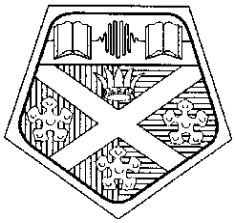

University of Strathclyde

Energy Systems Research Unit

Data Model Summary
ESP-r
Version 9 Series

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ESRU Report

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Table of Contents

0 Introduction
1 General format of data files
2 Zone geometry file
3 Zone construction file
4 Zone operation file
5 Zone utilities file
5.1 Zone shading/insolation file
5.2 Zone blind/shutter control file
5.3 Zone view factor file
5.4 Zone air flow file
5.5 Zone casual gain file
5.6 Zone convection-calculation control file
5.7 Zone transparent multi-layered constructions file
5.8 Zone casual gain control file
5.9 Zone CFD domain file
6 Fluid mass flow network description file
7 Pressure coefficients file
8 System configuration file
9 Configuration control file
10 Site obstructions file
11 Operation of *esp-r*
12 Adaptive gridding

Appendix Representative data for building energy analysis

As of ESP-r Version 8 Series the original user-unfriendly input data management program *imp* has been replaced by the generalised project manager *esp-r*. This new module offers a more coherent and user-friendly interface by hiding much of the file structure which underlies the use of ESP-r and giving on-line help and data definitions.
It is important to realise however that advanced use of ESP-r will require a working knowledge of its data structures and inherent relationships. Hence the need for this document. Note however that because of the pace of change of ESP-r, the file content definitions which follow may not correspond exactly with the version of ESP-r you are using. In cases of doubt, the information given by the project manager should be assumed correct.

0 Introduction

Prior to commencing data preparation, the target building (or building portion) and/or plant (or plant portion) must be subdivided into a number of discrete zones and plant components. This should be done in a manner which will accommodate the various issues to be examined. For example, a space within a building, represented as one zone, will allow an assessment of average energy states and comfort levels; it cannot provide information on temperature stratification or the enhanced loss of heat due to localised heating near the ceiling. This would require (at least) a two zone space representation scheme. The standard version of ESP-r allows the simultaneous processing of up to 50 building zones and up to 100 plant components. Each zone is considered as a volume of fluid (usually air) bounded by up to 25 polygonal surfaces of transparent, opaque or fictitious (not existing) composition; while plant components are considered as a number of fluid and solid regions in intimate contact. In both cases (zones and components), a number of differential equations will be active within *bps* to describe sub-region energy balance. The data required by *bps*, and described in this section in relation to the operation of *esp-r*, is required to establish and then integrate these differential equations. The theory underlying *bps*'s operation is reported in section 5.

It is possible to process configurations which exceed the upper limit in terms of zones, plant components or both. In this case a new version of *esp-r*, *bps* and *res* must be created by changing a 'parameter' statement in the appropriate Fortran 'include' file and then re-creating the object files.

Having established the desired building zoning strategy, the following 10 files (3 mandatory, 7 optional) can be created for each zone via the facilities of *esp-r* (see sub-section 4.2).

Mandatory: *geometry, construction and operation.*

Optional: *utilities, shading/insolation, blind/shutter control, view factor, air flow, casual gains, convection coefficients* and *transparent multi-layered constructions.*

The mandatory files contain the minimum descriptive information required for simulation purposes (that is, differential equation coefficient generation). This includes zone geometry, window and door locations and dimensions, default insolation schemes, construction (walls, ceilings, floors, windows and doors) thermophysical properties, surface finishes, casual gains, and default infiltration and zone coupled air flows. The zone utilities file holds a number of flags which exist to indicate whether or not one of the other optional zone files will exist. If it does, then its contents will supersede any corresponding default scheme held in a mandatory file. To summarise the data utilisation protocol:

- If a zone shading/insolation file does not exist, then the default insolation data of the zone geometry file is used with external shading set to zero. If the file does exist, then the time-series shading and/or insolation data held therein will be used in preference to the default. Of course, the default is only replaced if the data of the shading/insolation file is valid for the simulation period and surface

(shading) or window/surface (insolation) being considered. *Ish* can be used to create the shading/insolation file or, alternatively, data acquired from elsewhere (eg a monitoring scheme) can be inserted in the file via the facility of *esp-r*.

- If a zone blind/shutter control file does not exist, then zone windows are given the thermophysical and optical properties assigned to them in the zone constructions file. If this file does exist, then, during some defined period of time, or above some stated solar intensity level, given replacement properties are assumed. This allows window insulation or solar control devices to operate as a function of time and/or solar intensity. A blind/shutter control file can only be created via *esp-r*.
- If a zone convection coefficients file does not exist, then *bps* will assume buoyancy driven (or natural) convection at internal opaque and transparent surfaces and compute heat transfer coefficients from empirical equations derived from experimental data correlations. The corresponding external surface values are determined as a function of wind speed and direction and again use empirical correlations. When a convection coefficients file exists these computed convective heat transfer coefficients can be replaced, at any time within a simulation, by fixed user-specified values. The file is created via *esp-r*.
- If a zone view factor file does not exist, then simplified view factor assessment techniques are utilised by *bps* at run time. This is probably adequate for many simulation exercises. Should greater accuracy be desired, a view factor file can be created by *mrt* or by *esp-r* using data acquired from some other source.
- If a zone air flow file does not exist, then the default air flow profiles of the operations file, defining infiltration and zone-coupled air flow with potential thermostatic constraints superimposed, will be used. Alternatively, a time-series air flow file can be created via *mfs* (by prediction) or *esp-r* (if actual data is to hand). The contents of this file is then used in preference to the default profiles. Note that *bps* will override both mechanisms if a leakage and pressure distribution description is supplied to enable simultaneous heat and mass flow calculations. In any event, thermostatic constraints, as defined in a zone's operations file, will be applied so that prescribed or predicted air flow may be modified as a function of building temperatures or ambient conditions.
- If a zone casual gain file does not exist, then the casual gain profiles of the operations file are used. If such a file does exist then the time-series data supplied is used in addition to the operations file entries.
- If a transparent multi-layered constructions file does not exist then the simulation will proceed with all constructions assumed opaque. If a file does exist then the flagged constructions will be assumed transparent so that capacity and short- and long-wave effects will be modelled explicitly.

At any time after completion of the mandatory file set for all zones, the system configuration file is created. This, and the configuration control file, are the only files passed to *bps* at simulation time. Four other files can be constructed by *esp-r*: the configuration leakage distribution file defines the air flow leakage paths; the pressure coefficients file holds a number of coefficient sets which can be referenced by the previous file; the site obstructions file contains the geometry of site obstructions as required by *ish*; and the perspective display file contains the input geometry required by a separate perspective program. All data, as input, is validated before being output to disk file. In addition, *esp-r* offers area, volume and surface orientation checking as well as file editing and listing. On entering *esp-r*, the first action is usually to define the ESP-r databases for use in specifying the problem for simulation. This allows the event profiles database, both constructions databases and the windows database to be assigned for access during zone construction and operation file creation. Zone profiles, constructions and windows can then be defined by simple code number reference.

The required input data structures are detailed in the sub-sections that follow. Disk file formats are also given although this knowledge is not required by an *esp-r* user since formatting is automatic.

NB. During data preparation it is important to sensibly simplify the problem in hand since end results are often, paradoxically perhaps, only weakly related to the effort expended on setting up a configuration description. As a simple rule, a moderately experienced user should attempt to achieve the creation of the mandatory zone file-set within about 30 minutes/zone: but the data must be representative and be accurately entered (rubbish in, rubbish out!). Some simplification ideas include: zone combination to reduce the total number of zones for processing; considering zones as rectilinear if they deviate only slightly or if the

boundary conditions are simple (for example temperature only with negligible shortwave radiation effects); the concatenation of several windows in the same facade into a single window of equivalent area (of course this is not possible if detailed shading/insolation treatment is required); omitting vapour barriers in summer overhearing assessment applications; omitting doors completely when judged to have negligible impact; simplifying casual gain and air flow profiles to eliminate complexity whilst retaining underlying trends; and so on. The acceptability of such simplifications will depend entirely on the problem in hand, in terms of the accuracy expectations and the range of performance measures required from the simulation.

It should also be noted that ESP-r treats doors in a simplified manner as pure resistances with no associated storage. Thus in a problem where doors form a significant proportion of the surface, they should be modelled more rigorously as multilayered constructions.

1 General format of data files

File formatting is handled automatically by *esp-r* and, with the exception of the shading/insolation file (binary random access), all *esp-r* produced files are ASCII, sequential files written in free format. This allows entries to be placed without regard to exact positions on the line and separated by a comma or spaces. For example *2.3,6.7,9.11,1.5* or *2.3 6.7 9.11 1.5*.

All data in ESP-r are expressed in *SI* units with the exception of air change rates which are expressed in volume changes per hour (hr^{-1}).

2 Zone geometry file (mandatory)

There are basically three mechanisms for defining zone geometry. The first involves the creation, graphically, of primitive polygons or volumes which can then be stored for later concatenation to form the required shape. The second involves plan digitizing, with extrusion to obtain the third dimension. And the last involves the definition of body topography and topology by specifying vertex coordinates and giving an ordered list of the vertex numbers comprising each body polygon. The last mechanism is the one offered by *esp-r*, whilst the first two are offered as free-standing programs outside ESP-r.

esp-r allows three levels of geometry data input: corresponding to rectangular (*REC*), regular (*REG*) and general (*GEN*) shaped zones as follows

REC Each of the 4 zone walls are rectangular, vertical and of equal height. The ceiling and floors are rectangular, horizontal and of equal area.

An arbitrary site cartesian coordinate system is located so that the x-axis points east, the y-axis north and the z-axis vertically up. The x, y and z coordinates of the bottom left-hand corner (when viewed from the south) are specified, along with the length, DX, from the previous point along the easternmost pointing side, width, DY, and internal floor to ceiling height, DZ. Note that this definition allows the 'length' side to be less than the 'width' side. The orientation angle, DA, is also required. This is the angle measured from due east (the x-axis) to the 'length' side, where anticlockwise is positive. Figure 1 summarises the input requirements for this zone type.

REG Each of the zone walls are rectangular, vertical and of equal height. Ceiling and floors are horizontal polygons.

An arbitrary site cartesian coordinate system is located so that the x-axis points in any convenient direction but with the x-y plane horizontal. The following quantities are then specified: the number of vertical walls bounding the zone, the internal floor finish height (relative to the x-y plane), the internal ceiling surface height and the x and y coordinates of each zone corner vertex, commencing at any vertex and proceeding anticlockwise when viewed from above. The angle between the y-axis and north (anticlockwise positive) is also required to permit surface orientation determination. Figure 2 summarises the input requirements for this zone type.

GEN Any polyhedral zone bounded by planar polygons.

An arbitrary site cartesian coordinate system is located so that the x-axis points in any convenient direction but with the x-y plane horizontal. Relative to this is specified the total number of vertices comprising the zone, the total number of bounding surfaces, the x, y and z coordinates of each vertex (in any convenient order), the number of vertices comprising each surface and their anticlockwise order when viewed from outside the zone. The angle between the y-axis and north (anticlockwise positive) is then given to allow surface orientation computation.

Figure 3 summarises the input requirements for the *GEN* zone type.

To ease the input burden, it is desirable to simplify zone geometry as far as is allowed by the simulation objectives. For the same reason, it is also possible to change coordinate systems between zones, specifying each zone relative to a local coordinate system as though the other zones did not exist. For example, by considering all zones as type REC and located at the origin of a single coordinate system, the time required to specify zone geometry is reduced to less than a minute per zone. However, if this option is taken, it is then not possible to conduct a shading analysis, or to produce perspective views if required, since no information is available on relative position.

Zone window and door geometry is described relative to a local $x' - z'$ coordinate system located in the plane of the surface to which the window or door is attached. The x', z', DX' (width) and DZ' (height) dimensions (as shown in figures 1 through 3) are required for windows and the x', DX' and DZ' dimensions for doors. With a REC zone, the origin of this local coordinate system is situated at the bottom left-hand corner of each vertical wall (when viewed from outside the zone), the x'-axis extends along the length of the wall and in its plane, and the z'-axis is at right angles extending along the height. For the horizontal ceiling and floor, the $x' - z'$ coordinate system origin is located at the zone origin x, y and z coordinate with the x'-axis extending towards the next face vertex located anticlockwise when viewed from above (ceiling) or below (floor). With REG zones, the origin or wall coordinate systems are located as with type REC. For

the horizontal ceiling and floor, the origin is located at the x and y coordinate of the first defined wall corner in the REG specification, with the axes extending as with a REC. With GEN zones, the origin of *each* surface local coordinate system is located at the first vertex (in the ordered face list), with the x'-axis extending coplanar with the face and passing through the second vertex. The z'-axis is then placed at right angles to the x'-axis and pointing in the direction of the third vertex.

The following table lists the contents of each record as held within the zone geometry file (normally called ?.geo).

Table 1 The contents of a zone *geometry* file.

Record	Description of fields
1	Zone shape type (*REC*, *REG* or *GEN*)
2 for *REC*	x,y & z coordinate of bottom left-hand corner, length, width, height and angle of orientation.
2/1 for *REG*	Number of vertical walls, floor height, ceiling height and axes rotation angle.
2/2 for *REG*	x & y coordinates of each base corner vertex in anticlockwise order when viewed from above.
2/1 for *GEN*	Total number of vertices comprising zone, number of bounding surfaces and axes rotation angle.
2/2 for *GEN*	x,y & z coordinates of each vertex in any convenient order.
2/3 for *GEN*	For the first surface, the number of vertices and an anticlockwise description of each as seen from outside the zone.
2/4 for *GEN*	Repeat 2/3 for surface 2 .....
2/N for *GEN*	and continue until last surface.
3	Number of windows in each surface.
4/1	For first surface with windows, the x' & z' coordinates of bottom left-hand corner, width and height for each window in turn.
4/2	Repeat for next surface with windows .....
4/?	and continue until last window surface.
5	Number of doors in each surface.
6/1	For first surface with doors, the x' coordinate of bottom left-hand corner, width and height for each door in turn.
6/2	Repeat for next surface with doors .....
6/?	and continue until last door surface.
7	Default insolation scheme: number of internal surfaces to receive direct radiation [1,2 or all(3)], surface 1 number (for 1 or 2 receiving), surface 2 number (for 2 receiving) and surface with windows receiving [0(no surface) or receiving surface 1 or 2].

Table 1 Contents of a zone *geometry* file.

Note the contents of record 7: this contains a default insolation scheme to be used throughout a simulation in the absence of detailed insolation time-series data generated by *ish* and located in the zone shading/insolation file. Firstly, the number of internal zone surfaces which will share (receive) direct solar radiation penetrating zone windows must be defined. To the question, *'Number of insolated surfaces?'*, the following replies are permitted.

1: Means that only one internal surface will receive window transmitted shortwave radiation. For example, if the zone represents a solar collector, the receiving surface would be defined as the collector back plate. There is then no need to utilise *ish*.

2: Means that the incoming radiation will be split between two internal surfaces on the basis of simple area weighting. This is the appropriate choice for most building zones where simultaneous floor and wall insolation often occurs. Note that if more than one wall is insolated then it is necessary to invoke *ish*.

3: Means that the incoming radiation will be apportioned between all internal surfaces; that is, treated diffusely. This is an appropriate option in the case of translucent window coverings or diffusing direct gain devices in a passive solar design.

In the case of one or two insolated planes, their reference numbers are requested and the user is asked whether or not any windows in those surfaces should receive their share of the impinging radiation. If they do, then some of the incoming radiation will be re-transmitted to another zone or back to outside depending on the window's exposure. In the case of diffuse treatment, any windows in an insolated surface will be treated in this way. Note that the insolation data (in default form or as held in the shading/insolation file) merely serves to direct the point of application of the directly transmitted window radiation up to first reflection. The subsequent processing of the reflected flux and the initially transmitted diffuse beam is handled automatically by *bps*. The following table shows some example default insolation set-ups.

Default insolation data	Meaning
1,6,0,0	Default plane is opaque portion of surface 6.
1,6,0,6	Default plane is opaque *and* transparent portions of surface 6.
2,6,3,3	Opaque portion of surfaces 6 and 3 are insolated plus the transparent portion of surface 3.
2,6,3,-1	As last case but with transparent portions of both surfaces (6 and 3) insolated.
2,6,3,0	As last case but with transparent portion excluded.
3,0,0,0	Direct beam treated diffusely so that all internal surfaces are insolated

Table 2 Example default insolation plane definitions.

In specifying zone coordinates all quantities relate to internal dimensions. This forms a wireline skeleton from which internal surface areas, contained volumes and surface orientations can be deduced. The multi-layered constructions of the zone construction file are then superimposed on this skeleton. ESP-r adopts the following surface numbering scheme. This is the mechanism by which surfaces are referenced during problem definition and results recovery.

REC zones have six surfaces numbered as follows: 1 is the first vertical wall, encountered anticlockwise from the origin point; 2, 3 & 4 are the three following vertical walls, anticlockwise from the first; 5 is the horizontal ceiling; and 6 is the horizontal floor.

REG zones have N surfaces numbered as follows: 1 is the first vertical wall, encountered anticlockwise from vertex 1 as defined at input time; 2 to N-2 are the following vertical walls, anticlockwise from the first; N-1 is the horizontal ceiling; and N is the horizontal floor.

GEN zones have N surfaces where the order is defined by the user. It is advisable to adopt the convention that all walls are defined first in anticlockwise (when viewed from above) order commencing at the southernmost facing wall, followed by the ceiling/roof and, lastly, the floor.

In reply to *esp-r*'s promptings a few points should be remembered:

- Zone geometry is defined relative to some arbitrary site cartesian coordinate system. Windows and doors are defined relative to a local coordinate system located in the plane of the surface to which the window or door belongs.
- *The orientation angle of a REC zone defines the zone's orientation relative to east. The rotation angles of the other two shape types are specified relative to north and are there to allow coordinate specification relative to some convenience coordinate system, with subsequent rotations giving final topography*. See above for angle definitions.
- The default insolation data is only used if more detailed time-series insolation data is not made available via *ish*. The availability of such data is indicated by the setting of a corresponding flag in the zone utilities file.

Figures 1 through 3 demonstrate the surface numbering scheme for the three zone shape types and Figure 4 shows an example zone geometry file.

```
# geometry of reception defined in: ../zones/reception.geo
GEN  reception              # type   zone name
      34      14   0.000    # vertices, surfaces, rotation angle
#  X co-ord, Y co-ord, Z co-ord
      1.00000     1.00000     0.00000  # vert  1
      9.00000     1.00000     0.00000  # vert  2
      9.00000     4.50000     0.00000  # vert  3
      9.00000     9.00000     0.00000  # vert  4
      5.00000     9.00000     0.00000  # vert  5
      5.00000     5.00000     0.00000  # vert  6
      1.00000     5.00000     0.00000  # vert  7
      1.00000     1.00000     3.00000  # vert  8
      9.00000     1.00000     3.00000  # vert  9
      9.00000     4.50000     3.00000  # vert 10
      9.00000     9.00000     3.00000  # vert 11
      5.00000     9.00000     3.00000  # vert 12
      5.00000     5.00000     3.00000  # vert 13
      1.00000     5.00000     3.00000  # vert 14
      2.00000     1.00000     1.00000  # vert 15
      8.00000     1.00000     1.00000  # vert 16
      8.00000     1.00000     2.25000  # vert 17
      2.00000     1.00000     2.25000  # vert 18
      9.00000     5.00000     0.00000  # vert 19
      9.00000     6.00000     0.00000  # vert 20
      9.00000     6.00000     2.50000  # vert 21
      9.00000     5.00000     2.50000  # vert 22
      5.00000     7.00000     0.00000  # vert 23
      5.00000     6.00000     0.00000  # vert 24
      5.00000     6.00000     2.50000  # vert 25
      5.00000     7.00000     2.50000  # vert 26
      1.00000     3.00000     0.00000  # vert 27
      1.00000     2.00000     0.00000  # vert 28
      1.00000     2.00000     2.50000  # vert 29
      1.00000     3.00000     2.50000  # vert 30
      9.00000     2.00000     1.00000  # vert 31
      9.00000     4.00000     1.00000  # vert 32
      9.00000     4.00000     2.25000  # vert 33
      9.00000     2.00000     2.25000  # vert 34
# no of vertices followed by list of associated vert
  10,  1,  2,  9,  8,  1, 15, 18, 17, 16, 15,
  10,  2,  3, 10,  9,  2, 31, 34, 33, 32, 31,
   8,  3, 19, 22, 21, 20,  4, 11, 10,
   4,  4,  5, 12, 11,
   8,  5, 23, 26, 25, 24,  6, 13, 12,
   4,  6,  7, 14, 13,
   8,  7, 27, 30, 29, 28,  1,  8, 14,
   7,  8,  9, 10, 11, 12, 13, 14,
  13,  1, 28, 27,  7,  6, 24, 23,  5,  4, 20, 19,  3,  2,
   4, 15, 16, 17, 18,
   4, 19, 20, 21, 22,
   4, 23, 24, 25, 26,
   4, 27, 28, 29, 30,
   4, 31, 32, 33, 34,
# number of default windows within each surface
   0  0  0  0  0  0  0  0  0  0  0  0  0  0
# surfaces indentation (m)
 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
    3   0   0   0    # default insolation distribution
# surface attributes follow:
# id  surface      geom  loc/  mlc db       environment
# no  name         type  posn  name         other side
  1, south         OPAQ  VERT  extern_wall  EXTERIOR
  2, east          OPAQ  VERT  extern_wall  EXTERIOR
  3, passage       OPAQ  VERT  gyp_blk_ptn  SIMILAR
  4, north         OPAQ  VERT  extern_wall  EXTERIOR
  5, part_a        OPAQ  VERT  extern_wall  EXTERIOR
  6, part_b        OPAQ  VERT  extern_wall  EXTERIOR
  7, west          OPAQ  VERT  extern_wall  EXTERIOR
  8, ceiling       OPAQ  CEIL  roof_1       EXTERIOR
  9, floor        OPAQ  FLOR  floor_1      CONSTANT
 10, glz_s         TRAN  VERT  dbl_glz      EXTERIOR
 11, door_p        OPAQ  VERT  door         EXTERIOR
 12, door_a        OPAQ  VERT  door         EXTERIOR
 13, door_w        OPAQ  VERT  door         EXTERIOR
 14, east_glz      TRAN  VERT  dbl_glz      EXTERIOR
```

Figure 4 Example zone *geometry* file listing.

3 Zone construction file (mandatory)

The following table lists the contents of a zone construction file (usually held as ?.con).

Record	Description of fields
1/1 →	For each surface in turn, the construction is defined in terms of the total number of homogeneous elements (including air gaps) and, separately, the number of air gaps.
1/N	Repeating 1/1 for each surface in turn.
2/1 →	The position (an integer count from outside) and overall thermal resistance of each air gap in first construction with air gaps.
2/N	Repeating 2/1 for all constructions with air gaps.
3/1 →	For each element in surface 1: conductivity, density, specific heat and thickness; outside to inside order. For air gaps, only thickness is held, all other properties being set to zero.
3/N	Repeat 3/1 for all other constructions.
4/1 →	Window thermophysical properties for each window in turn in first surface with windows. Properties include shortwave direct transmittance and total transmittance for each of 5 angles of incidence. The window U-value is also held.
4/N	Repeat 4/1 for all other surfaces with windows.
5/1 →	Thermal transmittance value (U-value) for each door in first surface with doors.
5/N	Repeat 5/1 for all other surfaces with doors.
6	Internal surface emissivity for each construction, then external surface emissivity.
7	Internal surface solar absorptivity for each construction, then external surface solar absorptivity.

