmonic analysis/synthesis method. Suitable for calculation of temperatures and/or conditioning load requiring up to 240 equal time intervals. With data at 3-hourly intervals, calculations up to about one month in length can be performed. Over 100 separate buildings can be processed in one job. The method of ZSTEP computes transient building response from the building frequency response.

STEP: Calculates internal temperatures and/or heating/cooling loads for single-zone buildings. A fore-runner to ZSTEP. Up to 100 buildings may be processed in one job. Climatic data input only from 'cards'.

SUSTEP: A more efficient version of STEP. All four walls (N-E-S-W) are constrained to be of the same material as are all four windows. Computing time is thereby reduced. Suitable for calculations over lengthy periods.

2. PROGRAM STRUCTURE

2.1 Description of subroutines

ZSTEP	The main program. Calls to DATREAD, CALGORC, HARMNIC, CLBEHAV, PERFORM. Any mistakes generated in DATREAD, CALGORC, HARMNIC result in termination upon return.
DATREAD	Reads all input data. Building data from cards, climatic data from cards or permanent file (TAPE 10) as desired. Calls made each day to SUNANGL, SOLAHF so that all drivers are available. Writes onto a scratch file (TAPE 52) information regarding each building element, and combination data for each zone. If climatic data come from cards, then drivers for each day (21 x 24 of them) are written onto TAPE 52. If climatic data come from permanent file, drivers are written onto a separate scratch file TAPE 53. Various messages relating to data input errors are generated if these are present. TAPE 52(53) rewound.
SUNANGL	Calculates 24 hourly values of solar altitude and azimuth for a given day and month in a given location.
SOLAHF	Calculates 24 hourly values of sol-air temperatures (for the four wall and window orientations) and solar heat gains (for the four window orientations) for a given day and month in a given location. Call to functions TRANS, ABSORB (entry point in TRANS) each hour.
TRANS ABSORB	Calculates transmission and absorption of direct solar radiation by 3 mm clear glass according to ASHRAE method. Call to function POLY.
POLY	A polynomial evaluation function.
CALGORC	Reads stored information from scratch file TAPE 52 pertaining to each individual building element and calculates for each the admittance and transfer parameters and any heat flow multipliers which may be required. This is done at the steady state and 18 frequencies. Call to GORCUM, VANGORC.
GORCUM	Specifically calculates the overall admittance and transfer parameters at each frequency for the various heat transfer paths.
VANGORC	Serves to select portion of the overall R-C string (see 3.3.3 Heat Path (201) Cards) for a given building element counting from either direction as required for parallel paths and paths with heat flows. Calls GORCUM to provide the admittance and transfer parameters for the appropriate portion of the overall path.

HARMNIC	Reads stored information from scratch file TAPE 52 pertaining to zone formation and combination and calculates for each zone the overall harmonic response at the steady state and 18 frequencies due to the various temperature or heat flow pulses in all the zones. If the number of zones is greater than 1, a call is made to ZONE.
ZONE	For zoned buildings, forms and inverts the matrix of interzonal coefficients (complex), then forms the overall harmonic response at the steady state and each of 18 frequencies. Calls CMTINV. If the matrix is singular, an error message is generated.
CMTINV	Standard routine for inversion of a complex matrix. Calls MATINV, MATMPB.
MATINV MATMPB	Standard routines for inversion of a real matrix.
CLBEHAV	Forms response factors for all zones of interest.
PERFORM	Subroutine in which the hour-by-hour temperatures and/or loads are calculated. For each zone for which calculations are required, an array FUTTMP is incremented at every hour and at each of 26 future times by a product of response factor and pulse size. The drivers (pulse sizes) are read from scratch files (TAPE 52 or TAPE 53). Calls are made to HEATER 1, HEATER 2, COOLER (as required each hour) and SCRIBE (after each day).
SCRIBE HEATER 1 HEATER 2 COOLER	Subroutine SCRIBE performs writing tasks. At the end of each day, hour-by-hour temperatures are printed if required together with the daily load totals. At the end of each month or end of the calculation period, load totals, peak loads, mean temperatures and mean diurnal temperature ranges are calculated and printed. Results written onto TAPE 54 if required. HEATER 1, HEATER 2, COOLER are entry points in SCRIBE and take care of the thermostat arrangement. Calls to STEPLT1, STEPLT2 as required.
STEPLT1 STEPLT2	These provide temperature plots. STEPLT2 (entry point in STEPLT1) provides a second plot on the same axes as the first.

2.2 Flow Diagram

Figure 1 provides a basic flow diagram indicating the logical structure of ZSTEP. Note that subroutines DATREAD, CALGORC, HARMNIC, CLBEHAV and PERFORM are all called from ZSTEP. The parameter M is set to 1 in the first three of these subroutines if specified errors are detected; otherwise it is 0. If M = 1 is detected upon return to ZSTEP, the program terminates. The use of tape units 10, 53 and 54 (shown dashed) is optional, depending on data parameters.

3. INPUT

3.1 Data Requirements

There are essentially three types of input data required; SI units are used throughout.