Table 3 Contents of a zone *construction* file.

In use *esp-r* allows pre-defined constructions to be extracted from the multilayered constructions database for re-location in the zone construction file. In this case the number of homogeneous elements and air gaps, their relative positions, the data on thermophysical properties, and the surface finishes are all defined by the typing of a single coded database reference. Specifying a zone's construction is then very simple. It is also possible to mix the database facility with manual input so that some constructions are defined by multilayered database reference, some are built up element-by-element by primitives' database reference, and some are created by inputing the thermophysical properties for each homogeneous element.

In the same manner windows can be specified by giving index values which are coded pointers to a windows database where the incidence angle dependent, spectrally integrated values of solar transmittance, absorptance and reflectance are held, along with standard U-values.

In reply to *esp-r*'s prompting, a few points should be remembered:

- All units are S.I. which means that construction thicknesses are given in metres.
- Each data item has a corresponding default value as detailed in the on-line tutorial, which also describes the use of this facility.
- The total number of homogeneous elements comprising a construction includes any air gaps. Note that the number of air gaps is then specified separately.

- Air gap thermal resistances are combined convective/radiative values and will represent cavity conditions. The appendix gives some typical design values.
- When entering construction thermophysical properties directly at the terminal - that is, neither constructions' database is being used - the appropriate entry for an air gap is 0,0,0,x ; where x is the air gap thickness.
- The window indices are simply pointers to the windows' database managed by *win*. *esp-r* will access this database to recover, for each window type, the required thermophysical properties.
- Surface emissivity and solar absorptivity values are spectrally integrated and, in the case of absorptivity, are assumed to be independent of incidence angle.

During zone construction file creation it is normal to refer to the primitive and composite constructions' databases. The former database is named constr.db1 and the latter will have a name assigned by the user at the time of its creation. A windows' database can also be accessed. This is named window.db1. These databases must be assigned via the 0DEFDB command of the main *esp-r* menu prior to commencing zone construction file creation or editing.

Figure 5 shows an example listing of a zone *constructions* file.

```
# thermophysical properties of reception defined in ../zones/reception.con
# no of |air |surface(from geo)| multilayer construction
# layers|gaps|  no.  name      | database name
     4,     1  #  1 south       extern_wall
     4,     1  #  2 east        extern_wall
     5,     2  #  3 passage     gyp_blk_ptn
     4,     1  #  4 north       extern_wall
     4,     1  #  5 part_a      extern_wall
     4,     1  #  6 part_b      extern_wall
     4,     1  #  7 west        extern_wall
     4,     1  #  8 ceiling     roof_1
     4,     0  #  9 floor       floor_1
     3,     1  # 10 glz_s       dbl_glz
     1,     0  # 11 door_p      door
     1,     0  # 12 door_a      door
     1,     0  # 13 door_w      door
     3,     1  # 14 east_glz    dbl_glz
# air gap position & resistance for surface  1
  3,   0.170,
# air gap position & resistance for surface  2
  3,   0.170,
# air gap position & resistance for surface  3
  2,   0.170, 4,   0.170,
# air gap position & resistance for surface  4
  3,   0.170,
# air gap position & resistance for surface  5
  3,   0.170,
# air gap position & resistance for surface  6
  3,   0.170,
# air gap position & resistance for surface  7
  3,   0.170,
# air gap position & resistance for surface  8
  3,   0.170,
# air gap position & resistance for surface 10
  2,   0.170,
# air gap position & resistance for surface 14
  2,   0.170,
# conduc-  |  density | specific | thick- |dpnd|  ref. |  temp. |moisture| surf|lyr
# tivity   |          | heat     | ness(m)|type|  temp | factor | factor |     |
    0.9600,    2000.0,     650.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #  1  1
    0.0400,     250.0,     840.0,  0.0750,   0,   0.00, 0.00000, 0.00000  #     2
    0.0000,       0.0,       0.0,  0.0500,   0,   0.00, 0.00000, 0.00000  #     3
    0.4400,    1500.0,     650.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #     4
    0.9600,    2000.0,     650.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #  2  1
    0.0400,     250.0,     840.0,  0.0750,   0,   0.00, 0.00000, 0.00000  #     2
    0.0000,       0.0,       0.0,  0.0500,   0,   0.00, 0.00000, 0.00000  #     3
    0.4400,    1500.0,     650.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #     4
    0.1900,     950.0,     840.0,  0.0130,   0,   0.00, 0.00000, 0.00000  #  3  1
    0.0000,       0.0,       0.0,  0.0500,   0,   0.00, 0.00000, 0.00000  #     2
    0.5100,    1400.0,    1000.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #     3
    0.0000,       0.0,       0.0,  0.0500,   0,   0.00, 0.00000, 0.00000  #     4
    0.1900,     950.0,     840.0,  0.0130,   0,   0.00, 0.00000, 0.00000  #     5
    0.9600,    2000.0,     650.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #  4  1
    0.0400,     250.0,     840.0,  0.0750,   0,   0.00, 0.00000, 0.00000  #     2
    0.0000,       0.0,       0.0,  0.0500,   0,   0.00, 0.00000, 0.00000  #     3
    0.4400,    1500.0,     650.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #     4
    0.9600,    2000.0,     650.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #  5  1
    0.0400,     250.0,     840.0,  0.0750,   0,   0.00, 0.00000, 0.00000  #     2
```

```
    0.0000,       0.0,       0.0,  0.0500,   0,   0.00, 0.00000, 0.00000  #     3
    0.4400,    1500.0,     650.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #     4
    0.9600,    2000.0,     650.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #  6  1
    0.0400,     250.0,     840.0,  0.0750,   0,   0.00, 0.00000, 0.00000  #     2
    0.0000,       0.0,       0.0,  0.0500,   0,   0.00, 0.00000, 0.00000  #     3
    0.4400,    1500.0,     650.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #     4
    0.9600,    2000.0,     650.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #  7  1
    0.0400,     250.0,     840.0,  0.0750,   0,   0.00, 0.00000, 0.00000  #     2
    0.0000,       0.0,       0.0,  0.0500,   0,   0.00, 0.00000, 0.00000  #     3
    0.4400,    1500.0,     650.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #     4
    0.1900,     960.0,     837.0,  0.0120,   0,   0.00, 0.00000, 0.00000  #  8  1
    0.3800,    1200.0,     653.0,  0.0500,   0,   0.00, 0.00000, 0.00000  #     2
    0.0000,       0.0,       0.0,  0.0500,   0,   0.00, 0.00000, 0.00000  #     3
    0.3800,    1120.0,     840.0,  0.0080,   0,   0.00, 0.00000, 0.00000  #     4
    1.2800,    1460.0,     879.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #  9  1
    2.9000,    2650.0,     900.0,  0.1000,   0,   0.00, 0.00000, 0.00000  #     2
    1.4000,    2100.0,     653.0,  0.0500,   0,   0.00, 0.00000, 0.00000  #     3
    1.4000,    2100.0,     650.0,  0.0500,   0,   0.00, 0.00000, 0.00000  #     4
    0.7600,    2710.0,     837.0,  0.0060,   0,   0.00, 0.00000, 0.00000  # 10  1
    0.0000,       0.0,       0.0,  0.0120,   0,   0.00, 0.00000, 0.00000  #     2
    0.7600,    2710.0,     837.0,  0.0060,   0,   0.00, 0.00000, 0.00000  #     3
    0.1900,     700.0,    2390.0,  0.0250,   0,   0.00, 0.00000, 0.00000  # 11  1
    0.1900,     700.0,    2390.0,  0.0250,   0,   0.00, 0.00000, 0.00000  # 12  1
    0.1900,     700.0,    2390.0,  0.0250,   0,   0.00, 0.00000, 0.00000  # 13  1
    0.7600,    2710.0,     837.0,  0.0060,   0,   0.00, 0.00000, 0.00000  # 14  1
    0.0000,       0.0,       0.0,  0.0120,   0,   0.00, 0.00000, 0.00000  #     2
    0.7600,    2710.0,     837.0,  0.0060,   0,   0.00, 0.00000, 0.00000  #     3
# for each surface: inside face emissivity
  0.90 0.90 0.91 0.90 0.90 0.90 0.90 0.90 0.91 0.83 0.90 0.90 0.90 0.83
# for each surface: outside face emissivity
  0.90 0.90 0.91 0.90 0.90 0.90 0.90 0.90 0.90 0.83 0.90 0.90 0.90 0.83
# for each surface: inside face solar absorptivity
  0.65 0.65 0.22 0.65 0.65 0.65 0.65 0.60 0.65 0.05 0.65 0.65 0.65 0.05
# for each surface: outside face solar absorptivity
  0.70 0.70 0.22 0.70 0.70 0.70 0.70 0.90 0.85 0.05 0.65 0.65 0.65 0.05
# inside and exterior glazing maintenance factors
   1.00   1.00
```

Figure 5 Example zone *constructions* file listing.

4 Zone operation file (mandatory)

The following table lists the contents of each record of a zone operation file (usually held as ?.opr).

Record	Description of fields
1	Zone character descriptor.
2	Control index (see following text), lower and upper control temperatures (or wind speeds if index is 4, -4 or -14).
3	lower infiltration air change rate, zone-coupled air change rate and coupled zone definition (2 data items, say d1 and d2 - see following text) as required (depends on index).
4	upper infiltration air change rate, zone-coupled air change rate and coupled zone definition (2 data items, say d1 and d2 - see following text) as required (depends on index).
5	Default air flow scheme (records 3 and 4): number of distinct intervals within a typical weekday .....
6/1 →	then for each interval, the start time, finish time, infiltration air change rate, zone-coupled air change rate and coupled zone definition (2 data items, say d1 and d2 - see following text).
6/N	
7 & 8	As 5 & 6 but for a typical Saturday.
9 & 10	As 5 & 6 but for a typical Sunday.
11	Default casual heat gain scheme (records 9 and 10): number of distinct intervals within a typical weekday .....
12/1 →	then for each interval: the gain type, the start time, finish time, sensible heat gain, latent heat gain, radiant component and convective component.
12/N	
13 & 14	As 11 & 12 but for a typical Saturday.
15 & 16	As 11 & 12 but for a typical Sunday.

Table 4 Contents of a zone *operation* file.

At an early stage in design, it is usual to operate on the basis of design air flow and casual gain profiles as held in the zone operation file. As the design evolves, and more information becomes available on site conditions and constructional details, it is possible to override these profiles by data placed in a zone casual gain or air flow file. In the latter case the time-series data may be obtained by simulation using *mfs*. If even greater accuracy is required, a description of leakage and pressure distribution can be created so that energy and mass balance can be pursued simultaneously by *bps*.

In constructing a zone operation file, the following points should be noted.

- Thermostatic constraints can be imposed on zone air flows. An integer index controls the type of constraint as follows.

  0 indicates that no thermostatic control is active so that the default profiles will prevail irrespective of zone or incoming air temperatures.

1 indicates that both infiltration and zone-coupled air flow will be controlled on the basis of tests applied to the temperature of the zone air.

2 indicates that both infiltration and zone-coupled air flow will be controlled on the basis of tests applied to the temperature of the coupled zone air.

3 indicates that both infiltration and zone-coupled air flow will be controlled on the basis of tests applied to outside air temperature.

4 indicates that both infiltration and zone-coupled air flow will be controlled on the basis of tests applied to the outside wind speed.

-1, *-2*, *-3* and *-4* are the same as *1*, *2*, *3* and *4* respectively but control is imposed only on the zone-coupled air flow, with infiltration uncontrolled.

-11, *-12*, *-13* and *-14* are the same as *1*, *2*, *3* and *4* respectively but control is imposed only on zone infiltration, with zone-coupled air flow uncontrolled.

This allows air flow to be controlled on the basis of time-dependent zone air temperatures or ambient conditions. The lower and upper temperature limits define the range within which the specified air flow is *ON*. Outside this range the appropriate substitute air flow information is assumed as supplied by the user.

Index values 4 and -4 allow zone air flow to be controlled on the basis of the prevailing wind speed as follows. Note that in this case the upper and lower control temperatures become upper and lower control wind speeds.

4 indicates that both infiltration and zone-coupled air flows will have a magnitude arrived at by linear interpolation between the stated upper and lower ambient wind speed values. If the wind speed is greater than, or equal to, the upper value then the user-assigned air change magnitudes prevail. If the wind speed is equal to, or less than, the lower value then the air flows are set to zero. No information is then taken from the corresponding zone operations file.

-4 is as *4* but only infiltration is affected.

- A distinct interval is an interval of time during which air flow or casual gain regimes remain essentially constant. Start and finish times are expressed as decimal hour values lying between 0 and 24 inclusive. An interval is deemed to finish at the specified finish time but to start at the future time-row of the first computational time-step after the start time. This strategy gives the correct number of operational hours. The actual start time will therefore depend on the time-step size used at simulation time.
- All air change rates are specified relative to the volume of the zone in question. In the case of zone-coupled flow, the direction is from the coupled zone to the zone for which the zone operations file is being created.
- If zone-coupled air flow is active then the coupled zone must be referenced. Two data items are required to do this; say d_1 and d_2. If d_1 is set to a positive integer then this is taken to be the code number of the coupled zone; as assigned to that zone in the system configuration file (see Section 8) to uniquely identify it. In this case d_2 is not required. If, on the other hand, d_1 is set to 0 then this implies that the incoming air is at the constant temperature of d_2°C. All a user need do is to inform *esp-r* that zone-coupling exists, defining the coupled zone by giving its code number. If this is zero then the source air temperature will be requested.

- When defining an air flow or casual gain regime without making reference to the event profiles database, it is first necessary to estimate the number of distinct intervals which comprise the profile. This is done automatically when using database extraction. For example, consider the two casual gain profiles of figure 6: after decomposition, some 20 distinct casual gains must be entered to *esp-r*. Note that gains for different sources, if they exhibit different convective/radiant splits, must be treated separately. The radiant/convective portions will normally sum to unity, but need not, as with the case of a ventilated lighting fitting (remember the gain is defined relative to the zone not the source).
- Each casual gain must be assigned an integer type index in addition to the data describing its time of operation and heat gain characteristics. The requested type index will have one of the following values: 1 for occupants; 2 for lights; 3 for equipment.

  In the case of occupants, the heat gain is a function of the activity level. For example, for sedentary activity the metabolic rate is approximately 58 Watts per square metre (1 MET). In the case of jogging, this will rise to about 8 METS. An average person is of the order of 1.7 square metres of surface area.

  In addition, each of these indices may be negated. In this case the corresponding heat gain may be specified in units other than Watts. With occupants, the unit is floor area per person, each person emitting 95 Watts sensible, 45 Watts latent. With lights and equipment, the unit is Watts per square metre.

Figure 6 shows an example zone operation file (note that there is no thermostatic control on air flow).

```
# operations of reception defined in:
# reception.opr
base case         # operation name
# control(no control of air flow  ), low & high setpoints
   0     0.000     0.000
     1   # no Weekday flow periods
# Wkd: start, stop, infil, ventil, source, data
   0, 24,    0.300    0.000    0    0.000
     1   # no Saturday flow periods
# Sat: start, stop, infil, ventil, source, data
   0, 24,    0.300    0.000    0    0.000
     1   # no Sunday flow periods
# Sun: start, stop, infil, ventil, source, data
   0, 24,    0.300    0.000    0    0.000
     4   # no Weekday casual gains
# Wk: typ, sta, fin, sen, lat, rad, con, pf, +/-, pwr, volt, pha
   3,  0, 24,  800.0,    0.0, 0.2, 0.8, 0.0, 0,    0.0,    0.0, 1
   3,  9, 17,  450.0,    0.0, 0.2, 0.8, 0.0, 0,    0.0,    0.0, 1
   2,  9, 17,  600.0,    0.0, 0.1, 0.0, 0.0, 0,    0.0,    0.0, 1
   1,  9, 17,  540.0,  300.0, 0.2, 0.8, 0.0, 0,    0.0,    0.0, 1
     1   # no Saturday casual gains
# Wk: typ, sta, fin, sen, lat, rad, con, pf, +/-, pwr, volt, pha
   3,  0, 24,  800.0,    0.0, 0.2, 0.8, 0.0, 0,    0.0,    0.0, 1
     1   # no Sunday casual gains
# Wk: typ, sta, fin, sen, lat, rad, con, pf, +/-, pwr, volt, pha
   3,  0, 24,  800.0,    0.0, 0.2, 0.8, 0.0, 0,    0.0,    0.0, 1
# Labels for gain types
 Occupt Lights Equipt
```

Figure 6 Example zone *operations* file listing.

There are several standard profiles within the profiles' database, devised to cover a wide range of occupancy, lighting and equipment usage. These profiles can be used directly or

modified as required. The profiles are as follows.

1. 100% Continuous. This is the simplest case of 24 hour behaviour.
2. Normal working day profile. The heat source operates at its 100% level from 7h00 to 18h00.
3. Late night working. As profile 2 but with the off time later at 21h00.
4. Typical office operation. 100% level is from 9h00 to 12h00 and 14h00 to 17h00, with a reduced level between 7h00 and 9h00 and between 12h00 and 14h00.
5. Late night office operation. As profile 4 but with a full load extension to 21h00.
6. Typical factory operation. Two full load periods each of four hours duration with a reduced lunch-time and overnight load.
7. In term school operation. the load increases rapidly at 9h00, falls markedly at lunch-time and terminates at 16h00.
8. As profile 7 but with evening activity.
9. Domestic evening case.
10. Domestic, working household case.
11. Domestic, day-time occupancy case.
12. Hospital ward operation. Low night-time load, rising during the day to a maximum during visiting hours.

The profiles database is managed via the program *pro* from which profile graphs can be obtained.

5 Zone utilities file (no longer used)

This file contains a series of flags to indicate the existence of one or more of the optional zone files. In each case 1 means that the file exists, 0 that it does not. If a file is flagged to exist then its name is also held. The following table lists the contents of the zone utilities file (usually named ?.utl).

Record	Description of fields
1	Zone air flow file flag.
2	Air flow file name if flag=1.
3	Zone casual gains file flag.
4	Casual gains file name if flag=1.
5	Zone view factor file flag.
6	View factor file name if flag=1.
7	Zone shading/insolation file flag.
8	Shading/insolation file name if flag=1
9	Zone convection coefficient file flag.
10	Convection coefficient file name if flag=1.
11	Zone blind/shutter file flag.
12	Blind/shutter file name if flag=1.
13	Zone transparent multi-layered construction file flag.
14	Transparent multi-layered construction file name if flag=1
15	Zone casual gain control file flag.
16	Casual gain control file name if flag=1
17	Zone domain flow file flag.
18	Domain flow file name if flag=1

Table 5 Contents of a zone *utilities* file.

5.1 Zone shading/ insolation file (optional)

Bps is designed to use time-series shading/insolation (S/I) information extracted from the zone S/I file, if one exists. This allows the accurate modelling of the point of injection of the solar beam impinging on external and internal surfaces. The S/I file is a binary, random access, unformatted file of variable length records containing the following data.

- Hourly time-series of external opaque and transparent, direct beam, surface shading factors (0 to 1) for any user-specified surface, as caused by facade and/or surrounding obstructions.
- And/or the hourly time-series of internal opaque and transparent surface insolation to result from direct solar penetration through user-specified windows. This data is held separately for each *external window/receiving internal surface* combination.

In an attempt to restrict file size - a 10 sided zone with 5 windows would require 6Mbytes to hold the time-series data for 1 year! - the data is held only for user-specified surfaces. Also, the hourly data is only retained for each sun-up hour within that day of each month which possesses a solar declination judged to be closest to the average value for the month. This means that a whole year is represented by 12 sets of surface shading/insolation data; a mechanism which retains reasonable accuracy but greatly reduces disk space demands. In the absence of a S/I file, or if the S/I file does not contain data for the period or surface under consideration, then *bps* will default to zero external surface shading. The window transmitted radiation is then internally apportioned as a function of the default insolation scheme held in the zone geometry file.

A zone S/I file can be created via *esp-r*. In this case any shading and/or insolation data is entered manually for the surfaces and months of interest. Alternatively, *ish* can be used to predict external shading and internal insolation and to build the S/I file piecemeal over time.

Building surfaces which are self-shaded - that is face in a direction *away* from the sun - need not be considered since this occurrence is handled automatically by *bps*. However, shading by adjacent zones is not automatically taken into account, and in this case the shading factors need to be calculated by setting up the adjacent zones as obstruction blocks and running *ish*. Note also that window blinds are not treated as shading devices but are specified by means of a zone *blind/shutter control* file (in the case of default window treatment) or a zone *transparent multi-layer constructions* file (if windows are modelled explicitly).

5.2 Zone blind/ shutter control file (no longer used)

This file (usually named ?.bld) allows window solar coverings or insulating devices to be controlled as a function of time, solar intensity or ambient temperature. File contents are itemised in the following table.

Record	Description of fields
1	Number of distinct control intervals during a day. Also the surface number of the radiation sensor (if one exists).
2	Start and finish hours for the first interval.
3 *	For first interval: replacement shortwave direct transmittance for 5 angles of incidence and visible transmittance.
4 *	replacement total transmittance for 5 angles of incidence and U-value.
5	control index and activation point for first period.
6 →	Repeat records 2 - 5 for each additional control interval.
* Note that the window properties may define a window arrangement which has a blind or shutter in place. In this case the zone construction file will point to the uncovered window case. Conversely, the role of the two zone files can be reversed.	

Table 6 Contents of a zone *blind/shutter control* file.

A day period is firstly divided into a number of distinct intervals which may or may not span the complete day. Then, for each interval, a window is defined which will be accepted only if the *total* radiation intensity (direct + diffuse impinging on the window's facade after shading adjustments on the direct component) or ambient temperature, is greater than the specified actuation point defined in Wm^{-2} or °C respectively. The control index is used to select the control variable type (radiation; 0 or temperature; 1). By setting the actuation point at -99, the window device can be forced to operate for the entire interval regardless of solar intensity or temperature magnitudes. In the case of radiation control of the blind/shutter, the surface on which the radiation sensor is situated can be specified, and the operation of all external windows in the zone will then depend on the radiation intensity on that one surface. If the sensor surface is set to *zero*, then each external surface containing windows is treated separately; only windows in those surfaces receiving greater than the specified radiation limit will inherit the replacement properties.

Internal windows can be assigned the replacement properties if the U-value is specified as a negative quantity. To avoid inconsistency, it is necessary in this case to ensure that adjacent zones are given the same set of replacement properties and that they have the same control settings. Note that it is possible to set all internal and external window properties to be modified during a control period by specifying both a negative replacement U-value and a control value of -99.

The specified control scheme relates to each external window in a zone but that, at any point in time, different window arrangements may be in place depending on the incident radiation levels. If it is necessary to impose more than one control scheme on a zone, it will first be necessary to introduce additional zoning so that each sub-zone can still

possess a unique window control file. As with zone event profile definition, an interval is deemed to finish at the specified finish hour but to commence at the future time-row of the first computational time-step following the specified start hour. The start time will therefore depend on the simulation time-step.

Figure 8 shows a typical *blind/shutter control* file listing.

Record	Contents		
1	2, 0,	6	15, 18,
2	9, 12,	7	0.80, 0.70, 0.60, 0.50, 0.40, 0.6
3	0.70, 0.60, 0.50, 0.40, 0.30, 0.5,	8	0.83, 0.73, 0.63, 0.53, 0.43, 2.00,
4	0.73, 0.63, 0.53, 0.43, 0.33, 2.5,	9	1, 100.0,
5	0, -99.0,		

Figure 8 Typical *blind/shutter control* file listing.

5.3 Zone view factor file (optional)

This file allows the transfer of diffuse view factor information to *bps*, where it is used to improve the accuracy of the inter-surface longwave radiation exchange calculations. In the absence of such information *bps* generates approximate view factors on the basis of simple area weighting techniques.

Table 7 details the contents of this zone file (usually named ?.mrt) which can be constructed manually via *esp-r* or by calculation via *mrt*.

Record	Description of fields
1	Total number of bounding surfaces.
2	Diffuse view factor for each surface pairing (1 to 1, 1 to 2, 1 to 3, 1 to .... ; 2 to 1, 2 to 2, etc)

Table 7 Contents of a zone *view factor* file.

In many applications the use of *mrt* cannot be justified since the established geometry may not accurately represent the final design, or the positioning of zone contents may substantially modify the longwave exchanges. This facility should therefore only be invoked when high accuracy is required and the zone geometry is correctly described; for example in the modelling of a Trombe wall in a passive solar scheme, where longwave exchanges can be a principal heat flow path. Of course it can be routinely invoked if a zone's geometry is carefully defined.

5.4 Zone air flow file (optional)

This file (usually named ?.air) contains infiltration and zone-coupled air flow data which will be used to replace the default air flow scheme of the corresponding zone operation file. The facility is extremely useful for program validation exercises since measured air flow vectors can be treated as input to eliminate the high uncertainty often associated with air flow simulation. It also facilitates design research studies in which a number of guesstimated air flow regimes are to be studied in an attempt to gain performance insight and so generate a robust design solution. Note that ESP-r offers air flow simulation. In this case a description of the building's leakage and pressure distribution is created via *esp-r* and transmitted to *bps* via the system configuration file. The results of *bps*'s air flow simulation will then supersede the default air flow scheme of the operation file *and* the time-series data of the zone air flow file, should one exist. It follows therefore that if such an air flow simulation is requested there is little point in creating a zone air flow file. If the air flows are mostly pressure induced and not buoyancy driven, it is possible to offer the leakage and pressure distribution description to *mfs* instead of *bps*. The analysis of building air flow can then be conducted independently of the energy analysis, with the findings located in the zone air flow file for later use by *bps*. *Mfs* can automatically transfer its predictions to the zone file. Alternatively, the predictions can be taken for input to the zone file via *esp-r*. The advantage of this approach is that the predicted air flows can be characterised and fed to *bps* in a simplified form. This will greatly reduce the complexity of any energy simulation and so ease the analysis burden when *res* is used to investigate the results from *bps*.

Table 8 lists file contents (usually named ?.air).

Record	Description of fields
1	* Air Flow File (the first line *must* be identical to this).
2	For first simulation time-step: zone infiltration, then air *received* by zone from each zone in configuration.
4 →	Repeat record 2 for each simulation time-step.

Table 8 Contents of a zone *air flow* file.

All air flows are specified in air changes per hour (hr^{-1}) expressed relative to the volume of the zone to which the file relates. The zone-coupling is given in order 1 to x, 2 to x, 3 to x etc, where x is the target zone number; obviously x to x=0. It is important that data exists for the correct number of time-steps as will comprise the simulation, including the start-up period. The first data record in the file (that is record 2) will correspond to the future time-row of the first simulation time-step; for example 02.00 hrs for a one hour time-step and 01.10 hrs for a ten minute time-step. Note that *bps* commences a simulation at 01.00 hrs - the present time-row of the first time-step on the first start-up day.

5.5 Zone casual gain file (optional)

This file is similar in function to the preceding air flow file but with the filed casual gain entries acting to augment the default profiles of the zone operation file. This allows zone casual gains to vary from time-step to time-step as a simulation progresses: a useful facility for generating zone energy pulses in validation studies, or for accurately representing process heat inputs in a finely focused design study. The file can only be created via *esp-r*.

Table 9 lists file contents (usually named ?.cgn).

Record	Description of fields
1	* Casual Gains File (the first line *must* be identical to this).
2	For first simulation time-step: the total sensible convective, sensible radiant and latent heat gains (all in Watts) for the zone.
3 →	Repeat record 2 for each simulation time-step.

Table 9 Contents of a zone *casual gain* file.

As with the air flow file it is important to ensure that the number of records is matched to the number of simulation time-steps. Section 5.4 explains *bps*'s assumptions in this respect.

5.6 Zone convection-calculation control file (optional)

This file is used to impose control over the surface convection calculations performed by *bps*. Three types of control may be imposed through this file, which is in addition to the control that can be imposed using a simulation toggle.

Type 1 allows fixed coefficients to be specified for each surface (interior and exterior to the building). A list of coefficients is given for each 'inside' and 'outside' zone surface. A -1 entry for any surface indicates that the result from *bps*'s buoyancy calculations (based on the simulation toggle) will be used, i.e. no replacement value is offered.

Type 2 allows you to specify the correlation to use for each surface (only applicable for surfaces interior to the building). This could allow, for example, the use of the Alamdari & Hammond correlations for a wall, while using one of the Khalifa & Marshall correlations for a window. A number of empirical correlations and fixed values, extracted from the following sources, are supported:

> Alamdari and Hammond (1983), 'Improved Data Correlations for Buoyancy-Driven Convection in Rooms' BSER&T, 4(3) 106-12.
>
> Khalifa and Marshall (1990), 'Validation of Heat Transfer Coefficients on Interior Building Surfaces Using a Real-Sized Indoor Test Cell', Int. J. Heat and Mass Transfer, 33 (10) 2219-2236.
>
> Halcrow (1987), 'Heat Transfer at Internal Building Surfaces', Report to ETSU, British Department of Energy.
>
> CIBSE Guide (1988), 5th Edition, Table A3.4.
>
> CEN (1995), 'Thermal Performance of Buildings, Room Cooling Load Calculation, General Criteria for a Simplified Calculation Method', CEN/TC89/WG6 N.225 / JWG-N79, Section 6.2.2.

Each correlation is identified by an index. Refer to /usr/esru/src/esp-r/esrubld/convect.F, subroutine HTBUOY, where the index numbers are assigned to ICOR. A -1 indicates that a correlation will be chosen based on the simulation toggle. Correlations chosen for surfaces exterior to the building will be ignored.

Type 3 allows adaptive control of the calculations (only applicable for surfaces interior to the building). This method allows the convection calculations to *adapt* as the simulation progresses. You must assign *control law* for each interior surface, which defines how the calculations will adapt. The following control laws are available:

> Law 1: two correlations specified for each surface; one correlation used when plant is heating zone (radiation or convection); other correlation used when zone is unheated. Appropriate when plant system alters convection regime within zone.

Adaptive control is only applicable for interior building surfaces. Control laws specified for exterior surfaces will be ignored. As well, a control law specified for an 'outside' surface which faces the air-point of an adjacent zone will be ignored: the law specified in the neighbouring zone will take precedence. Specify law '99' in these cases where adaptive control is not applicable.

A typical day is divided into a number of distinct time intervals. A different control type can be prescribed for each time interval. The following table lists the file contents (usually named ?.htc).

Record	Description of fields
1	Number of distinct intervals.
2	Number of zone surfaces, *N* (must be the same as the corresponding entry in the zone geometry file).
3	For the first interval: start and finish hours.
4	Calculation control type (1-3)
If *type 1* control	
5	For the first interval: convection coefficient for each internal surface.
6	For the first interval: convection coefficient for each external surface.
If *type 2* control	
5	For the first interval: correlation indices for each internal surface.
6	For the first interval: correlation indices for each external surface.
If *type 3* control	
5 → 4+N	For the first interval: eight data fields/surface, one record for each surface. The first and fifth fields identify the control laws for the 'inside' and 'outside' surfaces, respectively. Fields two to four are the associated data for the 'inside' and fields five to eight are the associated data for the 'outside': the significance is dependent on the control law. For *law 1*, fields two and six hold the correlation index to use when the heater is on; fields three and seven hold the correlation index to use when the heater is off; fields four and eight are unused.
6 or N+1 →	Repeat records 3.... for each subsequent interval.

Table 10 Contents of a zone *convection-calculation control* file.

As elsewhere in ESP-r, an interval is assumed to finish at the defined finish hour but to start at the future time-row of the first simulation time-step.

5.7 Zone transparent multi-layered constructions file (optional)

This file holds the spectrally integrated shortwave properties for one or more zone multi-layered constructions comprising one or more transparent elements. For each homogeneous element the incident angle dependent absorptance is required. Then, for the combined multi-layered construction the overall transmittance curve is necessary. The file also contains control information on any blind/shutters that are associated with the transparent multi-layered constructions, together with the requisite replacement optical and thermophysical properties.

If zone windows are defined in the normal way (via a zone geometry file) then no nodes are used to represent the window layers. This means that window conduction is calculated from

$$q_c = \frac{\theta_o - \theta_i}{R}$$

where θ is air temperature, o and i refer to outside and inside respectively, and R is the overall resistance at any time as given by

$$R = \frac{1}{h_c + h_r}$$

where h_c is the time dependent convection coefficient and h_r is a fixed radiation coefficient determined from the initially specified standard U-value (but remember that if the U-value is negated then it is treated as being time invariant).

This conductive flux is applied at the zone air point. Therefore, unlike multi-layered constructions, windows are treated as resistance only, with an approximate treatment of longwave radiation. Also, because no window node is present, it is not possible to explicitly model shortwave absorption. Instead, a technique is used which calculates, directly, that portion of the absorbed shortwave flux which would be transmitted inward to the zone air point.

The *transparent multi-layer facility* allows windows to be treated with more precision. Now *all* surfaces (including windows) bounding a zone are entered as multi-layered constructions, with layers being declared transparent as appropriate. This means that windows can now be assigned a nodal scheme so that convective, conductive and longwave radiative exchanges are handled separately and explicitly, with solar absorption treated in an exacting manner.

The following step-by-step procedure should be followed to make use of the transparent multi-layered construction facility.

Step 1 Define zone geometry by entering *all* bounding surfaces whether opaque or transparent. This will probably mean defining the zone shape as GEN (or perhaps REG). There is now no need to define windows separately so your response should be NO in reply to the question, 'Are there any windows ?' (unless of course you also wish to include windows handled in the default manner).

Step 2 When defining zone constructions simply define the transparent multi-layered construction as if it were an opaque wall. That is by defining the k, ρ, C_p and δx values for each layer.

Step 3 Remember to create a zone utility file with the appropriate flag set to indicate the presence of a zone transparent multi-layered constructions file.

Step 4 Create the zone transparent multi-layered constructions file. The dialogue will go like this

Number of surfaces in zone ?

Answer by giving the number you input to the zone geometry file.

Transparent multi-layered construction index for each surface ?

If a surface is not transparent, enter 0. Otherwise enter a positive integer which defines a set of properties which have yet to be entered by you. For example, if there are six surfaces in the zone and the 2nd and 5th are both transparent and of the same construction, then you would enter 0 1 0 0 1 0. Alternatively if the two transparent constructions were of different construction you would enter 0 1 0 0 2 0. In the first case you will be asked for one set of properties, in the second case two.

In response to the following prompts, you must now enter the overall transmission curve (by giving the usual data for the 5 angles of incidence) and the absorption curve for each construction element (called a substrate). Note that *bps* will check to ensure that the number of substrates in this file, and the number of elements in the constructions file, are the same.

Blind/Shutter Control ?

Answer 1 if there is control, 0 if not.

If the answer is 1 (yes), the program prompts for the number of control periods, and then, for each control period, the details of the control and the replacement properties (see below for further discussion).

Step 5 You are now ready to simulate using *bps* (of course you must have created your zone operations file, the system configuration file and, perhaps, the configuration control file).

Table 10a details file contents (usually named ?.tmc).

Record	Description of fields
1	Total number of multi-layered constructions in zone.
2	For each construction: an index stating whether or not it is transparent (0 opaque; >0 transparent).
3	Number of elements (including air gap if any) of first transparent multi-layer construction (TMC).
4/1 → 4/N	For first TMC: direct transmittance at 5 angles of incidence; followed by the absorptance for each element - outside to inside - in turn and again for the 5 angles of incidence.
5	Control flag. If flag is zero then records 3 to 5 are repeated for each TMC. If flag is 1 then the file contains the following records 6 and 7.
6	Number of distinct control periods in a day.

Record	Description of fields
	Also the surface number of the radiation sensor (if one exists).
7/1	Start and finish hours for the first period.
7/2	Sensor type and activation point for period 1.
7/3 →	Replacement optical properties: direct transmittance at 5 angles of incidence; followed by the absorptance for each element - outside to inside - in turn and again for the 5 angles of incidence.
7/N	
7/N+1	Index to replacement thermophysical properties (zero if no replacement).
7/N+2 →	Replacement thermophysical properties read in here if index>0.
7/M	
7/M+1 →	Repeat 7/1 to 7/M for each control period.
8 →	Repeat records 3 to 7 for each TMC.

Table 10a Contents of a zone *transparent multi-layered constructions* file.

With regard to control, each TMC can be given a replacement set of transmission coefficients and absorptivities in each control period (maximum three/day). The TMCs are controlled independently, with the following control options:

(i) If the control variable is set to -99, then the blind/shutter is always ON in the control period, irrespective of radiation or temperature levels; that is, the control is on *time* only.

(ii) If the control sensor is temperature (type 1), then the blind/shutter will be ON whenever the external temperature exceeds the predefined level.

(iii) If the control sensor is for radiation (type 0), then:

  a) if the external surface number is given, then the blind/shutter will be ON for each TMC for which the (shaded) radiation on the specified external surface exceeds the predefined level for that TMC. This will simulate the case when there is a sensor on only one external surface.

  b) if the external surface number is not given (set to zero), then the blind/shutter will be ON for each TMC for which the (shaded) radiation on the external TMC surface exceeds the predefined level for that TMC. This will simulate the case when each external TMC surface has a sensor.

In addition, it is possible to replace the thermophysical properties of the TMC. For each control period, an index points to an alternative set of thermophysical properties from a construction in the multi-constructional database. It is important that the number of elements in the replacement construction is the same as for the original construction. The replacement values are read in and stored in this file. If the index is zero, the thermophysical properties are unchanged.

Some points to remember:

- The standard thermophysical properties of each element in the special multi-layered construction are specified in the zone constructions file as before.
- The index of record 2, if positive, points to the set of shortwave properties to be associated with a given construction. This means that, for example, more than one

transparent construction can point to the same set of properties. In this case, it will also inherit the same control periods and control settings. Conversely each construction can be associated with a unique set.

- It is possible to mix transparent constructions and ordinary windows in the same zone; it is even possible to have an ordinary window within a TMC. This means that some glazing systems will be treated exactly while others are processed at the default level.

Figure 9 shows the typical contents of a TMC file.

```
# transparent properties of reception defined in ../zones/reception.tmc
  14   # surfaces
# tmc index for each surface
  0  0  0  0  0  0  0  0  0  1  0  0  0  1
   3  DCF7671_06nb # layers in tmc type 1
# Transmission @ 5 angles & visible tr.
   0.611   0.583   0.534   0.384   0.170   0.760
# For each layer absorption @ 5 angles
   0.157   0.172   0.185   0.201   0.202
   0.001   0.002   0.003   0.004   0.005
   0.117   0.124   0.127   0.112   0.077
   0  # blind/shutter control flag
```

Figure 9 Typical zone *TMC* file listing.

5.8 Zone casual gain control file

Beginning with version #6.4b of January 1987 ESP-r has provided a number of control schemes for casual gains which represent artificial lighting. ESP-r kept track of the day-lighting contributions from all the exterior windows in the zone and whether or not direct sunlight was falling on each sensor.

ESP-r has traditionally made use of sensors located at user-specified points, calculating the daylight factors separately for each zone window. Shortwave illumination is included in the algorithm and the split flux method used to assess the internal reflected component. This is a typical engineering approach to the problem of predicting daylighting when insufficient information is available to allow a more explicit method.

Over time these facilities have been expanded and from Project Manager Version 2.9a (of April 1995) the following are offered:

- The user may define up to 4 lighting zones within a thermal zone, each with up to 9 sensors. Each lighting zone then represents an individual lighting system.
- Vertical (unobstructed) and horizontal external illuminance sensors are available.
- In the case of multiple lighting zones within a thermal zone, an aggregate casual gain may be obtained by summing the contributions from individual sensor/ gain combinations or by determining the average of all sensors controlling one lighting system.
- The illuminance from adjacent rooms is derived via ESP-r's shortwave radiation tracking procedures. This process is robust enough to take into account the effect of blind opening/ closing on the daylighting in adjacent rooms.
- Provision has been made for user supplied daylight factor data to be included in a casual gain control file.
- A new option for coupling lighting and thermal simulation has been introduced. This feature supports both data file based and concurrent application coupling between ESP-r and some separate lighting simulation environments. At the present time coupling with the Radiance lighting simulation program is available.

The following table shows the contents of the zone casual gain control file (usually named ?.cgc). Currently this file has to be created via text editing facilities. The *project manager* editing facility is under development.

Line	Description of fields
1	Identifier (three integer type numbers) of the casual gains to be controlled during Weekdays, Saturdays and Sundays. Default identifier for casual gain from artificial lighting is "2".
2	Number (an integer type number) of distinct casual gain control periods during a typical day. Maximum three control periods currently allowed.
3	For each control period in turn give the start hour (0-24) and finish hour (two integer type numbers) on separate lines.
4	Number (an integer type number) of lighting zones within this thermal zone. Maximum of four lighting zones allowed.
5	For each individual lighting zone:
5.1	Numbers (four real type numbers) indicating respectively: reference light level (set point) (Lux), switch-off light level (-), minimum dimming light output (-) and switch-off delay time (-).

Line	Description of fields
5.2	Percentage (a real type number) of total zone controlled casual gain associated with this lighting zone (-), number (an integer type number) of internal illuminance sensors and calculation type (an integer type number 1-4): 1 ESP-r internal daylight factor preprocessor; 2 user supplied daylight factors; 3 external sensor; 4 coupling with lighting simulation.
5.3	For each defined sensor: x, y & z coordinates (relative to zone origin) defining location of sensor, or for calculation type 3: surface number (external only) that the sensor is placed on, flag specifying vertical mounting (1.0) or horizontal mounting (0.0), dummy value,
5.4	For calculation type 2 (user supplied daylight factors) additional info:
5.4.1	Number (an integer type number) of windows (transparent multi-layer construction).
5.4.2	For each defined window its TMC surface identification number (an integer type number) and corresponding daylight factors for each defined sensor (a real type numbers).
5.5	The control law (-1 ON regardless; 0 OFF regardless; 1 ON if sensed condition is below set point (otherwise OFF); 2 as 1 but with step down/up action (0%, 50%, 100%); 3 as 1 but with proportional action; 4 as 1 but based on the Hunt probability switching function; 5 as 1 but with a top-up control and fixed ballast).

Table 10b Contents of a zone *casual gain control* file.

The relationships between several combinations of control law, sensor placement and analysis techniques are discussed below in the worked out example.

As an example we are using a one zone model of a simple room 4m wide, 5m deep and 3m high with a window on the south face. The casual gain control files acts on a common operation file which sets up a casual gain of type 2 (artificial lighting) with 864W of radiative/ convective flux between 8h00 - 12h00 and 14h00 and 17h00 on weekdays:

```
# operations of Room defined in:
# Room.opr
nil_operations   # operation name
# control(no control of air flow  ), low & high set points
  0    0.000    0.000
    3  # no Weekday flow periods
# Wkd: start, stop, infil, ventil, source, data
  0, 7,   0.500   0.000   0   0.000
  8, 16,   2.000   0.000   0   0.000
 17, 24,   0.500   0.000   0   0.000
   1  # no Saturday flow periods
# Sat: start, stop, infil, ventil, source, data
  0, 24,   0.500   0.000   0   0.000
    1  # no Sunday flow periods
# Sun: start, stop, infil, ventil, source, data
  0, 24,   0.500   0.000   0   0.000
    4  # no Weekday casual gains
# Wk: typ, sta, fin, sen, lat, rad, con, pf, +/-, pwr, volt, pha
  1,  8, 11, 1890.0, 1215.0, 0.8, 0.2, 0.00, 0,    0.0,    0.0, 1
  1, 14, 16, 1890.0, 1215.0, 0.8, 0.2, 0.00, 0,    0.0,    0.0, 1
  2,  8, 11,  864.0,    0.0, 0.4, 0.6, 0.90, 1,  864.0,  240.0, 1
  2, 14, 16,  864.0,    0.0, 0.4, 0.6, 0.90, 1,  864.0,  240.0, 1
    0  # no Saturday casual gains
    0  # no Sunday casual gains
# Labels for gain types
 Occupt Lights Equipt
```

Consider a zone lighting system comprising two control strategies: daylight linking and manual switching respectively. The casual gain control file for this control strategy is listed below:

```
2 2 2                  # Casual gain type to be controlled
1                      # Number of control periods
8 16                   # Start and finish hour
2                      # Number of lighting zones
# Information for every lighting zone
# Lighting zone 1
500 1.5 .1 1.          # Lux set point, switch-off light level, minimum dimming output, switch-off delay time
0.5 4 1                # % of casual gain, number of sensors, calculation type
```

```
2 2 .9          # x, y, z coordinates of sensor location
2 3 .9          # x, y, z coordinates of sensor location
3 2 .9          # x, y, z coordinates of sensor location
3 3 .9          # x, y, z coordinates of sensor location
3               # Control law for all control periods
# Lighting zone 2
500 1. 1. 1.    # Lux set point, switch-off light level, minimum dimming output, switch-off delay time
0.5 1 2         # % of casual gain, number of sensors, calculation type
2 4 .9          # x, y, z coordinates of sensor location
1               # Number of windows
7 .015          # TMC surface number, daylight factor
4               # Control law for all control periods
```

Note that casual gain type "2" will be controlled during Weekdays, Saturdays and Sundays. Only one control period is defined. This is usually adequate for most lighting controls. Start and finish hours "8 16" cover a time span from 8h00 to 17h00 when occupants are present and artificial lighting may be necessary. In order to allow for the simulation of two individual control strategies, two lighting zones are required.

As can be seen from the information defining the first lighting zone, a reference light level (or set point) has been set to 500 Lux. The switch-off light level is 150% of the reference light level and the minimum dimming light output is set to 10% (i.e. the dimming range is 100% - 10%). The switch-off delay time is set to 1 which represents 60 minutes. Note that at the present time sub-hour delay time delay times are not possible.

The first lighting zone will control 50% of the total zone controlled casual gain. The number of sensors has been set to 4 and the calculation type to 1, which calls for ESP-r's internal daylight factor preprocessor. Multiple lighting sensors are used to account for a variance in illuminance within the space in terms of what ceiling mounted photocells would "see". The average of these sensors will be used within the simulation. Finally, the control law identifier is set to 3, which represents proportional (dimming) control.

The second lighting zone has a reference light level of 500 Lux, with the switch-off light level and minimum dimming light output set to 100% which is adequate for a simple on-off control. For this case only one sensor is specified and the calculation type is set to 2, which calls for user specified daylight factors. For this type of calculation additional data are required. These include the number of windows (or TMCs), in this case 1, the TMC surface identifier, here 7, and the list of daylight factors, here only one set at 1.5%. Finally, the Hunt probability switching control function, type 4, is selected.