- a) Heat path data: These list the thermal resistance-capacitance pairs for each of the heat transfer paths in turn, and define the type of each path, e.g. normal external path, internal storage path, etc.
- b) Combination path data: For each zone in turn these combine the heat paths already specified according to the building plan. This includes specification of thermostatted heat flow paths. In addition the surface characteristics (absorptances, emittances) for the roof and the surface characteristics, horizontal sunbreak ratings and shading coefficients for the four orientations are specified.
- c) Climatic data cards: The requirement for vertical building surfaces oriented mutually at right angles implies that in general 14 types of external climatic drivers will suffice, viz sol-air temperatures, window sol-air temperatures and solar heat gains for N,E,S,W directions or oriented as desired, as well as air temperature and a horizontal (roof) sol-air temperature. These 14 drivers are calculated within the program itself for every hour of the calculation period. This requires input of 24 values each day for shade air temperature, direct solar irradiance on a surface normal to the solar beam, diffuse solar irradiance on a horizontal surface, external film resistance and total cloud amount. (Note that direct normal radiation may be calculated from horizontal radiation and solar position.) In addition, seven other driver types are allowed, corresponding to seven additional paths to be specified for each calculation. These drivers may be temperatures or heat flows. Again input of 24 values each day for these seven drivers is required. The climatic data may be entered from either cards or file. Data on file have been taken, where applicable, from standard climatic data files.

3.2 Data Availability

The program does not generate its own building thermal data. These are available from standard references (e.g. A.I.R.A.H. 1978). Combination path data can be obtained from the building drawings and specifications. Climatic data may be simulated or based on measured data. The number of locations for which measurements of the required climatic data are available is limited. Data on user characteristics can usually be estimated.

3.3 Data Preparation and Layout

The following is the layout of data input cards. A series of data preparation forms is given in Appendix A, whilst an example is given in Appendix B. Comment cards (with C in column 1) may be placed at will throughout the input sequence. In general cards other than comment cards must be in the order indicated in this section, or the run will terminate with an appropriate error message.

3.3.1 Option (199) Card

Card Columns	Contents	Format
1 - 3	Identity (value 199)	I3
4 - 5	NP (see below)	I2
6 - 9	Blank	4X
10	NTYPE (1) (see below)	I1
11 - 14	Blank	4X
15 - 18	NTYPE (2) (see below)	A4
19	Blank	1X
20 - 23	NTYPE (3) (see below)	A4
24	Blank	1X
25 - 32	NTYPE (4) (see below)	A8
33 - 80	Blank	48X

NP = 0 causes listing of input data + output of required results,
 NP = 1 causes output as for NP = 0 + response factors, FUTTMP array,
 NP = 2 causes output as for NP = 1 + drivers,
 NP = 3 causes output as for NP = 2 + transfer and admittance parameters,
 NP = 4 causes output as for NP = 3 + exponential coefficients B_n (eqn(2)).

If NTYPE (1) \neq 0 results are printed in full
 = 0 a summary of results is printed.

If NTYPE (2) = 4HTAPE, temperatures or loads as designated by NTYPE (3) are buffered
 out on TAPE 54 for the zone designated by NTYPE (4)
 \neq 4HTAPE, no temperatures or loads are buffered out on TAPE 54.

If NTYPE (3) = 4HTEMP, temperatures are buffered out on TAPE 54 if NTYPE(2) = 4HTAPE
 = 4HHEAT, heating loads are buffered out on TAPE 54 if NTYPE(2) = 4HTAPE
 = 4HCOOL, cooling loads are buffered out on TAPE 54 if NTYPE(2) = 4HTAPE

NTYPE (4) = is the name of the zone or building (A8 format) for which temperatures, or
 heating or cooling loads are to be buffered out on TAPE 54.

If minimum output of a summary of results is required, with no data to be buffered to
 TAPE 54, the 199 card may be omitted.

3.3.2 Option (200) Card

Card Columns	Contents	Format
1 - 3	Identity (value 200)	I3
4 - 15	F (see below)	F12.0
16 - 20	XS)	F 5.0
21 - 25	YMIN) plotting parameters (see below)	F 5.0
26 - 30	YMAX)	F 5.0
31 - 80	Blank	50X

The resistance-capacitance (R-C) pairs must be set down starting from the external side of the building or zone element and these data must end with a negative value of resistance to signal the end of the heat path.

Parallel branched paths are specified in a similar way but the resistance-capacitance pairs for the second branch are inserted in the resistance-capacitance string immediately after those for the first branch, the sequence then continuing to the inside of the building, and terminating with a negative resistance. On the first card for each heat path are required four numbers 4I1 format in columns 77-80 giving respectively the number of R-C pairs to the end of the first branch of a branched path, the number of R-C pairs to the end of the second branch of a branched path, the number of R-C pairs to the position of the first heat flow, and the number of R-C pairs to the position of the second heat flow, counting always from the outside. Such of these numbers as are not relevant may be punched as zeros or left blank (e.g. for normal transfer paths they will be 0 0 0 0).

A maximum of 100 sets of heat path data is permitted.

The program checks for invalid code numbers, more than 100 sets of heat path data, negative capacitance and more than 32 R-C pairs in one heat path.

3.3.4 End of Heat Paths (202) Card

Card Columns	Contents	Format
1 - 3	Identity (value 202)	I3
4 - 9	NZ1 (see below)	I6
10 - 15	NZ2 (see below)	I6
16 - 20	Blank	5X
21 - 50	NZ3(I) (see below)	10I3
51 - 80	Blank	30X

NZ1 is the number of zones in the building (maximum 10)

NZ2 is the number of zones for which temperatures and/or loads are required

(NZ3(I), I=1, NZ2) are the zone numbers of the zones for which temperatures and/or loads are required. There are a maximum of NZ1 such numbers.