In order to illustrate the structure of a casual gain control file consider the above lighting zone 2 with an external sensor. Part of the resulting file follows:

```
# Lighting zone 2
8000 1. 1. 1.   # Lux set point, switch-off light level, minimum dimming output, switch-off delay time
0.5 1 3         # % of casual gain, number of sensors, calculation type
1 1. 0          # external surface number, sensor position, dummy value
1               # Control law for all control periods
```

For the case of an external sensor, the x,y and z coordinates input line has a different meaning. The first number is the surface identifier, here 1, the second number is the sensor position (1 meaning vertical) and the last is not used. Only one sensor of this type may be defined per lighting zone.

The calculation type "4" represents a coupled lighting and thermal simulation. This facility is currently under testing and so has not been released with the present version of ESP-r.

5.8.1 Diagnostics

To assist the user in verifying the description of casual gain controls and sensor placement the ESP-r trace facility has been expanded to give the user information before and during a simulation. The trace diagnostics for several zones are reproduced below and include a summary of sensor locations, associated windows, contributions from outside and calculated daylight factors. Note that the internal reflected component is calculated via the *split flux* method as defined in *Architects Journal, Vol.120 1954*.

The diagnostics for a case with dimming and Hunt probability switching:

```
Subroutine INTLUM     Trace output   3     Zone  1

Day No. =   4 (i.e.  4th of Jan.),  Time  9:00 Hours
Light|Sens|sun |via   |daylight|visib|sun/dir|sky/dif|sensed|set  |ext vert
 zone|num.|seen|window|factor% |trnsm|contrib|contrib|lux   |point|ilum(Ev)
    1   1  no      7    6.34  0.76    0.0   132.7  132.7  500.    1047.
    1   2  no      7    3.64  0.76    0.0    76.2   76.2  500.    1047.
    1   3  no      7    5.47  0.76    0.0   114.6  114.6  500.    1047.
    1   4  no      7    3.41  0.76    0.0    71.4   71.4  500.    1047.
Light zone 1 Prop ESP-r calc df, ZFRAC= 0.40
    2   1  no      7    1.50  0.76    0.0    31.4   31.4  500.    1047.
Light zone 2 Hunt: ZFRAC=0.50 Occup arrival first elum(   31.) prob(0.80) r(0.00)
Fraction of lighting "ON" FRAC=0.90

Ext: Dir.hor.rad. W/m2(    0.0) Dif.hor.rad.(   18.0)
   : sun light lux(    0.0) sky light lux( 2093.3)
   : sun/dir efficacy (   0.00) sky/dif efficacy ( 116.30)
   : solar azi deg( 138.0) solar alt deg(   5.0)
Subroutine MZCASI     Trace output   4     Zone  1

Day No. =   4 (i.e.  4th of Jan.),  Time  9:00 Hours

Casual gain summary for weekdays

            |      Radiant       |    Convection      | Fraction |
            |  Present   Future |  Present    Future | Pres Futr|
Uncontrolled |      0.00   1512.00|     0.00    378.00|          |
Controlled   |      0.00    345.60|     0.00    518.40| 1.00 0.90|
Summation    |      1823.48W    , |       845.22W      |

Zone:    1  1
Electrical load summary for weekdays
          Real Power          Reactive Power
         |Present|Future|    |Present|Future|
              0.   779.           0.   377.
Ctrld  |Unctrld|Ctrld  |Unctrld|Ctrld  |Unctrld|Ctrld  |Unctrld
    0.       0.   864.       0.     0.       0.   418.     0.
```

Typical simulation diagnostics for case with dimming and external sensor:

```
Subroutine INTLUM     Trace output   3     Zone  1

Day No. =   4 (i.e.  4th of Jan.),  Time  9:00 Hours
Light|Sens|sun |via   |daylight|visib|sun/dir|sky/dif|sensed|set  |ext vert
 zone|num.|seen|window|factor% |trnsm|contrib|contrib|lux   |point|ilum(Ev)
    1   1  no      7    6.34  0.76    0.0   132.7  132.7  500.    1047.
    1   2  no      7    3.64  0.76    0.0    76.2   76.2  500.    1047.
    1   3  no      7    5.47  0.76    0.0   114.6  114.6  500.    1047.
    1   4  no      7    3.41  0.76    0.0    71.4   71.4  500.    1047.
Light zone 1 Prop ESP-r calc df, ZFRAC= 0.40
    2  1.0 N/A   N/A      1   N/A     N/A  0.0  2093.3 1046.7 8000.   N/A
Light zone 2 ON/OFF ext sensor, ZFRAC= 0.50
Fraction of lighting "ON" FRAC=0.90

Ext: Dir.hor.rad. W/m2(    0.0) Dif.hor.rad.(   18.0)
   : sun light lux(    0.0) sky light lux( 2093.3)
   : sun/dir efficacy (   0.00) sky/dif efficacy ( 116.30)
   : solar azi deg( 138.0) solar alt deg(   5.0)
Subroutine MZCASI     Trace output   4     Zone  1

Day No. =   4 (i.e.  4th of Jan.),  Time  9:00 Hours
```

Casual gain summary for weekdays

```
            |     Radiant       |    Convection      | Fraction |
            |  Present   Future |  Present    Future | Pres Futr|
Uncontrolled |      0.00   1512.00|      0.00    378.00|          |
Controlled   |      0.00    345.60|      0.00    518.40| 1.00 0.90|
Summation    |      1823.48W    , |       845.22W      |
```

Zone: 1 1
Electrical load summary for weekdays

```
          Real Power          Reactive Power
         |Present|Future|    |Present|Future|
              0.   779.           0.   377.
Ctrld  |Unctrld|Ctrld  |Unctrld|Ctrld  |Unctrld|Ctrld  |Unctrld
    0.      0.   864.     0.    0.      0.    418.     0.
```

5.8.2 Result analysis

The results analysis module *res* provides the possibility to analyse the controlled casual gains and electric power consumptions (if electric data are given in the zone operation file) in a variety of ways.

5.9 Zone CFD Domain File

dfs is the ESP-r CFD module capable of modelling indoor air flow. A zone or group of zones can be defined in order to predict internal flows. In such a case all boundary conditions must be provided - ventilation and/or infiltration rates, internal surface temperatures, etc - via configuration file. The user can simulate laminar or turbulent flows ($k-\varepsilon$ model). The solution is based on the SIMPLE algorithm and TDMA Gauss-Seidel. The differential equations are discretized using the hybrid scheme and the implicit formulation. As most of the building geometries are regular, dfs deals only with cartesian coordinates. The CFD model can also be integrated within bps (zone basis). In other words, one zone is chosen to be modelled by CFD and the remaining of the building is simulated by the conventional mixed approach. the integration is optional and a CFD flag is placed in the zone operation file. Two kinds of integration regarding the energy equations are available: Option 1 - Integration by convection coefficients; 2 - simultaneous solution of a zone energy equations (you should include 1 or 2 in the zone operation file). As soon as a fluid flow network is defined, the coupling of mass flow and momentum equations will exist. This integration consists of simultaneous solution of the equations. For further details about the integration theory consult Negrao (1995).

5.9.1 Domain Flow Definition

The input data are provided via a configuration file which contains instructions about the zone geometry, grid distribution, boundary conditions and some simulation control parameters.

5.9.2 Geometry and Grid

An automatic grid generation could locate, for example, an interface between a solid surface and an opening occur- ring inside some cells. A fraction of the volume of such cells would then be made solid and some fluid. In order to avoid this, and to conform the cell distribution with solid boundaries, openings, furniture, etc., grid and geometry are defined together. This procedure consists of dividing each dimension of the rectilinear domain into a certain number of regions. For each region, the direction, the length and the grid distribution is defined. The cells are independently distributed in each region according to a power law equation and the parameters necessary are shown in Table 1. To illustrate the process, consider the case where a door is located on a surface (as shown in Figure 1) and a grid must be distributed over the surface in the longitudinal direction. Three regions in such a direction are identified; one region located left of the door, one at the doorway and the last one placed to the right of the door. At the left region, the power law parameters are set to: $n > 0$, $|c| > 1$ and $c > 0$ in order to make the cell sizes increase from left to right. The cells are uniformly distributed at the doorway ($c = 1$) and the cell sizes decrease from right to left on the last region using the parameters $n > 0$, $|c| > 1$ and $c < 0$.

Table 1 Grid and geometry definition.

Dir.	N. of cells in the region	Dimens.	Power law coeffic.
X	n>0 Cells distributed over the whole reg.	L>0	c=1 Uniform distribution c>0 increase* if c>0 c<0 decrease* if c<0
Y	n<0 Cells distributed symmetrically over the region	|c|>1 Grid size	c=1 Uniform distribution c>0 decrease* if c>0 c<0 increase* if c<0
Z		|c|>1 Grid size	

* increase/decrease from the beginning to the end (or middle if n<0) of the region.

The grid can be specified in one, two or three dimensions depending on the type of air flow to be analysed.

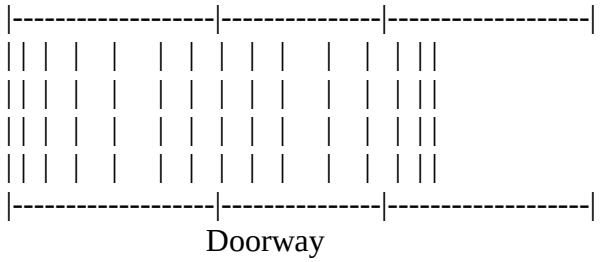

Figure 1 Example of dfs grid definition.

5.9.3 Equations

The user is able to define the nature of the flow (lam- inar or turbulent, two or three-dimensional) by choosing the equations to be solved. Energy and concentration equations and buoyancy effect are included or not in the simulation depending on the problem. The z direction is assumed to be vertical (direction of gravity) and buoyancy is only con- sidered in this direction. If a two-dimensional simulation is running in the x-y plane no buoyancy is taken into account. For example, if U, V, T, k and ε are specified, the flow is two-dimensional turbulent, the energy equation is solved but no buoyancy is involved.

5.9.4 Openings

Four types of boundary conditions are available to represent openings: pressure, mass flow rate, velocity and zero velocity gradient. They must be chosen according to the situation (usually velocity is fixed at the inlets and pres- sure, mass flow or zero velocity

gradient at outlets). Six planes, designated "West" and "East" (normal to x), "South" and "North" (normal to y) and "Low" and "High" (normal to z), are used to define the cell faces. The openings are then located at one of the six planes according to the grid definition in a certain number of cells. In other words, the plane name and the indices of the first and last cells inserted in the opening (in each direction) are specified. The definition of the plane is only relevant for velocity and zero gradient boundary types. For pressure and mass flow types this information becomes redundant. If an opening is introduced in a certain plane (say West) the indices of the initial and final cells in the direction normal to the plane (say x-direction) must be the same. Additionally, the air condition at openings must be provided in terms of mass flow rate (mass flow, velocity boundary type) or pressure (pres- sure boundary type). In the case of velocity boundary types, the velocity at the opening is based on the specified mass flow rate, air density at the opening and opening area. A positive mass flow rate indicates that the flow is entering the domain and an outlet flow is denoted by a negative value. Also, temperature and concentration only are defined, if necessary, at the inlets, since at the outlet it is assumed that the diffusive terms are overcome by the convec- tive terms and the gradients of such properties can be made equal to zero. To clarify the opening definition, consider the following example

Vel West 5 5 3 7 5 8 1.0 20.0 0.1 .

This indicates that velocity is fixed at the WEST face of the 5th cell in the x-direction. The opening is located at five cells (3rd, 4th, 5th, 6th and 7th cells) in the y- direction and at four cells (5th, 6th, 7th, and 8th cells) in the z-direction. 1kg/s of air is entering the domain at 20’C and with a 10% pollutant concentration. Table 2 presents the information necessary to describe an open- ing and the air condition at such a position.

For transient simulations, dynamic boundary conditions can also be specified. In such a situation, the air condi- tion in Table 2 is substituted by an identifier (a word or a number). The identifier points to three different files where time-series of mass flow (or pressure), temperature and concentration for each opening are defined. Each time- step, during the simulation, dfs reads the corresponding files and up-dates the boundary conditions.

Table 2 Opening definition

Type	Loc.	Initial and Final cells in x-axis	Initial and Final cells in y-axis	Initial and Final cells in z-axis	Air condition
Press Mass flow Veloc Zero veloc grad	West East South North Low High	IXi IXf	IYi IYf	IZi IZf	Mass flow (kg/s) Pressure (Pa) Temp. (’C) Conc. (-)

5.9.5 Solid Boundaries

The boundary conditions for solid surfaces are characterised by three types: fixed temperature, fixed heat flux or symmetric plane. For the first two types, only temperature or heat flux are specified and for the symmetric plane type no condition is specified since the gradient normal to the plane for all variables is assumed zero. The solid boundaries are positioned by applying the same procedure as for an opening. The information required to describe a solid boundary is introduced in Table 3. If a dynamic simulation is performed, an identifier (which can be a surface name or an index) substitutes the boundary condition in Table 3. Similarly to the openings, a file containing time-series of temperature or heat fluxes must be created.

Table 3 Solid boundary definition

Type	Loc.	Initial and Final cells in x-axis	Initial and Final cells in y-axis	Initial and Final cells in z-axis	Boundary condition
Temp.	West				Temperature (’C)
	East				
Heat Flux	South	IXi IXf	IYi IYf	IZi IZf	Heat Flux (W)
	North				
	Low				
Sym-metry	High				

Table 4 Heat/concentration source definition

Type	Initial and Final cells in x-axis	Initial and Final cells in y-axis	Initial and Final cells in z-axis	Boundary condit.	Blocked Cells?
Temperature				Temperature (’C)	Yes
Heat Flux	IXi IXf	IYi IYf	IZi IZf	Heat Flux (W)	No

5.9.7 Iteration Control

The convergence process is controlled by the user specified number of iterations and the maximum source of residuals allowed. The simulation stops when the tolerance of residuals or the defined number of iterations is reached, whichever occurs first.

The user has also the control over the relaxation factors. Linear and fictitious time-step relaxation factors can be selected for each of the transport variables (U, V, W, T, C, k, Epsilon) and also a linear relaxation can be chosen for turbulent viscosity. If a relaxation factor is not specified, a default value is assumed.

Convergence is also a function of the initial values of the variables. A solution can be achieved or not depending on the values assumed at the beginning of the iteration process. Initial values (uniform for the whole field) for each transport variable can be selected in order to speed up the convergence.

A previously converged solution saved to file can also be used to initiate variable values for a new simulation. This facility is named re-initialisation because after being partially run, the simulation can be re-started. For exam- ple, a zone may be subjected to a one day simulation and after 12 one hour time-steps the solution process diverges. To achieve convergence the relaxation factors can be reset and the simulation re-started, but instead of beginning from the first time-step it can be started from the last con- verged time-step without repeating the already converged hours. This is possible because both present and future values are set to the initialised values. Initialisation fields are only feasible at the first simulation time-step since after that the initial values for a certain time-step are the converged solution of the last time-step.

5.9.8 Results

The velocity component and scalar variable fields are saved to file for post-processing. dfs uses 3rd party codes to provide visualisation of the temperature and pressure fields and velocity profiles. The results can be selected to be stored at specific time-steps to avoid uninteresting results from overloading the disk.

The values of pressure and velocity components at moni- tored positions, and the corresponding residuals, can be observed graphically as the simulation progresses or through a monitoring file after the simulation has taken place. The user is able to choose a cell inside the domain where the variables are monitored.

All the information introduced in this section is pro- vided for dfs via a configuration file. To clarify the definition process, consider the zone Kitchen shown in Figure 3, The configura- tion file for this problem is presented in Figure 2. Compare this file with Figure 3 and observe that the grid is defined to conform with the openings (one inlet and one outlet), the equipment and the window. The non-isothermal (indicated by T), turbu- lent (denoted by the variables k and epsilon), three-dimensional flow (expressed by the grid definition in X, Y and Z and by the three velocity com- ponents, U, V and W) is solved including buoyancy (indicated by Buoyancy). Two types of boundaries were used to define the inlet (near the ceiling) and the outlet (near the floor): Velocity at the inlet and Mass flow at the outlet. Since the problem is dynamic, the air condition at the inlet and outlet are supplied in a file as a time-series (the identifiers Open_1 and Open_2 indicates that).

Unlike the bps problem where all conditions were defined at the outside surface in the dfs problem, the boun- dary conditions are defined at the inside surface. Apart from the West wall where heat flux is imposed, all surface temperatures are fixed. Observe that all surface conditions are denoted by an identifier. Deliberately, the identifiers are the surface names shown in Figure 2. Those temperature are obtained from a time- series included in a file. Note that 4, 2 and 2 surface boundaries were necessary to define the Back, the Part_kit and West walls, respectively. That is because the window and the openings are located at those walls.

```
------------------------------------------------------------------------------
#  Simulation Title
 Kitchen mechanical ventilated.
#  N. of x-Regions     N. of y-Regions     N. of z-Regions
     1                3                   1
#  Grid X-direction   N. of cells   Length   Pow. law coefficient
     X                7           3.00        1.0
#  Grid Y-direction   N. of cells   Length   Pow. law coefficient
     Y                4           1.50        1.0
     Y               -3           1.00        1.2
     Y                3           1.00        1.1
#  Grid Z-direction   N. of cells   Length   Pow. law coefficient
     Z                9           2.80        1.2
#  Variables:
     U   V   W   T   k   Epsilon   Buoyancy
#  Number of openings
       2
#  Opening type  location  Ii  If  Ji  Jf  Ki  Kf  P(Pa) or m(kg/s)  T('C)  C(-)
     Vel       South     1   1   6   7   8   9       Open_1
     Mas       North     10  10  1   2   1   2       Open_2
#  Number of solid boundaries
       12
#  Solid  Bnd. type    location  Ii  If  Ji  Jf  Ki  Kf   T('C) or Q(W)
     Heat          West     1   1   1  10   1   9       Front
     Temp          East     7   7   1   4   1   9       Back
     Temp          East     7   7   5   7   1   3       Back
     Temp          East     7   7   5   7   4   6       Window
     Temp          East     7   7   5   7   7   9       Back
     Temp          East     7   7   8  10   1   9       Back
     Temp          North    3   7  10  10   1   9       Part_kit
     Temp          North    1   2  10  10   2   9       Part_kit
     Temp          South    1   5   1   1   1   9       Right
     Temp          South    1   7   1   1   1   8       Right
     Temp          High     1   7   1  10   9   9       Ceiling
     Temp          Low      1   7   1  10   1   1       Floor
#  Number of heat/concentration sources
       1
#  Source type   Ii  If  Ji  Jf  Ki  Kf  T('C) or Q(W) or C(-) or CF(kg/s)  Yes(blocked) or No
     Heat       2   3   2   4   1   3          Equipment                    Yes
#  Max. n. of iterations        Max. source of residues
     200                       0.01
#  Number of relaxation factors
       5
#  Relaxation factor type     variable     value
       Linear               U          0.5
       Linear               V          0.5
       Linear               W          0.5
```

```
        Inertia              k          1.0
        Inertia              E          0.1
#   Number of variables to be initiated
        2
#   Initial conditions variable         initial value
          V                        0.10
          T                        20.0
#   Time-step interval to print results          result file name
            4                            Kitchen.res
#   Monitoring position IMON  JMON  KMON          monitoring file name
                  3    1    3              Kitchen.mon
#   Re-initialize simulation ?  Yes or No
                         No
Kitchen.flw
Kitchen.otp
Kitchen.wtp
Kitchen.eqp
-------------------------------------------------------------------------------
```

Figure 2 Example of a dfs configuration file.

Differently from bps, the equipment can be placed geometrically within the Kitchen and the heat released more precisely located. Additionally, as the equip- ment is a piece of furniture, some cells of the domain are blocked to represent it. The identifier Equip- ment in the configuration file indicates that a time-series of convec- tive heat is resident in a file.

The simulation stops after 200 iterations or if the sum of the residuals is less than 1% of the inlet momentum or mass flow rate. Five relaxation factors are specified: linear for velocity components and inertia for turbulent variables. The velocity component in the y direction is made equal to 0.1m/s for all cells in the domain and the tempera- ture field is initialised equal to 20’C. The vari- able fields are stored every four time-steps within the file Kitchen.res. The monitoring position is located at the cell 3,1,3 and the monitoring results, consisting of simulation residuals and monitoring values, are saved to the file Kitchen.mon. The re-initialisation facility is not invoked in this case.

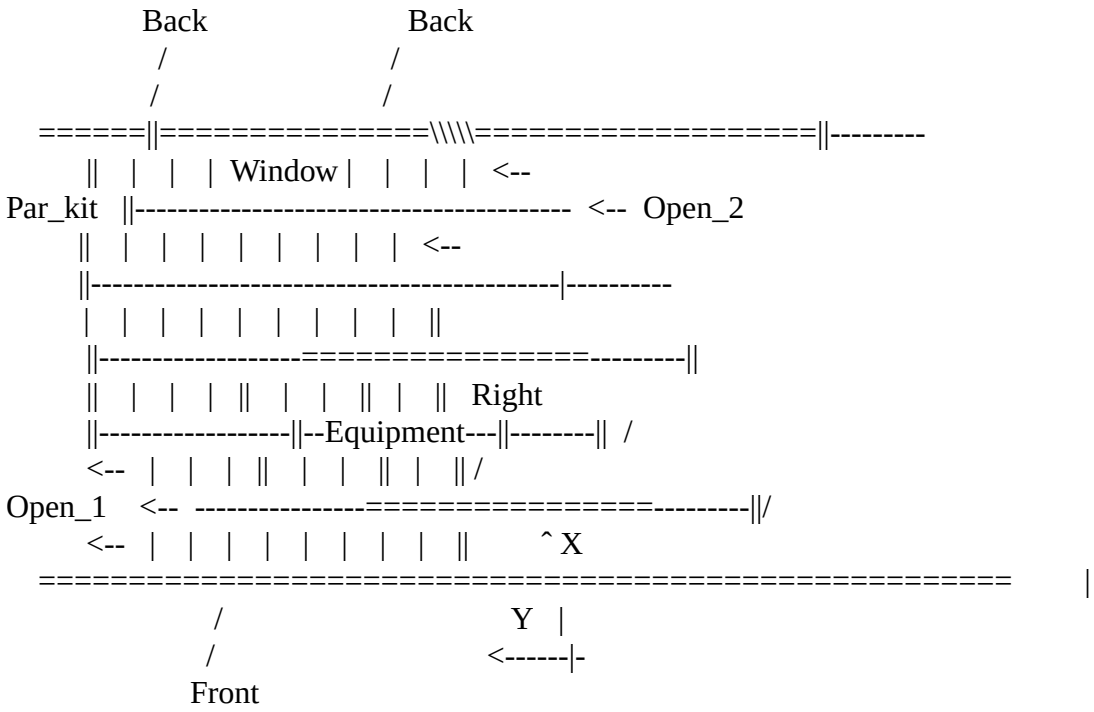

Figure 3 Geometry for the configuration file of Figure 2.

The last four lines in the file supplies the file names of the time-series of flow rates (kitchen.flw) at the open- ings, inlet temperatures (kitchen.otp), surface temperatures (kitchen.tmp) and Equipment heat sources (kitchen.wtp). The time-series of surface temperatures contained in the file Kitchen.wtp are shown in Figure 4. Observe that the first line in such a file indicates the surface name which must match the names provided as boundary conditions. Each column, therefore, contains the surface temperatures or heat fluxes (in the case of Front wall) at each simulation time- step. At each time-step (in this case 1h), the file is read and the surface temperatures up-dated. The other time-series files have the same format as the surface temperature file.

Time(h)	Front	Back	Window	Part_kit	Right	Ceiling	Floor
1.0	0.0	11.0	10.0	15.0	10.0	15.0	9.0
2.0	0.0	11.5	10.4	15.2	10.5	15.3	10.0
3.0	0.0	12.1	11.0	15.5	11.0	15.7	11.0

Figure 4 Time-series of surface temperatures.

5.9.9 Combining bps and dfs

After the discussion of the problem definition of bps and dfs, the problem definition of a combined domain becomes an easy task. Regarding the ther- mal coupling and momentum coupling approaches, the combined method runs as an optional feature and is activated during specified time-steps.

Considering the definition of zones, the problem can be specified in the same manner as introduced in bps and dfs configurations. However, instead of specifying the boundary conditions in the dfs required configuration, the identifier, which is employed for dynamic simulations, must be defined as surface names, connection names and source names in order to match the names specified in the bps configuration. In the case of the simple approach, bps creates a time-series of flow rates, inlet temperatures, surface temperatures, heat sources, etc. in the format of Figure 4. If one of the thermal coupling technique is invoked, surface names and source identifiers are matched within the simulation and the models exchange information accordingly.

In the case of momentum coupling, some other nodes, components and connections in the flow network must be defined. These new connections represent the link between the flow nodal network and the CFD domain. Considering the combined domain as in the diagram of Figure 5, the new network file assumes the format of Figure 6. It should be noted that the two connections in the original network file are not replaced by the new connections but are added to the connection list. In the dfs file, on the other hand, each connection is represented by one opening. Instead of defining one identifier as the opening boundary condition, two identifiers are required: one for the connection which represents the opening, and one for the connection in the original network which is replaced. As can be seen, connections in the network file are defined by five items (two nodes, one component and two heights). Each identifier in the dfs file comprises three items (two nodes and one component). The first node of the first connection must always be the node which represents the dfs cells in the network (see Figure 5.15). No order is required for the definition of the second identifier.

The approach of replacing original connections only during the coupling allows switching between the network and combined approaches during the simulation. In other words, if the combined approach is requested only at specific time-steps during the simulation, the original network can be employed before and after the required steps. Outside the requested time-steps, the replaced network nodes are reac- tivated and the coupling connections between dfs and the flow network are de-activated. Within the required time- steps the opposite takes place. Also, if at the specified time-steps the dfs calculations does not converge, the com- bined network is switched back to the original nodal network and the simulation can proceed without damaging the whole solution. This is also valid for the thermal couplings, although, the replacing mechanism is not necessary because each linkage between surface temperatures and air nodes is substituted by just one join of surface temperature and dfs cells.

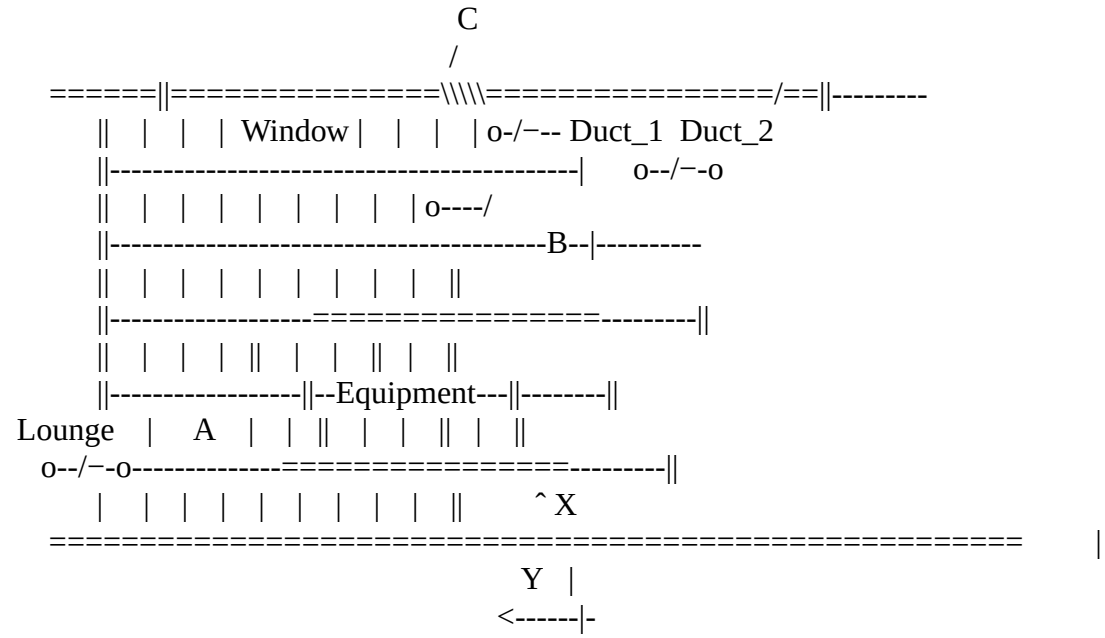

Figure 5 Combined domain.

```
------------------------------------------------------------------------------
  9    5    8    1.000    (nodes, components, connections, wind reduction)
Node   Fld. Type   Height    Temperature    Data_1       Data_2
Duct_1    1    2   2.9000          0.       50.000       1.0000
Duct_2    1    0   2.9000       20.000          0.          0.
Kitche    1    0   1.5000       20.000          0.          0.
Lounge    1    0   1.5000       20.000          0.          0.
Out_n     1    3   1.5000          0.       1.0000          0.
Out_e     1    3   1.5000          0.       1.0000        270.
A         1    0   0.3000       20.000          0.          0.
B         1    0   2.9000       20.000          0.          0.
C         1    0   2.9000       20.000          0.          0.
Comp   Type C+ L+ Description
duct     50  3  0 Laminar pipe vol. flow rate comp.   m = rho.f(L,R,mu,dP)
  1.00000    5.00000    2.50000E-02
open     40  3  0 Common orifice vol. flow rate comp. m = rho.f(Cd,A,rho,dP)
  1.00000    2.00000E-02   0.650000
open1    40  3  0 Common orifice vol. flow rate comp. m = rho.f(Cd,A,rho,dP)
  1.00000    1.00000E-02   0.650000
window   35  2  0 Constant mass flow rate component   m = a
  1.00000   0.500000
door    130  5  0 Specific air flow door             m = rho.f(W,H,dP)
  1.00000   0.800000    2.10000    1.00000   0.650000
+Node   dHght   -Node   dHght   Comp     Snod1  Snod2
Duct_2  0.000   Duct_1  0.000   duct
Duct_1  0.000   Kitche -0.700   open
Kitche  0.700   Lounge  0.700   open
Lounge  0.000   Out_n   0.000   door
```

```
 Lounge  0.000   Out_e   0.000   window
 B       0.000   Duct_1 -0.700   open1
 C       0.000   Duct_1 -0.700   open1
 A       0.000   Lounge -0.700   open
------------------------------------------------------------------------
```

Figure 6 Flow network file for a combined approach simulation.

```
------------------------------------------------------------------------
#   Simulation Title
  Kitchen mechanical ventilated.
#   N. of x-Regions      N. of y-Regions      N. of z-Regions
       1                    3                    1
#   Grid X-direction    N. of cells    Length   Pow. law coefficient
       X                    7           3.00          1.0
#   Grid Y-direction    N. of cells    Length    Pow. law coefficient
       Y                    4           1.50          1.0
       Y                   -3           1.00          1.2
       Y                    3           1.00          1.1
#   Grid Z-direction    N. of cells    Length    Pow. law coefficient
       Z                    9           2.80          1.2
#   Variables:
      U    V    W    T     k    Epsilon    Bouyancy
#   Number of openings
         3
#   Opening type   location   Ii  If  Ji  Jf  Ki  Kf   P(Pa) or m(kg/s)   T('C)   C(-)
      Vel        South      1   1   6   6   9   9   C  Duct_1  Open1   Duct_1  Kitche  Open
      Vel        South      1   1   7   7   9   9   B  Duct_1  Open1   Duct_1  Kitche  Open
      Mas        North     10  10   1   2   1   1   A  Lounge  Open    Kitche  Lounge  Open
#   Number of solid boundaries
         12
#   Solid  Bnd. type     location   Ii  If  Ji  Jf  Ki  Kf    T('C) or Q(W)
       Heat              West       1   1   1  10   1   9        Front
       Temp               East      7   7   1   4   1   9        Back
       Temp               East      7   7   5   7   1   3        Back
       Temp               East      7   7   5   7   4   6        Window
       Temp               East      7   7   5   7   7   9        Back
       Temp               East      7   7   8  10   1   9        Back
       Temp               North     3   7  10  10   1   9        Part_kit
       Temp               North     1   2  10  10   2   9        Part_kit
       Temp               South     1   5   1   1   1   9        Right
       Temp               South     1   7   1   1   1   8        Right
       Temp               High      1   7   1  10   9   9        Ceiling
       Temp               Low       1   7   1  10   1   1        Floor
#   Number of heat/concentration sources
         1
```

```
#  Source type    Ii  If  Ji  Jf  Ki  Kf   T('C) or Q(W) or C(-) or CF(kg/s)   Yes(blocked) or No
     Heat        2   3   2   4   1   3            Equipment                    Yes
#  Max. n. of iterations          Max. source of residues
      200                        0.01
#  Number of relaxation factors
       5
#  Relaxation factor type       variable       value
       Linear                  U             0.5
       Linear                  V             0.5
       Linear                  W             0.5
       Inertia                 k             1.0
       Inertia                 E             0.1
#  Number of variables to be initiated
       2
#  Initial conditions variable          initial value
          V                          0.10
          T                          20.0
#  Time-step interval to print results            result file name
             4                                Kitchen.res
#  Monitoring position IMON  JMON  KMON          monitoring file name
                    3     1     3               Kitchen.mon
#  Re-initialize simulation ?  Yes or No
                          No
-------------------------------------------------------------------------
```

Figure 7 dfs file for a combined approach simulation.

6 Fluid flow network description file (optional)

This file (usually named ?.mfn) describes a building and/or plant fluid mass flow network. Based on this description, *bps* can pursue mass flow simulation in tandem with the energy balance computations. The fluid mass flow simulation assumes one-dimensional steady flow in a building and/or plant configuration which is subjected to certain boundary conditions. This involves calculation of mass flow through the connections of a nodal network. The nodes of the network represent either internal or boundary pressures; the connections represent flow paths. The unknown fluid flows and pressures are found by an iterative mass balance approach in which non-boundary nodal pressures are adjusted until the mass residual of each internal node satisfies some criterion.
Information on potential mass flows is given to *esp-r* in terms of fluid type (presently only air and water are supported, but this can easily be expanded), node descriptions, flow component types (pipe/duct, pump, opening, crack, doorway, valve etc.), interconnections and boundary conditions. In this way a nodal network (or perhaps several decoupled subnetworks) of connecting resistances is constructed. This may then be attached, at its boundaries, to pressure coefficient sets which represent the relationship between free-stream wind vectors and the zone surface pressures to result. The file to emerge is referenced in the system configuration file for transfer, along with the pressure coefficients file (see following section), to *bps*. Alternatively, the mass flow network description and pressure coefficients files can be input to *mfs*. This allows independent mass flow studies of building and/or plant configurations which are predominately pressure driven. *mfs does* include buoyancy effects, but against fixed nodal temperatures. If this option is selected then the predicted mass flows can still be transferred to *bps* via the mechanism of the building and plant fluid mass flow file.

There are several important points to note when describing a fluid mass flow network:

- A mass flow network may consist of several sub-networks and is not restricted to one fluid. However, all nodes and components within a sub-network must be of the same fluid type. The possibilities with respect to node type are shown in Table 12, and the fluid mass flow component types currently on offer, are summarised in Table 16 at the end of this section.

Code	Type	Supplementary data
0	Internal; unknown pressure	None
1	Internal; known pressure	total pressure (Pa)
2	Boundary; known pressure	1) total pressure (Pa) 2) fluid temperature flag, indicating 0 = node temperature is constant 1 = node temperature equals outside air temperature
3	Boundary; wind pressure*	1) wind pressure coefficients index 2) surface azimuth (° clockwise from North)
* only allowed when fluid type is air		

Table 12 Mass flow network *node types*.

Record	Description of fields
1	Number of nodes, components, interconnections and wind reduction factor
2	A list of titles for the node data which follows
3 $\rightarrow$ I	For each node: name/identifier, fluid, type (internal or boundary with known, wind induced or unknown pressure), height above datum, temperature, and up to two supplementary data items
I+1	A list of titles for the flow components data which follows
I+2	For each flow component: name/identifier, type code (for duct/pipe, pump, crack, area, doorway, etc), number of component level supplementary data items for that type, number of connection level supplementary data items for that type (ie. additional node names), and short description
I+3	Component level supplementary data items
I+4 $\rightarrow$ J	Repeat records I+2 and I+3 for each additional flow component in turn
J+1	A list of titles for the connections data which follows
J+2 $\rightarrow$ K	For each interconnection in turn: name of node on +ve side of connection, height of +ve linkage point relative to node on +ve side, name of node on -ve side of connection, height of -ve linkage point relative to node on -ve side, name of connecting component, and up to two supplementary node names

Table 11 Contents of the *mass flow network description* file.

- It is quite easy to define a mass flow network which has no unique solution. One requirement for solution is that at least one of the node pressures is known. A second requirement is that all nodes must be linked, through some path, to a known pressure node.
- The nodes of the network represent either internal or boundary pressures. In this context, internal and boundary does not have to be the same as inside and outside (a building). Internal in terms of the network means that these nodes are subjected to the mass balance approach, whereas for boundary nodes, a mass balance is not established. The pressure at a node may be unknown or known; wind induced pressure is a special case of the latter. The defined network is then arrived at by connecting a number of internal and boundary nodes by branches which represent some resistance to inter-zone or intra-plant fluid flow. For the case of use by *bps*, the established mass flow network need not match the multi-zone and plant component network referenced in the system configuration file to define the building and/or plant for energy simulation. At the time of system configuration file construction, it is necessary, if a mass flow simulation is required, to define the mapping between building zones and plant components on the one hand and nodes defined as part of the mass flow network on the other hand. This allows some flexibility in problem description since the energy and mass flow systems are not constrained to the same boundary conditions. For example, it is possible to generate a partial building and

plant model, of 5 building zones and 10 plant components say, for energy simulation purposes, and then to deploy a greater number of nodes, say 50, to represent an air flow network which accurately expresses the leakage distribution of the entire building and flow characteristics of the mechanical ventilation system. Some of the mass flow nodes - 15 or less in this example - will correspond to the building zones or plant components, the others are merely present to enhance the fluid mass flow predictions. Of course the schemes can be exactly matched if required. Within *bps* only the temperatures of matched zones or plant components will vary with time. All other nodes in the mass flow network will retain, throughout a simulation, the temperatures assigned in the mass flow network description file. Note that the temperature of a node may be defined to be equal to the temperature of some other participating node. This is achieved by entering the name of the other node instead of the current node's temperature. By this mechanism more then one mass flow network node may be (temperature) linked to a building zone or plant component.

- The node reference height is used as part of the buoyancy calculations. It defines the mean height of the associated building zone or plant component.
- To determine wind induced pressure requires that the "free stream" wind velocity (as read from the climate file) be mapped onto the surface as a function of the wind's vertical velocity profile and the sheltering effect of remote and local facade obstructions. The latter effect is usually accounted for by a dimensionless pressure coefficient:

$$C_{p,i,d} = \frac{P_i}{1/2\rho V_{rd}{}^2} \ (-)$$

where $C_{p,i,d}$ is the pressure coefficient for a surface location i corresponding to wind from direction d, P_i is the surface pressure (Pa), ρ is the air density (kg/m^3) and V_{rd} is the wind speed (m/s) at some reference level r and from direction d (expressed relative to the external surface normal vector). The wind speed reference level is usually equal to the building height. The ratio between this local reference wind speed and the wind speed as read from the climate file, is called the wind speed reduction factor. The *mfs* user input module offers several possibilities with respect to input of this reduction factor. The first one is to input the wind speed reduction factor directly. Alternatively, the user must supply additional data (regarding terrain roughness etc.) so as to calculate the wind speed reduction factor from: (1) "powerlaw" wind profile, (2) logarithmic wind profile, or (3) LBL air infiltration model wind profile.
- For each boundary node with wind induced pressure, a reference must be made to an appropriate pressure coefficient set as held in the pressure coefficients file (see section 7). Any number of sets may reside in this file, with reference codes given simply as 1, 2, 3 and so on. It is the pressure coefficient, appropriate to the wind direction prevailing at any time, that dictates, as a function of the prevailing wind speed at roof height, the generated boundary (i.e. external surface) pressure.
- For wind induced boundary pressure nodes, the azimuth is required to define the zone's orientation relative to the building configuration. The required response is degrees from north, clockwise positive so that north is zero, east is 90° and south is 180°. In the case of an 'up' or 'down' zone, the azimuth has no meaning and may be

set to zero.

- Connections are defined by the nodes on either side. Note that a connection joining node A to B is different from one joining B to A. More then one connection may exist between two nodes. The relative heights are a convenient way of expressing the flow component inlet and outlet heights. For example, it is quite common for flow components in the building fabric to only differ with respect to inlet and outlet heights relative to the zone heights. If the flow component is part of a duct or pipe network, the relative heights will be zero.
- Some component types need additional data at the connection description level. These supplementary items may be the names of the nodes which play a role in the functioning of that component. Or, in case the component is some flow controller which receives a signal from the plant side (sensed property = 0), the data item is a pointer identifying a plant control loop in the system configuration file. At present supplementary items are only needed for the component types indicated in Table 13.

type	description	supplementary data
220	conduit ending in converging 3-leg junction	name of node to which the other entrance of the junction is connected
230	conduit starting in diverging 3-leg junction	name of node to which the other exit of the junction is connected
240	conduit ending in converging 4-leg junction	name of nodes (2) to which the other entrances of the junction are connected
250	conduit starting in diverging 4-leg junction	name of nodes (2) to which the other exits of the junction are connected
410 420 450 460	general flow corrector flow corrector with polynomial resistance ideal open/shut flow controller fixed flow rates controller	in case of a flow controller which receives a signal from the plant side (sensed property = 0), the data item is a pointer identifying a plant control loop in the system configuration file; and the supplementary node names are: in case of a temperature or pressure sensor the name of the referenced node, and in case of a temperature difference, pressure difference or mass flow rate sensor the names of two referenced nodes

Table 13 Component types and requirements for supplementary node names and data items.

- Like *mfs*, *esp-r* is endowed with interactive node, component and connection definition and editing facilities. If a node or component name does not correspond to a

11	12	15	0.438	(nodes, components, connections, wind reduction)		
Node	**Fld.**	**Type**	**Height**	**Temperature**	**Data_1**	**Data_2**
living	1	0	1.5000	21.000	0.	0.
kitche	1	0	1.5000	20.800	0.	0.
w_ctl	1	0	1.5000	20.800	0.	0.
bed	1	0	4.5000	21.000	0.	0.
bath	1	0	4.5000	21.000	0.	0.
south	1	3	1.5000	0.	18.000	180.00
north	1	3	1.5000	0.	18.000	0.
roof	1	3	7.0000	0.	20.000	0.
t_junc	1	0	5.0000	21.000	0.	0.
fan_in	1	0	6.0000	21.000	0.	0.
fan_ou	1	0	6.0000	21.000	0.	0.
Comp	**Type**	**C+**	**L+**	**Description**		
crack	120	3	0	Specific air flow crack	m = rho.f(W,L,dP)	
1.00	3.000E-03	5.000				
stairs	110	2	0	Specific air flow opening	m = rho.f(A,dP)	
1.000	1.000					
door	130	5	0	Specific air flow door	m = rho.f(W,H,dP)	
1.000	2.000	2.100	1.500	0.920		
window	40	3	0	Common orifice vol. flow rate comp.	m = rho.f(Cd,A,rho,dP)	
1.000	1.000	0.650				
grl_ex	40	3	0	Power law vol. flow component	m = rho.a.dP^b	
1.000	0.020	0.700				
grl_in	10	3	0	Power law vol. flow component	m = rho.a.dP^b	
1.000	5.000	0.500				
fan	310	7	0	General flow inducer component	dP= a0+Sai(m/rho)^i	
1.000	0.	1.000E-01	125.000	0.	-12500.0	0.
duct_1	220	13	1	Conduit ending in converging 3-leg junction & Ccp = f(q/qc)		
1.000	0.125	1.227E-02	2.500	1.500E-04	18.000	7.853E-03
1.000E-02	0.	0.	1.500	-0.970	0.	
duct_2	220	13	1	Conduit ending in converging 3-leg junction & Ccp = f(q/qc)		
1.000	0.1250	1.227E-02	2.000	1.500E-04	36.00	7.853E-03
-0.8000	2.970	-1.090	0.	0.	0.	
duct_3	210	6	0	General flow conduit component	m = rho.f(D,A,L,k,SCi)	
1.000	0.125	1.227E-02	1.500	1.500E-04	0.2500	
duct_4	210	6	0	General flow conduit component	m = rho.f(D,A,L,k,SCi)	
1.000	0.1250	1.227E-02	2.000	1.500E-04	2.900	
w_ctl	450	8	2	Ideal (frictionless) open/shut flow controller		
1.000	7.000	16.000	20.000	0.	2.000	20.000	0.
+Node	**dHght**	**-Node**	**dHght**	**Comp**	**Snod1**	**Snod2**
living	0.000	kitche	0.000	door		
living	1.500	bed	-1.500	stairs		
bed	-1.000	bath	-1.000	grl_in		
south	-1.300	living	-1.300	crack		
south	1.300	living	1.300	grl_ex		
south	3.500	bed	0.500	grl_ex		
bath	0.500	north	3.500	crack		
kitche	1.200	north	1.200	crack		
kitche	0.000	w_ctl	0.000	w_ctl	kitche	north
w_ctl	0.500	north	0.500	window		
kitche	0.500	t_junc	0.000	duct_1	bath	
bath	0.500	t_junc	0.000	duct_2	kitche	
t_junc	0.000	fan_in	0.000	duct_3		
fan_in	0.000	fan_ou	0.000	fan		
fan_ou	0.000	roof	0.000	duct_4		

Table 14 Example of a *mass flow network description* file.

name already specified then a new entry is created. Otherwise it is assumed that an existing entry is to be edited. During connection definition, the connected nodes are referenced; if the connection already exists then it can be edited or an additional connection created.

- For most mass flow component types, uni-directional fluid flow will result (in either direction). However, some component types - for example in case of a doorway due to the action of small density variations over the height - may show bi-directional fluid movement.
- During results analysis, the time-dependent mass flows through each connection may be recalled from a mass flow results file generated by *bps* or *mfs*. As an

example, a piece of a mass flow results file is shown in Table 15. This file holds for each time step: climate data, number of iterations (It), indication of iteration process success (OK), node and connection data and results. The node results comprise pressure (Pa), mass flow residual (kg/s) and the sum of the absolute values of all node coupled mass flows (kg/s). The connection results comprise total pressure difference across the connection (Pa), pressure difference due to stack effect (Pa) and one or two mass flows (a positive value indicates that the flow is from the node defined as positive towards the node defined as negative).