3.3.5 Combinations (203) Cards

Card Columns	Contents	Format
1 - 3	Identity (value 203)	I3
4 - 11	Zone name	A8
12 - 13	Path number	I2
14	Card number	I1
15 - 77	Heat path code/area (m ²) data	7(I4,F5.0)
78 - 80	Zone number (for path 0)	I3

These cards assign the heat paths defined by the 201 cards to the various zones and ascribe to each a path number as follows:

Path Number	Comment
1	Paths with air temperature as driver
2	" " horizontal solair temperature as driver
3	" " North wall " " " "
4	" " East wall " " " "
5	" " South wall " " " "
6	" " West wall " " " "
7	" " North window solar heat gain as driver
8	" " East " " " " " "
9	" " South " " " " " "
10	" " West " " " " " "
11	" " North " solair temperature as driver
12	" " East " " " " " "
13	" " South " " " " " "
14	" " West " " " " " "
15 - 21	Drivers specified on 208 card
22 - 23	Heating thermostat paths
24	Cooling thermostat path
25-(24 + NZ1)	Denotes interzone linkage

The first card for each zone is specified as path 0, and includes all the relevant admittance heat path code numbers with their areas. In addition, Card 1 for path 0 must have the zone number punched in cols 78 - 80. Interzone connections may then be specified using paths (24 + n), where n is the zone number of adjacent zones.

Cards for succeeding paths 1 to (24 + NZ1) should contain the transfer parameter heat path code numbers or heat flow multipliers for that path together with their areas. These numbers should be in the following ranges:

200 - 299	transfer parameters for normal paths
500 - 549	transfer parameters for normal paths with one heat flow
600 - 699	heat flow multiplier for normal paths with one heat flow
800 - 899	transfer 1st branch for normal parallel paths
900 - 999	transfer 2nd branch for normal parallel paths
1100 - 1199	transfer 1st branch for parallel paths with one heat flow
1200 - 1299	transfer 2nd branch for parallel paths with one heat flow
1300 - 1399	heat flow multiplier for parallel paths with one heat flow
1500 - 1599	transfer parameter for normal paths with two heat flows
1600 - 1699	heat flow multiplier 1 for normal paths with two heat flows
1700 - 1799	heat flow multiplier 2 for normal paths with two heat flows

In each case these numbers must be either 100, 200, or 300 greater than the corresponding admittance parameter numbers specified on the 201 cards and on the 203 cards for path 0.

In addition, certain standard heat path codes are used on 203 cards as follows:

11	finish of combinations for a path
21	transfer parameter for infiltration/ventilation path
22	admittance parameter for infiltration/ventilation path
31	heating by step pulse
32	heating by triangular pulse

Infiltration/ventilation paths may be modelled in terms of a pure conductance (reciprocal of resistance) connecting indoor and outdoor air temperatures. In practice, this conductance is equivalent to an area (m²) which, for a resistance of 1 m².K/W, is given by

$$A = \frac{40aV}{2.982(40 + a)} \quad (12)$$

where V is the volume of the space concerned (m³), and a is the air exchange rate expressed as number of space air changes per hour. This is the area which must be associated with heat path code numbers 21 and 22 in modelling infiltration/ventilation paths.

In the case of 31 and 32 codes, the associated area is used as a multiplier for the heat flow quantities read from the 208 cards.

When the 203 cards are being read the program checks that

- (a) number of zones is not excessive; the program can handle up to 10 of them
- (b) path number is between 0 and (24 + NZ1) inclusive
- (c) a path is not repeated
- (d) the zone and path number remain unchanged in successive cards
- (e) card numbers are in numerical order within each path
- (f) heat path code numbers are available
- (g) zones are specified in increasing order of zone number

and ceases if these conditions are not met.

3.3.6 Thermostat (203/204) Cards

Paths 22, 23 and 24 are thermostat paths; 22 and 23 are always heating, 24 is always cooling. It is necessary for the zones with these paths present to be numbered as zones 1 and 2. The 203 cards for paths 22, 23 and 24 contain the relevant transfer heat path code number (normally 31 or 32) and its "area" or multiplier. After 203 cards for such paths come two cards of the following form (quantities enclosed in square brackets refer to the second of the two cards).

Card Columns	Contents	Format
1 - 3	Identity (value 204)	I3
4 - 11	Zone name	A8
12 - 13	Path number	I2
14	Card number (value 2 [3])	I1
15 - 69	Optimum temperatures (°C) for hours 1 to 11 [14 to 24]	11F5.0
70 - 74	Optimum temperature for hour 12 [source temperature (°C)]	F5.0
75 - 79	Optimum temperature for hour 13 [thermostat differential (°C)]	F5.0
80	Blank	1X

The 204 cards enable the program to calculate the heating or cooling loads required to maintain any desired profile of internal temperature during a day. Provision is made for reading 24 values of optimum temperatures, covering a period of 24 hours, and two 204 cards are required for each path 22, 23 or 24 to contain this information. A constant thermostat differential is assumed, so that only a single value of the thermostat differential needs to be read from the second of the 204 cards of the path. The thermostat differential is always specified to be positive, and the program calculates the "switch on" temperature at which heating or cooling is activated as (optimum temperature - differential) or (optimum temperature + differential) respectively. The "switch off" temperature is the optimum temperature.