Date: 9/ 1/1967 12.00 Dryb= -1.0 Wdir= 345. Wvel= 1.4 It= 7 OK=1

Node	**Fld**	**Type**	**Temp**	**Hght**	**Pressure**	**Residual**	**Sabs(Flw)**	
living	1	0	21.0	1.5	-23.150	0.51258E-06	0.42086	
kitche	1	0	20.8	1.5	-23.154	-0.52800E-07	0.40522	
w_ctl	1	0	20.8	1.5	-18.796	0.	0.	
bed	1	0	21.0	4.5	-57.997	-0.15738E-03	0.39116E-01	
bath	1	0	21.0	4.5	-57.997	0.46190E-07	0.48436E-01	
south	1	3	-1.0	1.5	-19.835	-0.45106E-01	0.45106E-01	
north	1	3	-1.0	1.5	-18.331	-0.12443E-01	0.12443E-01	
roof	1	3	-1.0	7.0	-88.818	0.57706E-01	0.57706E-01	
t_junc	1	0	21.0	5.0	-124.63	-0.71409E-06	0.11541	
fan_in	1	0	21.0	6.0	-141.52	0.64808E-06	0.11541	
fan_ou	1	0	21.0	6.0	-46.206	-0.17658E-06	0.11541	

From	**To**	**Comp**	**Typ**	**Fld**	**Pi-Pj**	**Pstack**	**Flw 1**	**Flw 2**
living	kitche	door	130	1.	0.39953E-02	0.	0.19456	-0.16930
living	bed	stairs	110	1.	34.847	-34.847	0.20067E-01	0.
bed	bath	grl_in	10	1.	0.11370E-04	0.	0.19963E-01	0.
south	living	crack	120	1.	3.9248	1.4580	0.10021E-01	0.
south	living	grl_ex	40	1.	3.9248	-1.4580	0.35434E-01	0.
south	bed	grl_ex	40	1.	38.772	-38.772	-0.23101E-03	0.
bath	north	crack	120	1.	-40.119	38.772	-0.42940E-02	0.
kitche	north	crack	120	1.	-5.2753	1.3363	-0.82791E-02	0.
kitche	w_ctl	w_ctl	450	1.	-4.7185	0.	0.	0.
w_ctl	north	window	40	1.	-0.55680	0.55680	0.	0.
kitche	t_junc	duct_1	220	1.	101.67	-40.682	0.33541E-01	0.
bath	t_junc	duct_2	220	1.	66.823	-5.8078	0.24256E-01	0.
t_junc	fan_in	duct_3	210	1.	16.905	-11.616	0.57797E-01	0.
fan_in	fan_ou	fan	310	1.	-95.216	0.	0.57797E-01	0.
fan_ou	roof	duct_4	210	1.	42.710	-11.616	0.57797E-01	0.

Table 15 Example of some *mass flow network results*

type	description	"formula"	supplementary data[1]
10	Power law volume flow resistance component	$\dot{m} = \rho\ a\Delta P^b$	2. coefficient a 3. exponent b
15	Power law mass flow resistance component	$\dot{m} = a\Delta P^b$	2. coefficient a 3. exponent b
17	Power law mass flow resistance component	$\dot{m} = a\sqrt{\rho}\,\Delta P^b$	2. coefficient a 3. exponent b
20	Quadratic law volume flow resistance component	$\Delta P = a\dot{m}/\rho + b(\dot{m}/\rho)^2$	2. coefficient a 3. coefficient b
25	Quadratic law mass flow resistance component	$\Delta P = a\,\dot{m} + b\,\dot{m}^2$	2. coefficient a 3. coefficient b
30	Constant volume flow rate component	$\dot{m} = \rho\ a$	2. volume flow rate a
35	Constant mass flow rate component	$\dot{m} = a$	2. mass flow rate a
40	Common orifice flow component	$\dot{m} = \rho\ f(Cd\ A\ \rho\Delta P)$	2. opening area A

type	description	"formula"	supplementary data[1]
			3. discharge factor Cd
50	Laminar pipe flow component	$\dot{m} = \rho\ f(L\ R\ \mu\ \Delta P)$	2. length of flow path L 3. radius of opening R
110	Specific air flow opening[2]	$\dot{m} = \rho\ f(A \Delta P)$	2. area A
120	Specific air flow crack	$\dot{m} = \rho\ f(W\ L\ \Delta P)$	2. crack width W 3. crack length L
130	Specific air flow door	$\dot{m} = \rho\ f(W\ H\ Hr\ Cd\ \Delta P)$	2. door width W 3. door height H 4. reference height Hr[3] 5. discharge factor Cd[4]
210	General flow conduit (duct or pipe)	$\dot{m} = \rho\ f(D_h\ A\ L\ k\ \Sigma C_i\ \nu\ \Delta P)$	2. hydraulic diameter D_h 3. cross-sectional area A 4. conduit length L 5. wall roughness k 6. sum of local dynamic loss factors ΣC_i
220	Flow conduit ending in converging 3-leg junction[5]	$\dot{m} = \rho\ f(D_h\ A\ L\ k\ \Sigma C_i\ \nu\ \Delta P)$ $C_{c,\,p} = f(a_{0\text{–}5}, \frac{q_p}{q_c}, \frac{q_{p'}}{q_c})$[6]	2-6. see type 210 7. cross-sectional area A_c of common section 8. coefficient a_0 9. coefficient a_1 10. coefficient a_2 11. coefficient a_3 12. coefficient a_4 13. coefficient a_5
230	Flow conduit starting in diverging 3-leg junction[5]	$\dot{m} = \rho\ f(D_h\ A\ L\ k\ \Sigma C_i\ \nu\ \Delta P)$ $C_{c,\,p} = f(a_{0\text{–}5}, \frac{q_p}{q_c}, \frac{q_{p'}}{q_c})$[6]	2-6. see type 210 7. cross-sectional area A_c of common section 8. coefficient a_0 9. coefficient a_1 10. coefficient a_2 11. coefficient a_3 12. coefficient a_4 13. coefficient a_5
240	Flow conduit ending in converging 4-leg junction[5]	$\dot{m} = \rho\ f(D_h\ A\ L\ k\ \Sigma C_i\ \nu\ \Delta P)$ $C_{c,\,p} = f(a_{0\text{–}9}, \frac{q_p}{q_c}, \frac{q_{p'}}{q_c}, \frac{q_{p''}}{q_c})$[7]	2-6. see type 210 7. cross-sectional area A_c of common section 8. coefficient a_0 9. coefficient a_1 10. coefficient a_2 11. coefficient a_3 12. coefficient a_4 13. coefficient a_5 14. coefficient a_6 15. coefficient a_7 16. coefficient a_8 17. coefficient a_9
250	Flow conduit starting in diverging 4-leg junction[5]	$\dot{m} = \rho\ f(D_h\ A\ L\ k\ \Sigma C_i\ \nu\ \Delta P)$	2-6. see type 210 7. cross-sectional area A_c of common section

type	description	"formula"	supplementary data[1]
		$C_{c,\,p} = f(a_{0\text{–}9}, \frac{q_p}{q_c}, \frac{q_{p'}}{q_c}, \frac{q_{p''}}{q_c})$[7]	8. coefficient a_0 9. coefficient a_1 10. coefficient a_2 11. coefficient a_3 12. coefficient a_4 13. coefficient a_5 14. coefficient a_6 15. coefficient a_7 16. coefficient a_8 17. coefficient a_9
310	General flow inducer (pump or fan)	$\Delta P = \sum_{i=0}^{3} a_i(\dot{m}/\rho)^i$ $\dot{q}_{\min} \le \dot{m}/\rho \le \dot{q}_{\max}$	2. min. volume flow $\dot{q}_{\min}$ 3. max. volume flow $\dot{q}_{\max}$ 4. coefficient a_0 5. coefficient a_1 6. coefficient a_2 7. coefficient a_3
410	General flow corrector[5,8]	$\dot{m} = \rho\ f(\rho_0\, \Delta P_0\, k_{vs}\, k_{v0}\, k_{vr}\, H/H_{100})$ $H/H_{100} = f(day\ time\ S_l\ H_l\ S_u\ H_u)$	2. standard density ρ_0 3. standard pressure ΔP_0 4. index for characteristic 5. vol. flow if fully-open k_{vs} 6. theor. flow if closed k_{v0} (%) 7. min. flow for charac. k_{vr} (%) 8. control period day type index 9. control period start hour 10. control period finish hour 11. H/H_{100} outside period (%) 12. sensed property index 13. signal lower limit S_l 14. H/H_{100} at S_l (%) 15. signal upper limit S_u 16. H/H_{100} at S_u (%) 17. ΔS to overcome hysteresis
420	Flow corrector with polynomial flow resistance[5,8]	$\dot{m} = f(\rho A\, \Delta P\, C)$ $C = \sum_{i=0}^{3} a_i(H/H_{100})^i$ $H/H_{100} = f(day\ time\ S_l\ H_l\ S_u\ H_u)$	2. area A of section containing corrector 3. coefficient a_0 4. coefficient a_1 5. coefficient a_2 6. coefficient a_3 7. control period day type index 8. control period start hour 9. control period finish hour 10. H/H_{100} outside period (%) 11. sensed property index 12. signal lower limit S_l 13. H/H_{100} at S_l (%) 14. signal upper limit S_u 15. H/H_{100} at S_u (%) 16. ΔS to overcome hysteresis
450	Ideal (frictionless) open/shut[5,8] flow controller	$\dot{m} = 0$ or $\Delta P = 0$	2. control period day type index 3. control period start hour 4. control period finish hour 5. open(1)/shut(0) outside control period 6. sensed property index 7. signal set point S_{sp} 8. open(1)/shut(0) when $S \ge S_{sp}$
460	Fixed flow rates controller[5,8] flow controller	$\dot{m}/\rho = \dot{q}_0$ or $= \dot{q}_l$ or $= \dot{q}_u$	2. control period day type index 3. control period start hour

type	description	"formula"	supplementary data[1]
			4. control period finish hour 5. volume flow rate outside control period ($\dot{q}_0$) 6. sensed property index 7. signal set point S_{sp} 8. volume flow rate ($\dot{q}_0$) when $S < S_{sp}$ 9. volume flow rate ($\dot{q}_0$) when $S \geq S_{sp}$

Notes

(1) first supplementary data item is always fluid type (1 = air, 2 = water); unless indicated otherwise, all data is expressed in SI (derived) units, ie. s, m, kg, N

(2) identical to type 40 with $Cd = 0.65$ [–]

(3) often set to: $Hr = 1.50$ [m]

(4) often set to: $Cd = 0.92$ [–]

(5) this component also needs supplementary data at the connection description level

(6) $C_{c,\,p}$ is the local loss factor representing the dynamic losses due to the junction. Subscript c indicates common flow path. Subscript p refers to the junction's section which is connected to the conduit being described and indicates either straight or branch flow path; subscript p' then indicates the other entrance/exit of the junction. p' is defined by the first supplementary data item at the connection description level. The expression for the local dynamic loss factor is:

$$C_{c,\,p} = a_0 + a_1\left(\frac{\dot{q}_p}{\dot{q}_c}\right) + a_2\left(\frac{\dot{q}_p}{\dot{q}_c}\right)^2 + a_3\left(\frac{\dot{q}_{p'}}{\dot{q}_c}\right) + a_4\left(\frac{\dot{q}_{p'}}{\dot{q}_c}\right)^2 + a_5\left(\frac{\dot{q}_p}{\dot{q}_c}\cdot\frac{\dot{q}_{p'}}{\dot{q}_c}\right) \quad (–)$$

(7) $C_{c,\,p}$ is the local loss factor representing the dynamic losses due to the junction. Subscript c indicates common flow path. Subscript p refers to the junction's section which is connected to the conduit being described and indicates either straight or branch flow path; subscripts p' and p" then indicate the other entrances/exits of the junction. p' is defined by the first supplementary data item at the connection description level, and p" is defined by the second supplementary data item. The expression for the local dynamic loss factor is:

$$C_{c,\,p} = a_0 + a_1\left(\frac{\dot{q}_p}{\dot{q}_c}\right) + a_2\left(\frac{\dot{q}_p}{\dot{q}_c}\right)^2 + a_3\left(\frac{\dot{q}_{p'}}{\dot{q}_c}\right) + a_4\left(\frac{\dot{q}_{p'}}{\dot{q}_c}\right)^2 + a_5\left(\frac{\dot{q}_p}{\dot{q}_c}\cdot\frac{\dot{q}_{p'}}{\dot{q}_c}\right)$$

$$+ a_6\left(\frac{\dot{q}_{p"}}{\dot{q}_c}\right) + a_7\left(\frac{\dot{q}_{p"}}{\dot{q}_c}\right)^2 + a_8\left(\frac{\dot{q}_p}{\dot{q}_c}\cdot\frac{\dot{q}_{p"}}{\dot{q}_c}\right) + a_9\left(\frac{\dot{q}_{p'}}{\dot{q}_c}\cdot\frac{\dot{q}_{p"}}{\dot{q}_c}\right) \quad (–)$$

(8) "standard" here refers to conditions implicit in k_{vs}, k_{v0}, k_{vr}

index for characteristic: 1 = linear behaviour; 2 = logarithmic behaviour

H/H_{100} denotes the percentage valve position (H, ie. stem displacement or blade angle) relative to fully open position H_{100}

day type index: 1 weekdays only; 2 Saturday only; 3 Sunday only; 4 Saturday+Sunday; 5 weekdays+Saturday; 6 weekdays+Sunday; 7 every day

sensed property index: 0 sensor defined in configuration control file; 1 nodal temperature T_{n1} $(°C)$[5]; 2 signed nodal temperature difference $T_{n1} - T_{n2}$ (K) [5]; 3 absolute nodal temperature difference $|T_{n1} - T_{n2}|$ (K) [5]; 4 nodal pressure P_{n1} (Pa) [5]; 5 signed nodal pressure difference $P_{n1} - P_{n2}$ (Pa) [5]; 6 absolute nodal pressure difference $|P_{n1} - P_{n2}|$ (Pa) [5]; 7 signed mass flow rate (kg/s) in the connection from node $n1$ to $n2$[5]; 8 absolute mass flow rate (kg/s) in the connection from node $n1$ to $n2$[5]; 9 wind speed (m/s); 10 wind direction (degrees clockwise from North); 11 diffuse horizontal solar radiation (W/m^2); 12 direct normal solar radiation (W/m^2); 13 relative humidity of outdoor air (%)

when $S_l < S < S_u$, H/H_{100} is found by linear interpolation between H_l and H_u and taking into account the hysteresis

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Table 16 Currently supported *fluid flow component types*.

7 Pressure coefficients file (optional)

Prior to creating a description of a building's leakage distribution, it is necessary to ensure that a number of pressure coefficient sets are available to represent the relationship between free stream wind velocities and the pressures generated on the various building surfaces. A coefficient set is comprised of 16 values, each corresponding to wind approaching within a 22.5° compass sector. An individual pressure coefficient then gives the surface pressure generated by wind approaching from a given direction in terms of any intervening site obstructions:

$$C_{id} = \frac{P_{id}}{\frac{1}{2}\rho V_f^2}$$

where C_{id} is the pressure coefficient for some surface location i and corresponding to wind from direction d, P_{id} is the surface pressure (Nm^{-2}), ρ the air density (kgm^{-3}) and V_f the free stream wind speed for direction d (ms^{-1}).

The following table summarises the contents of the pressure coefficients file. If the pressure coefficient for an external surface is independent of wind direction - as in the case of an unobstructed horizontal roof - then 16 equal values must be entered.

Record	Description of fields
1	Number of coefficient sets held.
2	For first set: pressure coefficient for 16 compass directions.
3 →	Repeat record 2 for each additional set.

Table 17 Contents of a *pressure coefficients* file.

The 16 compass directions are expressed relative to the external surface normal vector. The first coefficient therefore corresponds to wind impinging normally on the surface, with the following values corresponding to 22.5°, 45°, 67.5°, 90°, 112.5°, 135°, 157.5°, 180°, 202.5°, 225°, 247.5°, 270°, 292.5°, 315° and 337.5° progressing clockwise in plan from above. A coefficient set can therefore be used for more than one surface, if appropriate, since it is independent of absolute surface orientation.

A standard pressure coefficients collection is available with ESP-r and is called **pressc.db1**. The following table shows the 29 sets.

Database Reference	The pressure coefficient sets of the file pressc.db1
1	0.700 0.525 0.350 -0.075 -0.500 -0.450 -0.400 -0.300 -0.200 -0.300 -0.400 -0.450 -0.500 -0.075 0.350 0.525
2	-0.800 -0.750 -0.700 -0.650 -0.600 -0.550 -0.500 -0.450 -0.400 -0.450 -0.500 -0.550 -0.600 -0.650 -0.700 -0.750
3	-0.400 -0.450 -0.500 -0.550 -0.600 -0.550 -0.500 -0.450 -0.400 -0.450 -0.500 -0.550 -0.600 -0.550 -0.500 -0.450
4	0.300 -0.050 -0.400 -0.500 -0.600 -0.500 -0.400 -0.450 -0.500 -0.450 -0.400 -0.500 -0.600 -0.500 -0.400 -0.050
5	0.400 0.250 0.100 -0.100 -0.300 -0.325 -0.350 -0.275 -0.200 -0.275 -0.350 -0.325 -0.300 -0.100 0.100 0.250
6	-0.600 -0.550 -0.500 -0.450 -0.400 -0.450 -0.500 -0.550 -0.600 -0.550 -0.500 -0.450 -0.400 -0.450 -0.500 -0.550
7	-0.350 -0.400 -0.450 -0.500 -0.550 -0.500 -0.450 -0.400 -0.350 -0.400 -0.450 -0.500 -0.550 -0.500 -0.450 -0.400
8	0.300 -0.100 -0.500 -0.550 -0.600 -0.550 -0.500 -0.500 -0.500 -0.500 -0.500 -0.550 -0.600 -0.550 -0.500 -0.100
9	0.200 0.125 0.050 -0.100 -0.250 -0.275 -0.300 -0.275 -0.250 -0.275 -0.300 -0.275 -0.250 -0.100 0.050 0.125
10	-0.500 -0.500 -0.500 -0.450 -0.400 -0.450 -0.500 -0.500 -0.500 -0.500 -0.500 -0.450 -0.400 -0.450 -0.500 -0.500
11	-0.300 -0.350 -0.400 -0.450 -0.500 -0.450 -0.400 -0.350 -0.300 -0.350 -0.400 -0.450 -0.500 -0.450 -0.400 -0.350
12	0.250 -0.025 -0.300 -0.400 -0.500 -0.400 -0.300 -0.350 -0.400 -0.350 -0.300 -0.400 -0.500 -0.400 -0.300 -0.025
13	0.500 0.375 0.250 -0.125 -0.500 -0.650 -0.800 -0.750 -0.700 -0.750 -0.800 -0.650 -0.500 -0.125 0.250 0.375
14	0.600 0.400 0.200 -0.350 -0.900 -0.750 -0.600 -0.475 -0.350 -0.475 -0.600 -0.750 -0.900 -0.350 0.200 0.400
15	-0.700 -0.700 -0.700 -0.750 -0.800 -0.750 -0.700 -0.700 -0.700 -0.700 -0.700 -0.750 -0.800 -0.750 -0.700 -0.700

Database Reference	The pressure coefficient sets of the file pressc.db1
16	-0.700 -0.700 -0.700 -0.700 -0.700 -0.650 -0.600 -0.550 -0.500 -0.550 -0.600 -0.650 -0.700 -0.700 -0.700 -0.700
17	0.250 0.125 0.000 -0.300 -0.600 -0.750 -0.900 -0.850 -0.800 -0.850 -0.900 -0.750 -0.600 -0.300 0.000 0.125
18	0.250 0.150 0.060 -0.150 -0.350 -0.470 -0.600 -0.550 -0.500 -0.550 -0.600 -0.470 -0.350 -0.150 0.060 0.160
19	0.400 0.300 0.200 -0.200 -0.600 -0.550 -0.500 -0.400 -0.300 -0.400 -0.500 -0.550 -0.600 -0.200 0.200 0.300
20	-0.600 -0.600 -0.600 -0.600 -0.600 -0.600 -0.600 -0.600 -0.600 -0.600 -0.600 -0.600 -0.600 -0.600 -0.600 -0.600
21	-0.600 -0.600 -0.600 -0.580 -0.550 -0.550 -0.550 -0.500 -0.450 -0.500 -0.550 -0.550 -0.550 -0.580 -0.600 -0.600
22	0.150 0.035 -0.080 -0.240 -0.400 -0.575 -0.750 -0.675 -0.600 -0.675 -0.750 -0.575 -0.400 -0.240 -0.080 0.035
23	0.060 -0.030 -0.120 -0.160 -0.200 -0.290 -0.380 -0.340 -0.300 -0.340 -0.380 -0.290 -0.200 -0.160 -0.120 -0.030
24	0.180 0.165 0.150 -0.075 -0.300 -0.310 -0.320 -0.260 -0.200 -0.260 -0.320 -0.310 -0.300 -0.075 0.150 0.165
25	-0.490 -0.475 -0.460 -0.435 -0.410 -0.435 -0.460 -0.475 -0.490 -0.475 -0.460 -0.435 -0.410 -0.435 -0.460 -0.475
26	-0.490 -0.475 -0.460 -0.435 -0.410 -0.435 -0.460 -0.430 -0.400 -0.430 -0.460 -0.435 -0.410 -0.435 -0.460 -0.475
27	0.060 -0.045 -0.150 -0.190 -0.230 -0.420 -0.600 -0.510 -0.420 -0.510 -0.600 -0.420 -0.230 -0.190 -0.150 -0.045
28	0.900 0.700 0.500 0.200 -0.100 -0.100 -0.200 -0.200 -0.200 -0.200 -0.200 -0.100 -0.100 0.200 0.500 0.700
29	-0.100 -0.100 -0.100 -0.100 -0.100 -0.100 -0.100 -0.100 -0.100 -0.100 -0.100 -0.100 -0.100 -0.100 -0.100 -0.100

Table 18 Pressure coefficient sets of the *pressc.db1* database.

The collection is comprised of 29 coefficient sets. The first 27 are taken from a publication of the IEA's Air Infiltration and Ventilation Centre (*Air Infiltration Calculation Techniques - An Applications Guide*). These sets can be used (with care) for low-rise buildings (up to 3 storeys).

The following table describes each coefficient set in terms of surface aspect, dimensions and exposure.

Database Reference	**Facade Description**	**Length to width Ratio**	**Exposure**
1	Wall	1:1	Exposed
2	Roof, pitch > 10 deg	1:1	Exposed
3	Roof, pitch 10-30 deg	1:1	Exposed
4	Roof, pitch > 30 deg	1:1	Exposed
5	Wall	1:1	Semi-Exposed
6	Roof, pitch < 10 deg	1:1	Semi-Exposed
7	Roof, pitch 10-30 deg	1:1	Semi-Exposed
8	Roof, pitch > 30 deg	1:1	Semi-Exposed
9	Wall	1:1	Sheltered
10	Roof, pitch < 10 deg	1:1	Sheltered
11	Roof, pitch 10-30 deg	1:1	Sheltered
12	Roof, pitch > 30 deg	1:1	Sheltered
13	Long Wall	2:1	Exposed
14	Short Wall	1:2	Exposed
15	Roof, pitch < 10 deg	2:1	Exposed
16	Roof, pitch 10-30 deg	2:1	Exposed
17	Roof, pitch > 30 deg	2:1	Exposed
18	Long Wall	2:1	Semi-Exposed
19	Short Wall	1:2	Semi-Exposed
20	Roof, pitch < 10 deg	2:1	Semi-Exposed
21	Roof, pitch 10-30 deg	2:1	Semi-Exposed
22	Roof, pitch > 30 deg	2:1	Semi-Exposed
23	Long Wall	2:1	Sheltered
24	Short Wall	1:2	Sheltered
25	Roof, pitch < 10 deg	2:1	Sheltered
26	Roof, pitch 10-30 deg	2:1	Sheltered
27	Roof, pitch > 30 deg	2:1	Sheltered
28	Wall	1:1	Exposed
29	Roof, no pitch	1:1	Exposed

8 System configuration file (mandatory)

This is the file which is passed to **bps**, along with the configuration control file if one exists, to define the building and/or plant problem for simulation processing. The file contains site details, a reference to the various zone files which define the building problem, a reference to the plant components which comprise the plant network, and information on how the building zones and plant components interlock. The following table summarises file contents.

Record	Description of fields
1	Configuration type (1, 2 or 3) defining a building only, plant only or building/plant simulation.
2	Site latitude and longitude difference.
3/1	Site exposure type and ground reflectivity.
3/2	If exposure type=8, three user specified view factors are held; in order: buildings, sky and ground.
Then if a building simulation is required	
4	* Building (this record may be omitted)
5	Title of building configuration.
6	Number of zones.
7	For first zone: code number.
8	For first zone: operation file name.
9	For first zone: geometry file name.
10	For first zone: construction file name.
11	For first zone: utilities file index.
12	For first zone: utilities file name if the record 11 index is 1.
13 → I	Repeat records 7 through 12 for each additional zone in turn.
I+1	Total number of zone bounding surfaces in building configuration.
I+2 → J	For each bounding surface: zone number, surface number, connection type (1-5), supplementary data (2 items).
J+1 → K	Sets of ground temperature profiles if indicated by the supplementary data for type 4 connections.
K+1	Air flow simulation index (0 or 1). If 0, no building air flow simulation is performed. If index 1, the following 4 records are entered.
K+2	Configuration mass (=air) flow network description file name.
K+3	Wind pressure coefficients file.
K+4	Name of mass flow results file.
K+5	For each building zone, an air flow node is referenced by name or number
Then if a plant simulation is required	
K+2 or K+6, say L	* Plant (this record may be omitted)
L+1	Name of plant components' database; **plantc.db1**.
L+2	Plant configuration title.
L+3	Number of plant components, required matrix type (1/energy only; 2/energy & first phase mass; 3/energy & second phase mass).
L+4	For first component: code number, database reference code.
L+5	For first component: number of controlled variables and associated data array for each.
L+6 → M	Repeat records L+4 and L+5 for each plant component.
M+1	Number of component inter-connections.
M+2 → N	For each inter-connection receiving node: component number, node number, connector type, supplementary data (2 items), mass diversion ratio.

Record	Description of fields
N+1	Number of plant containments.
N+2 → P-1	For each containment: component number, containment type, supplementary data (3 items).
P	Plant fluid flow simulation index (0 or 1). If 1 and building air flow index equal to 0, the following 4 records are entered. If 1 and building air flow index equal to 1, enter record Q only.
P+1	Configuration mass flow network description file name.
P+2	Wind pressure coefficients file name.
P+3	Name of mass flow results file.
P+4 or Q	For each plant component inter-connection receiving node, a mass flow network *connection* is referenced by number

Table 19 Contents of the *system configuration* file.

A number of important points are now discussed in relation to describing a configuration.

- By simply changing the configuration type, from 3 to 1 for example, the same file can be used to describe a combined building/plant configuration and a building only configuration. This would allow a study of the performance of several building design elements prior to the introduction of mechanical control.
- Site latitude is +ve if north of the equator, -ve if south. The longitude difference is the *difference* between the site longitude and some reference longitude located within the time zone. It is used to determine the difference between local mean time and solar time. If the Greenwich meridian is used as the reference, then the longitude difference becomes the absolute longitude. **Sites to the east of the reference longitude are assigned a +ve difference, sites to the west a -ve difference**.
- The site exposure type is used to determine the appropriate surroundings, sky and ground view factors to be used in external longwave radiation calculations. The following types are active

  1: city centre, normal case / **2**: urban site, normal case / **3**: rural site, normal case / **4:** city centre, normal exposure / **5**: city centre, sheltered exposure / **6**: isolated rural site / **7**: totally enclosed configuration / **8**: user specified view factors.
- When specifying the zone files it is recommended that the full file address, including sub-directory paths, be given so that simulations can be initiated from another disk area.
- The information of records I+1 through J define zone interlocking. For each zone bounding surface a connection type is defined as follows

  0: defines the surface as external. No supplementary data is required.

  1: the surface is connected to a zone which is not participating in the configuration but which is environmentally identical to the zone to which the surface belongs. No supplementary data is required.

  2: the surface is connected to a zone which is not participating in the configuration but whose environmental conditions are known and constant. The 2 supplementary data items are used to define the constant temperature ($°C$) of this zone and to provide an estimate of any radiation (Wm^{-2}) absorbed by the outermost boundary of the surface in question.

3: the surface connects to another participating zone. The 2 supplementary data items then define the coupled zone and the surface therein which abutts the surface in question (remember at this point only geometric zone skeletons are being interlocked).

4: the surface is in contact with the ground. In this case, the first supplementary data item is a positive integer or zero.

If the former, then it points to one of a set of temperature profiles already installed in **bps**. Each of these represents the annual variation in ground temperature, month-by-month, for different geographical locations. Figure 14 shows these temperature sets. The second supplementary data item is then zero.

Profile	Mean Monthly Temperature (°C)	Description
1	7.28 6.5 6.56 7.33 9.06 11.39 13.5 14.33 14.11 11.72 10.72 8.67	Typical UK: level open terrain at 1.3m depth.
2	6.0 8.0 10.0 12.0 13.0 14.0 15.0 14.0 13.0 12.0 10.0 8.0	Characteristic step-wise variation of 6-15°C.
3	4.9 4.4 4.1 6.4 9.0 12.9 15.5 15.5 16.4 15.2 9.4 8.7	Temperatures set at previous month average: data from Kew 1967.
4	3.5 3.61 5.22 8.11 11.39 14.61 16.22 15.78 13.39 10.22 6.72 4.78	12km from Glasgow at 32.2m altitude, 0.305m depth beneath a short grass surface measured at 9h00 each day.
5	6.72 6.11 6.28 7.39 9.28 11.39 13.11 13.72 13.28 11.78 9.72 7.89	12km from Glasgow at 32.2m altitude, 1.219m depth beneath a short grass surface measured at 9h00 each day.

Figure 14 Ground temperature sets.

If the latter, then a user-specified ground temperature profile will be used by **bps**. In this case the second supplementary data item is a positive integer which refers to one of (perhaps) several user-specified profiles. After all connections have been specified, the temperature profiles are entered.

5: the surface is adiabatic.

- If air flow simulation is to be performed by the incorporated version of **mfs**, the air flow simulation index of record K+1 has to be set to 1. In that case, record K+2 identifies the mass flow network description file, and record K+3 identifies the file holding the wind pressure coefficients. After a **bps** run, the mass (=air) flow results file of record K+4 will hold all time dependent mass flows for each network branch. These results supplement those of the simulation results file also produced by **bps** for analysis via **res**. The mass flow results file can be inspected by terminal/printer listing or, if tables and graphs are required, via the output facilities of **mfs**. The data of record K+5 defines the relationship between building zones and the nodes established for mass flow simulation purposes. The building zones and the mass flow network nodes may or may not match. If a building zone does not have an mass flow network counterpart then a **0** is entered. In this event, the default air flow profiles of the zone operation file, or the time-series air flows of the zone air flow file should one exist, will be assumed.
- If a plant network is to participate in the simulation, it is necessary to decide on the number of components. For example, a simple air conditioning system may be

comprised of a mixing box, humidifier, supply fan, cooler and heater. Or it may be considered necessary to append a return air plenum and several duct lengths to represent the distribution system. Once a decision has been made **pdb** must be used to examine ESP-r's plant components' database (**plantc.db1**) to determine if the required components are on offer. Should a component be missing, a mathematical model must be created and installed in ESP-r. Note that since ESP-r's plant models are not confined to the steady state, this procedure may not be a trivial one. Section 5 details the formulation and installation of a dynamic component model.

- At this stage an index is entered to specify the type of simulation required as follows

  1: indicates that an energy only simulation is required. This is an appropriate option for all simulations in which circuit mass flow rates can be prescribed.

  2: indicates that an energy plus one phase mass balance is required. This option is appropriate for a simulation in which a single phase fluid (eg water) is to be controlled on the basis of the predicted temperature at some point in the plant network. In this case two matrices are established for the plant network; one to represent energy balance, the other to represent mass balance.

  3: indicates that an energy plus two phase mass balance is required. This is an appropriate choice in the case of air conditioning systems, for example, where it is necessary to control the water vapour level within the air stream. In this case three matrices are established for the plant network; one for energy balance, and one for each of the two phase mass balances.

  Of course, the installed mathematical models must be capable of generating the information required by the requested matrix type. For example, it is possible to install an energy only model in **bps** and then to request a mass balance for that component. Such a mis-match would be detected and disallowed by **esp-r**.

- For each plant component a code number is given and the component is then defined by a coded reference to its entry in the plant components' database.
- When a component model is formulated, the author must define which variables may be subjected to control action. For example, in a gas-fired water boiler model, the heat flux injected to the combustion chamber may be an elected control variable. When the configuration control file is established (see section 9), a control loop may then be assigned to determine this variable on the basis of some sensed condition and active control law. In the event that such a loop is not established, each control variable associated with a component must be assigned a realistic value. Record L+5 does this. Consider the case of an air conditioning cooling coil. In a simple component model, the heat flux extracted from the air stream by the coolant may be treated as a control variable. A control loop is then established, which in terms of some control system behaviour, acts to determine the required flux exchange to achieve some stable off-coil condition. If such a control loop is not set up, then the flux exchange will remain constant at the value assigned in the system configuration file as the default.
- The plant components are now inter-connected, similar to the building zone coupling. Note, however, that connections are only defined for receiving nodes. Each plant component is referenced in terms of its code number and its connected node, then a connection type is given followed by supplementary data to define the

connections:

1: the node is connected to a component which is not participating in the configuration but which is environmentally identical to the component to which the node belongs. No supplementary data is required.

2: the node is connected to a component which is not participating in the configuration but whose environmental conditions are known and constant. The 2 supplementary data items are used to define the constant temperature (expressed in $0.1\ ^{\circ}C$) and constant humidity ratio (in $10^{-4}\ kg/kg$) of this component.

3: the node connects to another participating component. The 2 supplementary data items then define the coupled component and the node therein.

4: the node is connected to a building zone air point. The 1st supplementary data item defines the connected building zone.

The 3rd supplementary data item always defines the mass diversion ratio (ie the ratio between mass flow originating from connected node and total mass flow leaving that node). Note that in case of mass flow network simulation this data will be obsolete.

- The containment information of record N+2 is optional and is used to define the immediate boundary condition of a plant component. With many components, the exchange of heat energy with the surroundings is negligible relative to the internal energy processes. For these components no containment information is required and no environmental interaction will take place. With other components a containment type can be entered as follows:

  0: outside air temperature is used and the 1st supplementary data item defines the variation from this value (de- or increment)

  1: containment is at temperature of a specified plant node. The 3 supplementary data items define the component, the node and some constant temperature shift (de- or increment) respectively. The selfcontainment case can be identified by setting the first 2 items equal to 0.

  2: containment is at a constant temperature, the value of which is in the 1st supplementary data item.

  3: containment is a building zone where the 3 supplementary data items define the building zone, the surface number and the node number therein (counting from 'outside') respectively. If the latter two are both zero then the zone air temperature is used. In case only the last item is zero, then the surface node temperature is used.

  Note that the connection between building zones and plant components - in terms of delivered plant energy - is specified as part of the zone control function as explained in the following sub-section.

- The mass flow simulation index of record P, indicates whether or not mass flow simulation will be performed by the incorporated version of **mfs**. If not, the mass flow balance will be based on mass diversion ratios of record M+2. In case the air flow simulation index of record K+1 is zero, records P+1 to P+3 identifie the mass flow problem description files and the mass flow results file respectively. After a **bps** run,

the mass flow results file of record K+4 or P+3 will hold all time dependent fluid mass flows for each network branch. These results supplement those of the simulation results file also produced by **bps** for analysis via **res**. The mass flow results file can be inspected by terminal/printer listing or, if tables and graphs are required, via the output facilities of **mfs**.

If the mass flow index of record P is 1, then the data of record P+4 or Q defines the relationship between the *receiving nodes* of the *plant component* inter-connections and the *connections* established for the mass flow network. In contrast to the building zones, each plant component inter-connection receiving node *must* be assigned a mass flow network counterpart.

- It should be noted that it is quite easy to define a mass flow network which has no unique solution. One requirement for solution is that at least one of the node pressures is known. A second requirement is that all nodes must be linked, through some path, to a known pressure node. It is advised to first examine a mass flow network with **mfs**, to see if it is solvable, before it is linked to the building and/or plant configuration.

Figure 15 shows some example building/plant system configurations and some alternative system configuration files that could result from an **esp-r** session. Figure 16 shows a typical configuration file listing (here for a simple one zone problem).

```
* CONFIGURATION3.0
# ESRU system configuration defined by file
# bld_simple.cfg
*date Wed Jun  6 17:23:56 2001  # latest file modification
*root bld_simple
*zonpth ../zones                # path to zones
*netpth ./                      # path to networks
*ctlpth ../ctl                  # path to controls
*radpth ./                      # path to radiance files
*imgpth ../images               # path to project images
*indx    1 # Building only
 51.700   -0.500   # Latitude & Longitude (diff from meridian)
      2   0.250   # Site exposure & ground reflectivity
* DATABASES
*prm  /usr/esru/esp-r/databases/constr.db2
*mlc  /usr/esru/esp-r/databases/multicon.db2
*opt  /usr/esru/esp-r/databases/optics.db2
*prs  /usr/esru/esp-r/databases/pressc.db1
*evn  /usr/esru/esp-r/databases/profiles.db1
*clm  /usr/esru/esp-r/climate/clm67
*pdb  /usr/esru/esp-r/databases/plantc.db1
*vew    -80.0  -100.0   100.0     4.4     4.4     1.5 40.0
*year  1967 # assessment year
*img GIF   FZON  ../images/simple_montg.gif
# prim energy conv (heat,cool,lights,fan,sml pwr,hot water)
*pecnv  1.250 3.600 3.600 3.600 3.600 1.250
*htemis   190.000    0.200    0.100 # heating emissions CO2,NOX,SOX
*clemis   612.000    2.060    7.500 # cooling emissions CO2,NOX,SOX
*ltemis   612.000    2.060    7.500 # lighting emissions CO2,NOX,SOX
*fnemis   612.000    2.060    7.500 # fan/pump emissions CO2,NOX,SOX
*spemis   612.000    2.060    7.500 # small power emissions CO2,NOX,SOX
*hwemis   190.000    0.200    0.100 # dhw emissions CO2,NOX,SOX
# sim setup: no. sets startup zone_ts plant_ts save_lv
*sps     1    2    1   10    2
   9   1  15   1  def      # period & name
*sblr bld_simple.res
*end_set
*end_sps
* PROJ LOG
bld_simple.log
* Building
L-shaped reception, convective heating, ideal control
      1  # no of zones
*zon   1   # reference for reception
*opr ../zones/reception.opr  # schedules
*geo ../zones/reception.geo  # geometry
*con ../zones/reception.con  # construction
*tmc ../zones/reception.tmc  # transparent constr
*zend
*cnn  bld_simple.cnn  # connections
      0   # no fluid flow network
```

Figure 16 Example system configuration file

9 Configuration control file (optional but usually required)

All building and plant control details are held in one file - the *configuration control file.* This holds details on all sensor and actuator locations and defines the time dependent operation of the active controllers which link a sensor and actuator throughout a simulation.

The building's control strategy is comprised of one or more *control functions.* These are then associated with building zones to define the time dependent control objectives. A plant system, if active, is governed by one or more *control loops.* In essence, control functions and loops are the same, differing only in the types of control laws used to link the sensor and actuator.

The following table summarises the contents of the configuration control file (usually named ?.ctl).

Record	Description of Fields
1	Identifying character string for overall control (≤ 12 characters).
Then if building control functions exist	
2	* Building (if no functions, go directly to record 13).
3	Identifying character string for building control regime (≤ 12 characters).
4	Number of control functions.
For each control function cycle to record 12	
5	* Control Function
6	Sensor location (3 data items).
7	Actuator location (3 data items).
8	Number of control day types.
For each day type cycle to record 12	
9	Start and finish dates of validity (year day numbers, January 1st = day 1).
10	Number of distinct control periods.
For each control period cycle to record 12	
11	Controller type, control law, period start time.
12	Number of data items associated with the control law, then data values.
13	List of associated control functions for each zone in system configuration.
Then if plant control loops exist	
14	* Plant
15	Identifying character string for plant control regime (≤ 12 characters).
16	Number of plant control loops.
For each control loop cycle to record 24	
17	* Control loop
18	Sensor location (3 data items).
19	Actuator location (3 data items).
20	Number of control day types.
Then for each day type cycle to record 24	
21	Start and finish dates of validity.
22	Number of distinct control periods.
Then for each control period cycle to record 24	
23	Controller type, control law, period start time.
24	Number of data items associated with the control law, then data values.

Table 20 Contents of the *configuration control* file.

Several important points should be noted.

- A configuration control file may contain any number of control functions, some of which may be referenced to dictate zone conditions. This matching is undertaken by the user within *bps* at runtime. All specified control loops will act on the defined plant network. Of course, if a plant network is not defined (in the system configuration file), then any defined control loops will be ignored by *bps*.
- If no configuration control file is offered to *bps* then the entire system configuration as defined will ‘free-float’ throughout the simulation period. In the same way, any

building zone or plant component not assigned a control function or loop will ‘free-float’ under the influence of the other zones and components active in the simulation.

- A sensor exists to measure some control variable for transmission to the control law representing some active controller. Sensors location is defined by four data items I_1, I_2, I_3 and I_4 assigned the following meanings.

I_1		I_2		I_3		I_4	
Value	Description	Value	Description	Value	Description	Value	Description
>0	Sensor measuring a zone-side temperature. Numerical value defines zone.	**=0**	Zone air temperature sensed.	**=0**	ie not used.	**=> 0**	Supplementary or nested control function (0 means none).
>0		**>0**	Indicates that the sensor is located at a surface or within a construction.	**=0**	Sensor measuring surface I_2 temperature.	**=> 0**	Supplementary or nested control function (0 means none).
>0		**>0**		**>0**	Sensor measuring internal construction state. I_3 defines location: position 1 is outermost surface, 2 is centre plane of outermost homogeneous element, 3 is at boundary between two outermost homogeneous elements, 4 is at centre plane of next to outermost homogeneous element, and so on.	**=> 0**	Supplementary or nested control function (0 means none).
=0	Sensor measuring air temperature of whichever zone the control function is associated with at simulation time.	**=0**	ie not used	**=0**	ie not used	**=> 0**	Supplementary or nested control function (0 means none).
-1	Sensor measuring the temperature of a plant component node.	**>0**	I_2 identifies the plant component.	**>0**	I_3 identifies the location (node) within the component.	**=> 0**	Supplementary or nested control function (0 means none).
-2	Sensor measuring a mix of zone air and mean radiant temperature.	**>0**	I_2 identifies the zone.	**>0**	I_3 is the convective weighting factor (percent), say C. The sensed temperature is then determined from: $\theta_s = \frac{\theta_a C}{100} + \frac{\theta_r (100 - C)}{100}$; where θ is temperature and s, a and r indicate sensed, air and mean radiant values respectively.	**=> 0**	Supplementary or nested control function (0 means none).
=-3	Sensor measuring ambient conditions	**=0**	Dry bulb temperature.	**=0**	ie not used.	**=> 0**	Supplementary or nested control function (0 means none).
=-3		**=1**	Sol-air temperature.	**=0**	ie not used.	**=> 0**	Supplementary or nested control function (0 means none).
=-3		**=2**	Wind velocity.	**=0**	ie not used.	**=> 0**	Supplementary or nested control function (0 means none).
=-3		**=3**	Wind direction.	**=0**	ie not used.	**=> 0**	Supplementary or nested control function (0 means none).

I_1		I_2		I_3		I_4	
Value	Description	Value	Description	Value	Description	Value	Description
=-3		**=4**	Diffuse horizontal radiation.	**=0**	ie not used.	**=> 0**	Supplementary or nested control function (0 means none).
=-3		**=5**	Direct normal radiation.	**=0**	ie not used.	**=> 0**	Supplementary or nested control function (0 means none).
=-3		**=6**	Relative humidity.	**=0**	ie not used.	**=> 0**	Supplementary or nested control function (0 means none).
=-99	Multi-layered construction thermo-physical property substitution mode.	**>0**	Zone air temperature value above which substitution is required.	**>0**	Zone air temperature value below which substitution is required.	**=> 0**	Supplementary or nested control function (0 means none).

Table 21 Sensor location definition.

Thus 0,0,0,0 would indicate control on the air temperature of whichever zone was assigned the corresponding control function (no nested control function); 5,0,0,4 would indicate zone 5 air temperature control with control function 4 nested (that is called after the current control function); 3,5,0,0 would indicate zone 3, construction 5 surface temperature control and no nested control function; 2,6,1,0 would indicate zone 2, construction 6, outermost surface temperature control and no nested control function; -1,15,3,1 would indicate plant component 15, node 3 temperature control with control function 1 nested; -2,7,65,0 would indicate zone 7 mixed temperature control with a 65 percent air temperature weighting, 35 percent mean radiant temperature weighting and no nested control function; and -99,25,10,0 would indicate that the associated zone should have up to three of its constructions substituted if the zone air temperature rises above 25°C or falls below 10°C.

The 0,?,?,? sensor location allows the same control function to be used for more than one zone. This will greatly reduce the size and complexity of the configuration control file in the case of large multizone problems.

- Actuators exist to transmit the output of a controller to some building zone or plant component, usually to reduce the deviation of the sensed control variable from some user-specified value (or set point). Like the sensor, actuator location is defined by 3 data items (say J_1, J_2 and J_3). Note however that actuators cannot be placed external to the building.

J_1		J_2		J_3	
Value	Description	Value	Description	Value	Description
>0	Actuator located in zone. Numerical value defines zone.	**=0**	Zone air point.	**=0**	ie not used.
>0		**>0**	Indicates that the actuator is located at a surface or within a construction.	**=0**	Actuator located at surface J_2.

J_1		J_2		J_3	
Value	Description	Value	Description	Value	Description
>0		**>0**		**>0**	Actuator located inside a construction. J_3 defines location: position is specified analogous to that for a sensor.
>0		**>0**		**>0**	Alternatively this definition, when used in conjunction with a type -99,?,?,? sensor, defines the three multi-layered constructions for thermo-physical property substitution throughout a simulation. Either or both of the J_3 and J_3 definitions may be zero if only one or two constructions are to be substituted.
=0	Actuator is located at the air point of whichever zone the control function is associated with at simulation time.	**=0**	ie not used.	**=0**	ie not used.
-1	Actuator located within a plant component.	**>0**	J_2 identifies the plant component.	**>0**	J_3 identifies the location (node) within the component.
-2	Actuator is a special type which will input a convective and radiant flux to a zone.	**>0**	J_2 identifies the zone.	**>0**	J_3 is the convective weighting factor (pecent), say C. The injected convective flux to the air point is then determined from: $q_c = \frac{q_{cl}\, C}{100}$ and the injected radiant flux to the zone surfaces is given by $q_r = \frac{q_{cl}\,(1-C)}{100}$; where q is flux and c and r indicate convective and radiant fluxes respectively and q_{cl} is some flux quantity produced by an active control law in response to the sensed control variable.