The plant capacity (maximum rate of heat input or removal) is specified in terms of the multiplier associated with heat path code numbers 31 or 32 and the source temperature on the second 204 card. Denoting optimum temperature by T_o , source temperature T_s , multiplier M and plant capacity $I(W)$, then

$$I = \begin{cases} M(T_s - T_o) & \text{for heating} \\ M(T_o - T_s) & \text{for cooling} \end{cases} \quad (13)$$

Thus if $M = 1000$, the plant capacity (kW) is given by $(T_s - T_o)$ for heating and $(T_o - T_s)$ for cooling.

The thermostat cards are the last of the combination cards for the given zone. The 204 cards follow the 203 card for each of paths 22, 23 and 24. The path number on the 204 card is the same as that on the previous 203 card and the card number continues from the previous 203 card. The program checks identity, name of building or zone, path number, card number and that there are no more than two heating and one cooling paths.

3.3.7 End of Combinations (205) Card

Card Columns	Contents	Format
1 - 3	Identity (value 205)	I3
4 - 80	Blank	77X

3.3.8 Miscellaneous (206/207) Cards

Card Columns	Contents	Format
1 - 3	Identity (value 206)	I3
4 - 11	Blank	8X
12	NOREPT (see below)	I1
13 - 16	Initial temperature of system	F4.0
17 - 22	Day and month of first day of calculation	2I3
23 - 37	Latitude, longitude and standard longitude of location	3F5.0
38 - 40	Bearing of "northernmost" wall in degrees	F3.0

Card Columns	Contents	Format
41 - 43	Roof solar absorptance	F3.0
44 - 55	N,E,S,W wall solar abosrptances	4F3.0
56 - 67	N,E,S,W, window shanding coefficients	4F3.0
68 - 79	N,E,S,W, window horizontal sunbreak ratings (%)	4F3.0
80	JPLOT (see below)	I1
1 - 3	Identity (value 207)	I3
4 - 6	Low temperature emittance of roof	F3.0
7 - 18	Low temperature emittance of N,E,S,W walls	4F3.0
19 - 80	Blank	62X

If the variable NOREPT = 0, day 1 is repeated 10 times for each zone before actual calculations commence. If NOREPT = 1, day 1 is not repeated.

The variable JPLOT signals plotting requirements as follows:

JPLOT = 0 or blank	No plotting
JPLOT = 1	Plot on new set of axes
JPLOT = 2	Plot on same set of axes as previous plot(s)

Latitude conventions to be observed are:

- Latitude North positive, South negative
- Longitude East positive, West negative

Note that solar absorptances, low temperature emittances, window shading coefficients and horizontal sunbreak ratings are unable to be varied between zones.

3.3.9 Climatic data (208) Cards

There are two options:

- (i) Data from magnetic tape or permanent file.

Card Columns	Contents	Format
1 - 3	Identity (value 208)	I3
4 - 7	MODE (value 4HTAPE)	A4
8	IPRINT	I1
9 - 80	Blank	72X

When MODE = 4HTAPE, weather data normally read from succeeding 208 cards are read from file TAPE10 instead of from cards. The data format required on TAPE10 is different from the format used when the data are read from cards, and is JYEAR (I2 format), JMONTH (I2 format), JDAY (I2 format), NCARD (I2 format), data as on cols 9 - 80 of the 208 cards (I2F6 format) as described in (ii) below.

An end-of-file (EOF) is required on TAPE10 at the end of each month, and a double EOF at the end of all the weather data (even if < 1 month). The calculation proceeds until this double EOF is encountered. These data may be set up on file from standard climatic data tapes, using a program called STEPDAT.

If IPRINT = 1 the data read from TAPE10 and the resultant drivers are listed on the output file, otherwise not.

(ii) Data from punched cards.

Card Columns	Contents	Format
1 - 3	Identity (value 208)	I3
4 - 6	Day number	I3
7 - 8	Card number	I2
9 - 80	Data as detailed below	12F6.0

For each day each pair of 208 cards contains the following data for hours 1 to 24.

Cards Nos 1 and 2 shade air temperature in °C

" "	3 and 4	direct solar irradiance on a surface normal to the solar beam in W/m ²
" "	5 and 6	diffuse solar irradiance on a horizontal surface in W/m ²
" "	7 and 8	outdoor film resistance in m ² .K/W
" "	9 and 10	total cloud amount in oktas
" "	11 and 12	drivers or heat flows for path 15
" "	13 and 14	" " " " " " 16
" "	15 and 16	" " " " " " 17
" "	17 and 18	" " " " " " 18
" "	19 and 20	" " " " " " 19
" "	21 and 22	" " " " " " 20
" "	23 and 24	" " " " " " 21

The program calculates sol-air temperatures and heat flows and allots them as drivers for the various paths.

The card numbers should run from 1 to 24 within each day, representing the 24 hours. This convention is maintained even if F (200 card) is not unity, and temperatures are for other than hourly. The program checks the order of days and the order of card numbers.

3.3.10 End of All Data (222) Card

Card Columns	Contents	Format
1 - 3	Identity (value 222)	I3
4 - 80	Blank	77X

This instructs the program to proceed with the calculation.

4. OPERATION

4.1 Usage

The program generally exists in both un-compiled and pre-compiled forms on file. Therefore batch input of the program itself is unnecessary and is certainly to be discouraged since ZSTEP source contains about 2100 cards. Batch input of data is possible. Again, however, data can be placed on file and modified as required at CSIRONET terminals. Climatic data are available on file and for lengthy calculations (e.g. 8760 hours) this is clearly the only option. There is no fully interactive mode of the program.

Once data have been prepared and checked, fairly minimal skills are required to run a calculation. Clearly some familiarity with the computer editing system is necessary.

4.2 Costs

The cost C(\$) involved in executing a six-zone job of the type outlined in Appendix B on priority 1000 on CSIRONET obeys fairly well the following relationship

$$C = 0.82 + 0.63 m + 0.13z + 0.38mz \quad (14)$$

where m is the number of months in the calculation and z is the number of zones for which calculations are required (\equiv NZ2 as specified on the 202 Card). Thus if m = 12 and z = 6, cost is about \$36.50; if m = 12 and z = 1, cost is about \$13.

The costs involved in running on different priorities on CSIRONET are related to priority 1000 costs as follows:

$$C(P0001) = 0.19 C(P1000) + 0.16$$

$$C(P2000) = 1.25 C(P1000) - 0.05 \quad (15)$$

Thus using priority 0001, and taking the penalty of overnight turnaround, the cost quoted above with m = 12 and z = 1 is \$2.60.

Execution time E(secs) obeys a relationship similar in nature to (14), viz

$$E = 0.27 + 0.495m + 0.16z + 0.39mz \quad (16)$$

Thus if m = 12 and z = 6, execution time is about 35.5 secs. If m = 12 and z = 1, execution time is about 11.1 secs. Compilation time is about 4.5 secs.

For a building with the number of zones differing from 6, approximate costs and times may be obtained by multiplying the results from (14) and (16) by the ratio (number of zones/6).

The costs quoted here relate to use by CSIRO users of the Organization's Cyber 76 in Canberra, and are valid at the time of writing.

5. OUTPUT

5.1 Form and Options

The printed output consists of information in two forms, firstly regarding each heat flow path for every zone (e.g. response factors) and secondly the required results (internal temperatures, load totals, peak loads).

Building input data (though not climatic) are *always* printed. Regarding the first form, options are available through the NP parameter on the 199 card to print response factors, calculated climatic drivers and the frequency response for each path. Included in the last of these options are the admittance and transfer parameters at 18 different frequencies covering the range of interest in building heat transfer problems. Regarding the second form, summary information for each month and for the total period of the calculation is *always* printed. This consists of means and mean diurnal ranges of external temperature and for the internal temperatures of each zone required, as well as mean load totals (MJ) and peak load (kW) for the relevant zones. There is a second option through the NTYPE parameter on the 199 card which enables hour-by-hour temperatures and loads to be printed.

An example of the program output is contained in Appendix C of both the external temperature and the internal temperature of required zones.

There is a *non-printed* output option available through the NTYPE parameter on the 199 card in which hour-by-hour loads or temperatures may be outputted to file and subsequently analyzed as desired. Various programs are available for this analysis – in particular for providing a frequency distribution of calculated loads or temperatures.

There is a temperature plotting output option available through the JPLOT parameter on the 206 card.

6. APPLICATIONS

6.1 Evaluations

A comparison of temperatures predicted using program CARE with measured temperatures in a model building has been carried out by Muncey and Holden (1967). It was concluded that "diurnal ranges of internal temperature were often 60° F, and discrepancies in the comparison were of the order of 1° F or less; this error is satisfactorily small and suggests that this method and others adopting comparable assumptions can reasonably be used in thermal calculations for buildings".

6.2 Applications to Date

The program has thus far been applied to the passive design of a low-energy-consuming house which has been built at Highett. The related programs CARE, STEP and SUSTEP have been used in many design studies, for example see Gupta & Spencer (1970), Ballantyne and Spencer (1972), Spencer and Anson (1973), Scanes (1974), Ballantyne (1975), Walsh (1976, 1977).

The program has its greatest application as a thermal design tool for planned buildings.

6.3 Planned Developments

Further developments underway relate to

- enabling the program to better account for variable thermal networks, e.g. variable ventilation rates, opening and closing of blinds, etc;
- incorporation of items of plant into the program thus enabling energy consumption (as opposed to theoretical load requirements) to be calculated;
- increasing the ease with which design variations may be evaluated;
- calculation of latent loads;
- improvement in modelling of inter-zonal heat transfer, particularly that due to air movement.

7. REFERENCES

American Society of Heating, Refrigerating and Air Conditioning Engineers (1977). 'Handbook of Fundamentals'.

Australian Institute of Refrigeration, Air Conditioning and Heating (1978). 'Design Data Manual', Ch. 3-Thermal Properties.

Ballantyne, E.R. (1975). Energy costs of dwellings. *Thermal Insulation* 1(1), 7-14.

Ballantyne, E.R. and Spencer, J.W. (1969). Solar radiation incident on building surfaces and solar heat gains through windows. *Proc. Symp. on Environmental Physics as Applied to Buildings*, Vol. II, CBRI, Roorkee, India.

Ballantyne, E.R. and Spencer, J.W. (1972). Climate and comfort in a humid tropical area. *Build Int.* 5(4) 214-219.

Gupta, C.L. and Spencer, J.W. (1970). Building design for optimum thermal performance. *Aust. Refrig. Air Cond. Heat.* 24(11), 18-25.

Hoglund, B.I., Mitalas, G.P. and Stephenson, D.G. (1967). Surface temperatures and heat fluxes for flat roofs. *Build. Sci.* 2, 29-36.

Muncey, R.W. (1953). The calculation of temperatures inside buildings having variable external conditions. *Aust. J. Appl. Sci.* 4, 189-196.

Muncey, R.W. (1963). The thermal response of a building to sudden changes of temperature or heat flow. *Aust. J. Appl. Sci.* 14, 123-128.

Muncey, R.W. and Holden, T.S. (1967). The calculation of internal temperatures - a demonstration experiment. *Build. Sci.* 2, 191-196.

Muncey, R.W. and Spencer, J.W. (1966). Calculation of non-steady heat flow: considerations of radiation within the room. *J. Inst. Heat Vent. Eng.* 34, 35-38.

Muncey, R.W. and Spencer, J.W. (1969). Calculations of temperatures in buildings by the matrix method: some particular cases. *Build. Sci.* 3, 227-229.

Muncey, R.W., Spencer, J.W. and Gupta, C.L. (1970). Method for thermal calculations using total building responses factors. *Proc. Conf. on Use of Computers for Environmental Engineering Related to Buildings*, NBS Build. Sci. Series, No. 39, 111-116.

Scanes, P.S. (1974). Climatic design data for use in thermal calculations for buildings - estimated clear sky solar radiation versus measured solar radiation. *Build. Sci.* 9(3), 219-225.

Spencer, J.W. (1965). Calculation of solar position for building purposes. CSIRO, DBR Tech. Paper No. 14.

Spencer, J.W. and Anson, M. (1973). The effect of building design variations on air conditioning loads. *Archit. Sci. Rev.* 16(2), 114-117.

Van Gorcum, A.H. (1950). Theoretical considerations on the conduction of fluctuating heat flow. Appl. Sci. Res. (The Hague) A2, 272-280.

Walsh, P.J. (1976). Climatic variability, climatic change and the thermal performance of buildings. Archit. Sci. Rev. 19(64) 90-98.

Walsh, P.J. (1977). Some aspects of the role of solar radiation in determining dwelling heating and cooling energy requirements. ICHMT International Seminar on Heat Transfer in Buildings, Dubrovnik, August - September 1977.

Walsh, P.J. (1978). Calculation of the thermal behaviour of zoned buildings. In preparation.

APPENDIX A

The following data preparation sheets have been prepared as an aid to layout of data input.

GENERAL DATA SHEET

PROGRAM
ZSTEP (Version 1)

NAME

JOB

DATE

PAGE NO.

Deck Layout - Sheet 1

IDENT	N P	NTYPE (1)	NTYPE(2)	NTYPE (3)	NTYPE (4)	Parameters determine form of output											
199		F	XS	YMIN	YMAX	Optional: Climatic data is normally hourly. This can be changed to some other interval F hours by inclusion of '200' card.											
200						See notes for XS, YMIN, YMAX Graph plotting.											
201		see separate sheet 2.															
		NO OF ZONES															
		IN BUILDING	IN LIST	LIST OF ZONE NOS FOR WHICH TEMPS AND/OR LOADS ARE REQUIRED													
202																	
203		see separate sheet 3.															
203		thermostat cards - see separate sheet 4.															
204																	
205		End of combinations card															
		INITIAL SYSTEM	INITIAL	* SOUTH, WEST	-VE	Bearing of STANDARD Northern Wall	ROOF	ABSORPTION WALL	WINDOW SHADING COEFFS'				WINDOW HORIZONTAL SUNBREAK RATINGS (%)				
		TEMP.	DAY	MONTH	LATITUDE	LONGITUDE	LONGITUDE	N	E	S	W	N	E	S	W		
206		LOW	TEMPERATURE	EMITTANCE	WALLS												
		ROOF	N	E	S	W											
207																	
208	TAPE	Thermal data - either from file TAPE 10 (as shown here) or from cards (see separate sheet 5). See notes if data to be printed.															
222		Proceed with calculation.															

APPENDIX B

The following is an example of the layout of data input cards. It is a conventional three-bedroom detached dwelling (Figure 2) which for thermal calculation purposes has been subdivided into six zones (Figure 3) in each of which the temperature is assumed constant. The zones are the living area, combined bedroom area, passage, service area, roofspace and the junction point between the floor (concrete slab-on-ground) and the ground.

We seek to calculate hourly thermal performance in zones 1 (living area) and 2 (bedroom area). Zone 1 is to be heated by a 50 kW plant with thermostat set to 20°C between hours 0700 and 2200 inclusive for each day of the calculation, with a 1°C thermostat differential. Climatic data comes from file and begins on 1 June. The location is Melbourne (latitude 38° S, longitude 145° E) and the length of the calculation is three months, though this is not obvious from the input data. Summary information only at the end of each month of the calculation period is required. The layout of input data shown here is, in fact, the listing supplied as part of the output.

203BEDROOMS281 207 4.1 11
 203BEDROOMS291 204 36.9 11
 203BEDROOMS301 500 36.9 11
 203 PASSAGE 01 100 7.5 400 16.8 103 1.0 300 2.4 107 67.6 109 7.1 104 16.8 3
 203 PASSAGE 02 22 34.7 11
 203 PASSAGE 11 21 15.2 11
 203 PASSAGE 31 200 1.2 209 2.2 11
 203 PASSAGE 61 200 6.1 11
 203 PASSAGE 71 600 1.0 11
 203 PASSAGE111 203 1.0 11
 203 PASSAGE171 31 1 11
 203 PASSAGE251 207 29.6 209 4.9 21 21.6 11
 203 PASSAGE261 207 28.9 11
 203 PASSAGE281 207 9.1 11
 203 PASSAGE291 204 16.8 11
 203 PASSAGE301 500 16.8 11
 203 SERVICE 01 100 15.7 103 0.6 109 2.9 104 10.4 400 10.4 107 18.6 500 15.0 4
 203 SERVICE 02 22 8.17 11
 203 SERVICE 11 21 8.17 11
 203 SFRVICE 41 200 9.1 209 2.9 11
 203 SERVICE 51 200 6.6 11
 203 SERVICE 81 600 0.6 11
 203 SERVICE121 203 0.6 11
 203 SERVICE181 31 1 11
 203 SERVICE251 207 5.4 11
 203 SERVICE261 207 4.1 11
 203 SERVICE271 207 9.1 11
 203 SFRVICE291 204 10.4 11
 203 SFRVICE301 500 10.4 11
 203 ROOFSP 01 102102.2 114102.2 22 24.3 11 5
 203 ROOFSP 11 21 24.3 11
 203 ROOFSP 21 202102.2 11
 203 ROOFSP 251 214 38.1 11
 203 ROOFSP 261 214 36.9 11
 203 ROOFSP 271 214 16.8 11
 203 ROOFSP 281 214 10.4 11
 203 GROUND 01 410 64.1 411 38.1 108102.2 118102.2 11 6
 203 GROUND 11 208102.2 218102.2 11
 203 GROUND 71 610 1.0 611 12.1 11
 203 GROUND 81 610 0.6 11
 203 GROUND 91 610 8.1 11
 203 GROUND 251 511 38.1 11
 203 GROUND 261 510 36.9 11
 203 GROUND 271 510 16.8 11
 203 GROUND 281 510 10.4 11
 205
 206 20 1 6-38.0145.0150.0 0 .8 .8 .8 .8 .8 .9 .9 .9 .9 40 0 20 0
 207 .9 .9 .9 .9 .9
 208TAPE
 222

APPENDIX C

The following gives the output pertaining to the example of Appendix B.

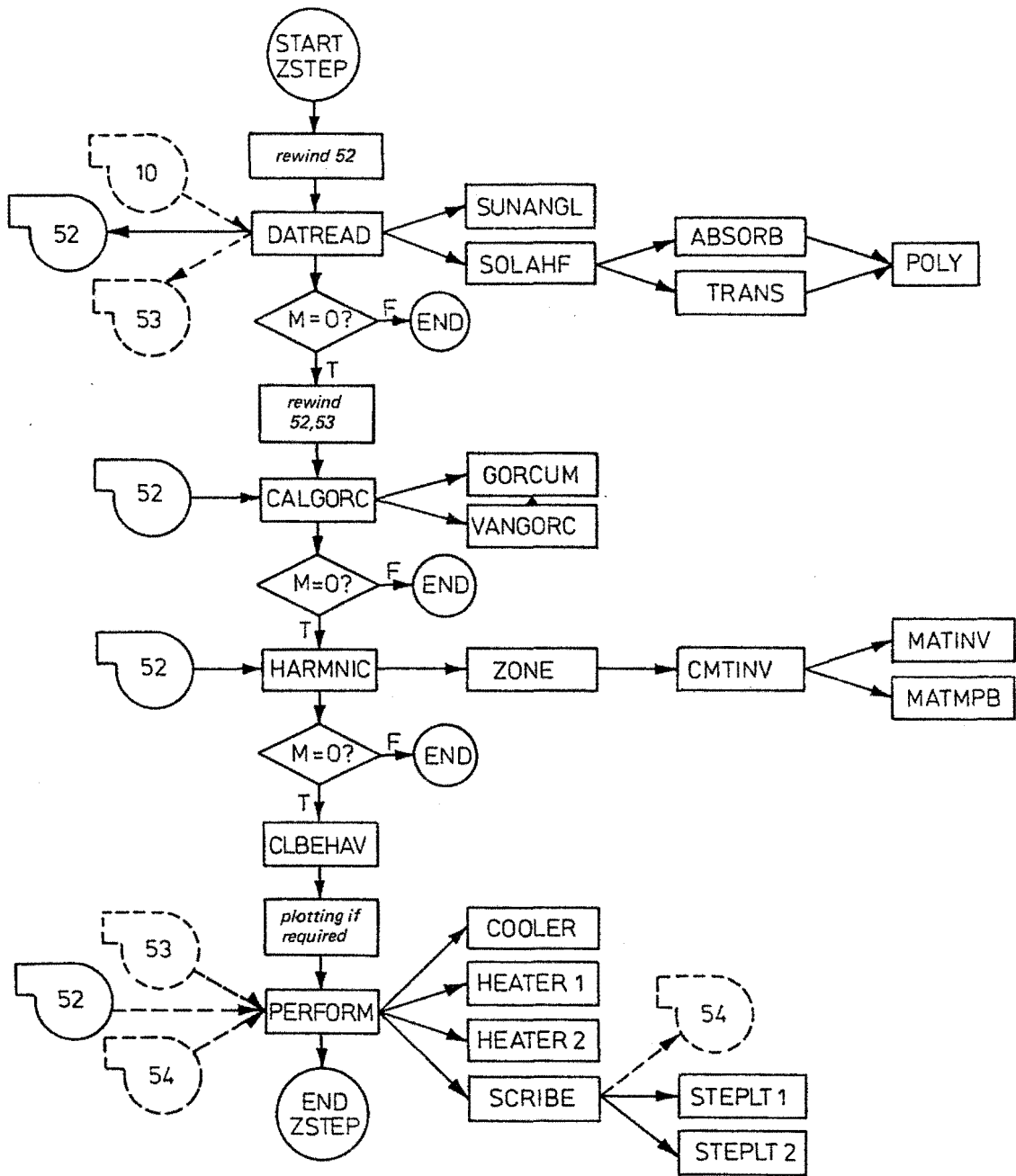


Figure 1 Logical structure for ZSTEP.

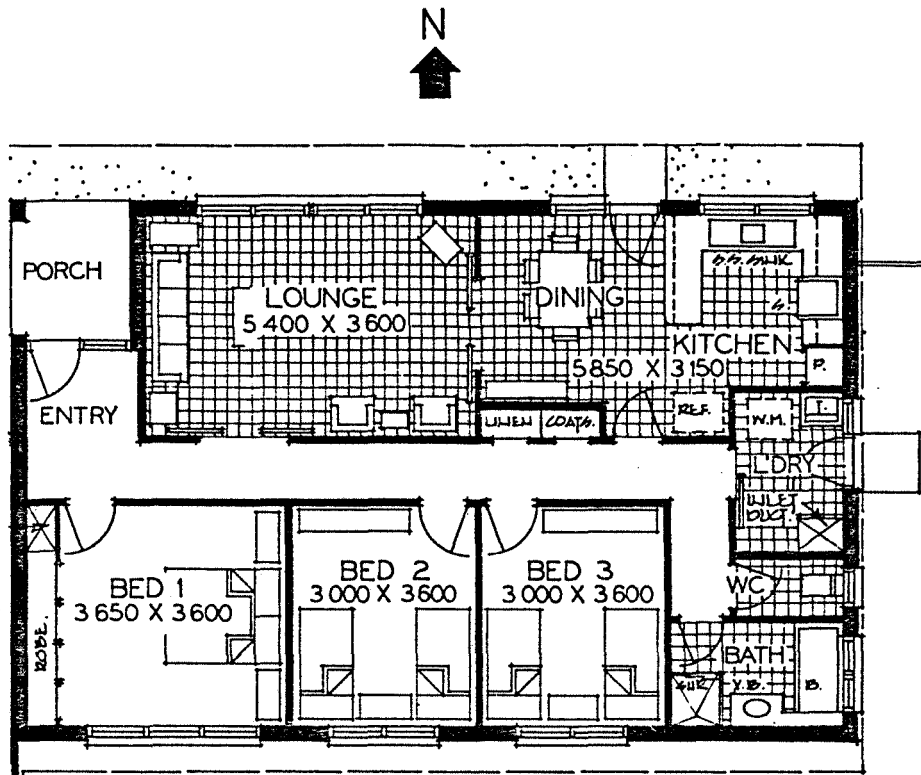


Figure 2 Plan of the dwelling used for the example contained in Appendix B.

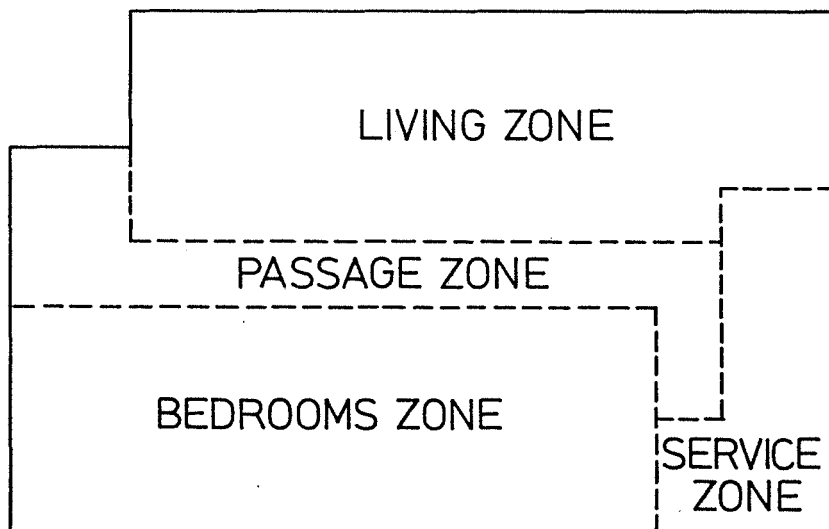


Figure 3 Subdivision into zones of the dwelling shown in Figure 2. The roofspace and ground zones are not indicated here.