Table 22 Actuator location definition.

Again the 0,?,? option permits the same control function to be associated with a number of different zones.

- The actual property sensed by the sensor and actuated at the actuator is controlled by the controller *type* of records 11 and 23. The following possibilities exist:

Index	Sensed property	Actuated property
0	temperature	heat flux
1	temperature	flow rate
2	enthalpy	heat flux
3	enthalpy	flow rate
4	1st phase mass flow rate	heat flux
5	1st phase mass flow rate	flow rate

Index	Sensed property	Actuated property
6	2nd phase mass flow rate	heat flux
7	2nd phase mass flow rate	flow rate
8	additional plant output	heat flux
9	additional plant output	flow rate
10	temperature	variable expecting numerical value
11	enthalpy	variable expecting numerical value
12	1st phase mass flow rate	variable expecting numerical value
13	2nd phase mass flow rate	variable expecting numerical value
14	additional plant output†	variable expecting numerical value

Table 23 Active controller types.

- Control day types are days during which some specified control regime is in force. Any number of day types can be specified in terms of a start and finish date. This allows many control possibilities: seasonal requiring 4 day types, monthly requiring 12, weekly requiring 52, summer and winter with holidays treated differently from both, daily requiring 365!, and so on. If the number of day type is given as 0 then this implies the special case of Weekday/Saturday/Sunday control in which only 3 day types are active corresponding to weekdays, Saturdays and Sundays.
- Day types are then subdivided into distinct periods during which the control action is fixed. For each period a control type is specified as defined in the foregoing table. Reference is then made to a control law. This defines a control algorithm which, throughout the period, will represent the logic of some controller (real or imaginary). ESP-r allows the insertion of new control laws. The procedure to be followed is detailed in section 5. The following tables lists the control laws currently on offer for use within building control functions and plant control loops. In each case the required data values of records 12 and 24 are also given.

Control law	**Description**
1	Ideal control offering different heating and cooling set points. When invoked will cause the sensed condition to attain the specified set point. Heating and cooling capacities can be restricted so that the set points may not be attainable. Suitable for use only with a type 0 controller. 6 required data items: 1; maximum heating capacity (W)/ 2; minimum heating capacity (W)/ 3; maximum cooling capacity (W)/ 4; minimum cooling capacity (W)/ 5; heating set point for control variable (°C)/ 6; cooling set point for control variable (°C).
2	A free-float controller imposing no control action. No required data items.
3	An ideal pre-heat or pre-cool algorithm. When activated, the control variable will evolve, exponentially, towards some given set point, arriving there by the end of the period for which this control action is defined. Suitable for use only with a type 0 controller.

† Type 14 is also the appropriate choice in case of a sensor type -3 and sensed variable other than temperature or enthalpy

Control law	Description
	6 required data items: 1; maximum heating capacity (W)/ 2; minimum heating capacity (W)/ 3; maximum cooling capacity (W)/ 4; minimum cooling capacity (W)/ 5; heating set point for control variable (°C)/ 6; cooling set point for control variable (°C).
4	Ideal fixed heat injection or extraction. If the sensed temperature falls below the user-specified heating actuation point or rises above the cooling actuation point, then the specified flux is added or extracted convectively. Suitable for use only with a type 0 controller. 4 required data items: 1; heating flux (W)/ 2; cooling flux (W)/ 3; actuation temperature for heating (°C)/ 4; actuation temperature for cooling (°C).
5	Proportional+integral+derivative (PID) control action suitable for use with a type 0 controller. Care must be taken in the selection of the maximum and minimum heating and cooling capacities. For example, if the maximum capacity is too large, then the controlled temperature will remain at or above the upper limit. 9 required data items if P only control; 10 required data items if PI or PD control; 11 required data items if PID control. 1; control mode: 1 if P control; 2 if PI;3 for PD control;4 for PID./ 2; maximum heating capacity (W)/ 3; minimum heating capacity (W)/ 4; set point temperature for heating (°C)/ 5; throttling range for heating (°C)/ 6; maximum cooling capacity (W)/ 7; minimum cooling capacity (W)/ 8; set point temperature for cooling (°C)/ 9; throttling range for cooling (°C). If control mode = 2: 10; integral action time. If control mode = 3: 10; derivative action time. If control mode = 4: 10; integral action time, 11; derivative action time.
6	Determines the flux connection between the zone and a user-specified plant component. Suitable for use only with a type 0 controller. 5 misc. data items (note: 7 misc. data items required if ‘Control Point’ option required in ’res’). 1; coupled plant component identifier/ 2; node location within this component/ 3; an index specifying type of flux coupling calculation. 1 means an $mC_p(\theta_s - \theta_a)$ calculation; 2 means plant component model calculated heat exchange based on prevailing building zone conditions. This heat flux is ’picked up’ by this control law and transferred to the building zone according to any actuator type. No other indices are active at present./ 4; maximum heating flux permitted (W)/ 5; maximum cooling flux permitted (W)/ If ‘Control Point’ option required in ‘res’, then two other data items are required: 6; controlled plant component identifier/ 7; control variable for the controlled plant component.
7	A multi-stage controller with hysteresis. Suitable for use only with a type 0 controller. 12 required data items: 1; heating supplied when unit off - base load stage 0 (W)/ 2; heating supplied at stage 1 - must be ≥ stage 0 (W)/ 3; heating supplied at stage 2 - must be ≥ stage 1 (W)/ 4; heating supplied at stage 3 - must be ≥ stage 2 (W)/ 5; cooling supplied when unit off - base load stage 0 (W)/ 6; cooling supplied at stage 1 - must be ≥ stage 0 (W)/ 7; cooling supplied at stage 2 - must be ≥ stage 1 (W)/ 8; cooling supplied at stage 3 - must be ≥ stage 2 (W)/ 9; heating set point temperature (°C)/ 10; heating dead band (°C), (≥ 0)/ 11; cooling set point temperature (°C)/ 12; cooling dead band (°C), (≥ 0).
8	A variable supply temperature system with limit constraints. Suitable for use only with a type 0 controller. 6 required data items:

Control law	Description
	1; maximum supply air temperature (°C)/ 2; minimum supply air temperature (°C)/ 3; air volume flow rate (m^3s^{-1})/ 4; heating set point temperature (°C)/ 5; cooling set point temperature (°C)/ 6; cooling availability index (0 - cooling, 1 - no cooling).
9	A heat pipe model which operates by transferring heat from some outermost construction node to some innermost construction node. The algorithm iterates until the two nodes are within the stated temperature difference tolerance and the flux required to achieve this is within the flux difference tolerance relative to that flux calculated from a U δt model which represents the heat pipe physics. Convergence may require small simulation time-steps. Suitable for use only with a type 0 controller. 9 required data items: 1; an iteration index (0 - no iterate, 1 - iterate) usually 1/ 2; construction containing the heat pipe/ 3; outermost heat pipe node/ 4; innermost heat pipe node/ 5; critical temperature (°C)/ 6; maximum number of iterations/ 7; temperature difference tolerance/ 8; flux difference tolerance (W)/ 9; trace flag (0 - no trace, 1 - trace).
10	Allows separate flux ON and flux OFF set points to be specified for both heating and cooling. During the ON periods the maximum specified flux is injected. After the OFF condition the flux input is not reactivated until ON condition is reached. Care must be taken in the setting of the input flux. Suitable for use only with a type 0 controller. 6 required data items: 1; maximum heating capacity (W)/ 2; maximum cooling capacity (W)/ 3; heating ON set point temperature (°C)/ 4; heating OFF set point temperature (°C)/ 5; cooling ON set point temperature (°C)/ 6; cooling OFF set point temperature (°C).
11	This multi-sensor ideal controller will bring the temperature of the associated zone to the greatest/lowest/mean/weighted value of the auxiliary sensor(s). Heating and cooling flux constraints are permitted. Suitable for use only with a type 0 controller. Up to 16 required data items: 1; max heating flux capacity (W)/ 2; min cooling flux capacity (W)/ 3; max cooling flux capacity (W)/ 4; min cooling flux capacity (W)/ 5; number of auxiliary sensors for control function/ 6; sensor 'mode of operation' flag:- = 1: (ref sensor)-(greatest value of auxiliary sensors); = 2: (ref sensor)-(least value of auxiliary sensors); = 3: (ref sensor)-(mean value of auxiliary sensors); = 4: (ref sensor)-(weighting of auxiliary sensors)./ 7-10; sensor details for 1st auxiliary sensors (as Table 21)./ 11-14; sensor details for 2nd auxiliary sensors (as Table 21)./ If type 4 sensor mode; 15,16;sensor percentage weightings for the two auxiliary sensors (note: these weightings must sum to 100.0, e.g, 40 60).
12	This multi-sensor on-off controller will attempt to bring the temperature of the associated zone to the greatest/lowest/mean/weighted value of the auxiliary sensor(s). Heating and cooling flux constraints are permitted. Suitable for use only with a type 0 controller. Up to 16 required data items:

Control law	Description
	1; max heating flux capacity (W)/ 2; min cooling flux capacity (W)/ 3; max cooling flux capacity (W)/ 4; min cooling flux capacity (W)/ 5; number of auxiliary sensors for control function/ 6; sensor 'mode of operation' flag:- = 1: (ref sensor)-(greatest value of auxiliary sensors); = 2: (ref sensor)-(least value of auxiliary sensors); = 3: (ref sensor)-(mean value of auxiliary sensors); = 4: (ref sensor)-(weighting of auxiliary sensors)./ 7-10; sensor details for 1st auxiliary sensors (as Table 21)./ 11-14; sensor details for 2nd auxiliary sensors (as Table 21)./ If type 4 sensor mode; 15,16; sensor percentage weightings for the two auxiliary sensors (note: these weightings must sum to 100.0, e.g, 40 60).
13	This is a time-proportioning on/off controller. It is suitable for use with a type 0 controller. Heating and cooling restrictions are allowed. 12 required data items: 1; max heating capacity (W)/ 2; max cooling capacity (W)/ 3; heating ON set point temp. (deg.C)/ 4; heating OFF set point temp. (deg.C)/ 5; cooling ON set point temp. (deg.C)/ 6; cooling OFF set point temp. (deg.C)/ 7; total heating cycle period (minutes)/ 8; minimum heating ON cycle time (minutes)/ 9; minimum heating OFF cycle time (minutes)/ 10; total cooling cycle period (minutes)/ 11; ;minimum cooling ON cycle time (minutes)/ 12; minimum cooling OFF cycle time (minutes)/
14	This is a floating action ('three-position') controller. It is suitable for use with a type 0 controller. Heating and cooling restrictions are allowed. 14 required data items: 1; heating set-point (deg.C)/ 2; heating deadband (deg.C)/ 3; heating "shut switch" differential (deg.C)/ 4; heating "open switch" differential (deg.C)/ 5; cooling set-point (deg.C)/ 6; cooling deadband (deg.C)/ 7; cooling "open switch" differential (deg.C)/ 8; cooling "shut switch" differential (deg.C)/ 9; maximum heating flux (W)/ 10; minimum heating flux (W)/ 11; rate of change of heater actuator (time-steps)/ 12; maximum cooling flux (W)/ 13; minimum cooling flux (W)/ 14; rate of change of cooling actuator (time-steps)/
99	Multi-layered construction thermo-physical property substitution mode. At the specified times, the references multi-layered constructions will be substituted by the specified new constructions as a function of tests applied to the zone air temperature. Up to three zone constructions can be substituted. Since the associated controller type has no meaning, any value may be input (usually 0). 4 required data items: 1; flag to indicate whether substitution is required (o, no; 1, yes)/ 2; multi-layered database construction reference for first construction for substitution (as defined by the actuator's J_1 value/ 3; multi-layered database construction reference for second construction (if actuator's J_2 value not zero)/ 4; multi-layered database construction reference for third construction (if actuator's J_3 value not zero).

Table 23a Active control laws for use as part of a building control function.

The data of record 13 of Table 19 allocates control functions to building zones. For example, if 3 control functions have been defined then for a three zone problem "1 2 3" would indicate that zone 1 was to be allocated control function 1, zone 2 control function 2 and so on; "1 2 0" would indicate that zone three was to be uncontrolled; while "1 0 1" would indicate that zones 1 and 3 would share the same control function, while zone 2 would be uncontrolled. Clearly the defined control functions can be arbitrarily allocated to zones - for example "1 0 0 4 0 2 0 0 0 3" is allocated each

of 4 control functions to some of 10 zones as required. A special case exists with control function 99 which cannot be directly allocated to a building zone. Instead it is referenced by (or nested within) another control function. This ensured that the system control action precedes the construction substitution. Thus, if 5 control functions have been defined, with the fifth relating to construction substitution (a "-99 ? ?" sensor) then a 5 zone control function allocation of "1 2 3 4 0" (or any other permutation) would be legal while "1 2 3 4 5" (or any other permutation including the use of 5) would not. Instead, control function 5 should be nested within control functions 1 through 4 as required (this is done via the I_4 sensor data item of control function 1 through 4). To indicate that control function nesting is active the affected control function should be negated. Thus, if some of the zone three constructions were to be substituted, then "1 2 3 4 0" would become "1 2 -3 4 0", with control function 5 referenced from control function 3.

Index	Control law description
0	All plant component control variables set to zero. This would also be the appropriate choice in case of a control loop which is set up to define sensor location and sensor type for a mass flow corrector component. No required data items.
1	PID control action for use with a type of controller which actuates heat flux. Number of data items depends on PID algorithm selected. 1: PID algorithm types:- 1 for heating - Non-recursive Positional P, PI, PD, or PID. 2 for heating - Recursive Positional P, PI, PD, or PID. 3 for heating - Recursive Velocity PI [rectangular integration]. 4 for heating - Recursive Velocity PID [rectangular integration]. 5 for heating - Recursive Velocity PID [trapezoidal integration]. -1 for cooling - Non-recursive Positional P, PI, PD, or PID. -2 for cooling - Recursive Positional P, PI, PD, or PID. -3 for cooling - Recursive Velocity PI [rectangular integration]. -4 for cooling - Recursive Velocity PID [rectangular integration]. -5 for cooling - Recursive Velocity PID [trapezoidal integration]. 2: maximum flux (*W*)/ 3: minimum flux (*W*)/ 4: set point for control variable (*SU*)/ 5: throttling range for heating (*SU*)/ If PID algorithm selected is type 1, -1, 2, or -2, then: 6: integral action flag (flag = 1 if integral action required; 0 otherwise). If integral action flag is 1, then; 7: integral action time(*Ssecs*); 8: derivative action flag, and if this flag is set to 1 then; 9: derivative action time. However, if integral action flag is 0: 7: derivative action flag, 8: derivative action time (if flag set to 1). If derivative action flag is 1: 8: derivative action time Else if PID algorithm selected is type 3 or -3 then: 6: integral action time(*Ssecs*). Else if PID algorithm selected is type 4, -4, 5, or -5, then:

Index	Control law description
	6: integral action time(*Ssecs*); 7: derivative action time(*Ssecs*).
2	PID control action for use with a type of controller which actuates flow rate. Number of data items depends on PID algorithm selected. 1: PID algorithm types:- 1 for heating - Non-recursive Positional P, PI, PD, or PID. 2 for heating - Recursive Positional P, PI, PD, or PID. 3 for heating - Recursive Velocity PI [rectangular integration]. 4 for heating - Recursive Velocity PID [rectangular integration]. 5 for heating - Recursive Velocity PID [trapezoidal integration]. -1 for cooling - Non-recursive Positional P, PI, PD, or PID. -2 for cooling - Recursive Positional P, PI, PD, or PID. -3 for cooling - Recursive Velocity PI [rectangular integration]. -4 for cooling - Recursive Velocity PID [rectangular integration]. -5 for cooling - Recursive Velocity PID [trapezoidal integration]. 2: maximum flux (*W*)/ 3: minimum flux (*W*)/ 4: set point for control variable (*SU*)/ 5: throttling range for heating (*SU*)/ If PID algorithm selected is type 1, -1, 2, or -2, then: 6: integral action flag (flag = 1 if integral action required; 0 otherwise). If integral action flag is 1, then: 7: integral action time(*Ssecs*); 8: derivative action flag, and if this is set to 1; 9: derivative action time. However, if integral action flag is 0: 7: derivative action flag, 8: derivative action time (if flag set to 1). Else if PID algorithm selected is type 3 or -3 then: 6: integral action time(*Ssecs*). Else if PID algorithm selected is type 4, -4, 5, or -5, then: 6: integral action time(*Ssecs*); 7: derivative action time(*Ssecs*).
3	Basic proportional numerical value generator for use with a type of controller acting on a variable which expects such a signal 5 required data items: 1: output O_u when $S \geq S_u$ (-)/ 2: output O_l when $S \leq S_l$ (-)/ 3: upper set point for control variable S_u (*SU*)/ 4: lower set point for control variable S_l (*SU*)/ 5: ΔS to overcome controller's hysteresis (*SU*)
4	Optimum start controller generating either ON (ie. 1) signal or heating flux, when time is past the optimum start time necessary to reach desired temperature level at a specified time† 5 required data items: 1: output, ie. either "1" or heating flux (*W*)/ 2: time when desired temperature should be reached (*hour*)/ 3: desired temperature level θ_0 ($^\circ C$)/ 4: coefficient a_0 (s)/ 5: coefficient a_1 (s/K)/
*	For control laws 1. and 2. the upper set point equals the set point plus half the throttling range, and the lower set point equals the set point minus half the throttling range.

Index	Control law description
	The recursive algorithms should be selected in the case of (direct) digital microprocessor-based PID control. The choice between positional or velocity PID controllers is determined by the form of actuator: positional for analog actuators (e.g., pneumatic devices); velocity for incremental types (e.g., stepper motors). Integral action is added to proportional action to reduce sustained deviation from the set point. Derivative action is added to reduce the effects of system time-lags. The values for the integral and/or derivative action time constants (together with the maximum and minimum flux/flow values) must be selected ('tuned') with care. Typically for building services plant the integral action time will have a value of about 200 seconds, and the derivative action time constant a value of up to 500 seconds.
*	*SU* stands for *Sensor Units* indicating that the units are assumed to correspond to the sensor
*	Behaviour of control law 3. is similar to relationship sketched in Figure ....

Table 23b Active control laws for use as part of a plant control loops.

Figure 17 shows an example configuration control file.

```
bld_simple.ctl  # overall descr
* Building
convective heating  # bld descr
   1  # No. of functions
* Control function
# measures the temperature of the current zone.
    0    0    0    0  # sensor data
# actuates air point of the current zone
    0    0    0  # actuator data
    0 # No. day types
    1  365  # valid Sun  1 Jan - Sun 31 Dec
     4  # No. of periods in day
    0    2   0.000  # ctl type, law (free floating), start @
      0.  # No. of data items
    0    1   7.000  # ctl type, law (basic control), start @
      6.  # No. of data items
  3000.000 0.000 0.000 0.000 15.000 100.000
    0    1   9.000  # ctl type, law (basic control), start @
      6.  # No. of data items
  3000.000 0.000 0.000 0.000 20.000 100.000
    0    2  18.000  # ctl type, law (free floating), start @
      0.  # No. of data items
    1  365  # valid Sun  1 Jan - Sun 31 Dec
     1  # No. of periods in day
    0    2   0.000  # ctl type, law (free floating), start @
      0.  # No. of data items
    1  365  # valid Sun  1 Jan - Sun 31 Dec
     1  # No. of periods in day
    0    2   0.000  # ctl type, law (free floating), start @
      0.  # No. of data items
# Function:Zone links
   1
```

Figure 17 Example configuration control file

From ESP-r Version 8 Series it is also possible to impose control on a fluid flow network. The procedure is similar to that outlined above for the building and plant, with the defining information appended to the configuration control file. Using the facility, a connection or set of connections of the same type (i.e. defined by the same component model) can be assigned a time varying control schedule.

Sensor Location

The sensor can be placed anywhere in the model to sense building, plant or flow network conditions. For the building- and plant-side, the sensor definitions given previously are valid. In addition, the sensor can be located within the flow network as follows.

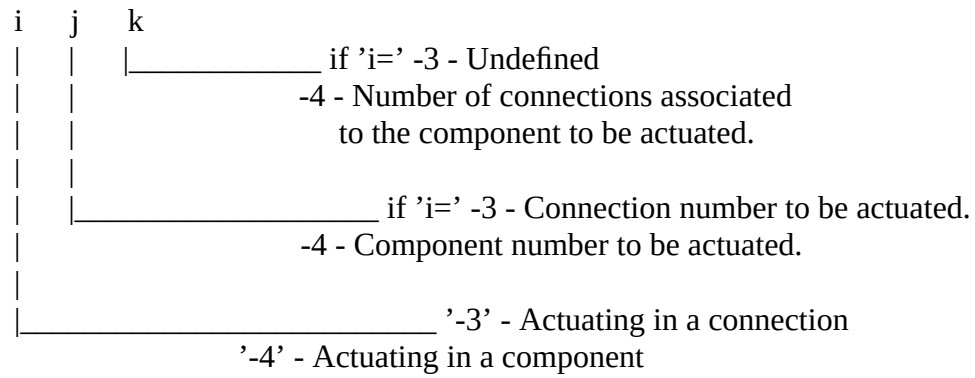
```
i     j     k

|     |     |
|     |     |_________________  Identifying number of the second node
|     |                 (when sensing property differences).
|     |
|     |_____________________________  Identifing number of the node or connection.
|
|_____________________________________ -4  Sensing property of any node or connection
                                  in the network depending on controller type.
```

Examples:

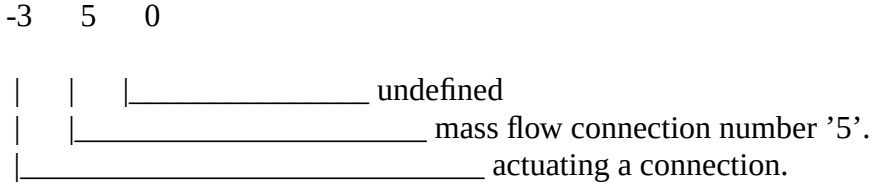
```
 1     2     0

 |     |     |
 |     |     |_____________ undefined
 |     |_____________________ sensor located in surface 2.
 |_____________________________ sensor located in zone 1.

-4     5     0

 |     |     |
 |     |     |_____________ undefined
 |     |_____________________ node or connection number of sensing property.
 |_____________________________ sensing property of a node or connection in network.
```

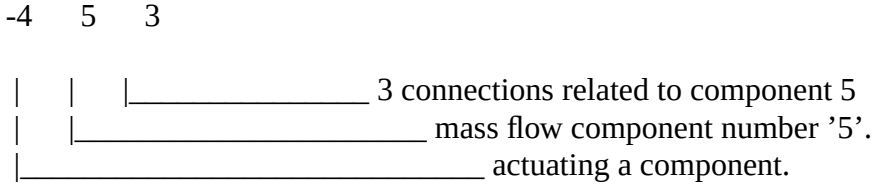
Actuator Location

Two actuator types are possible: one acting on a specified flow connection, the other acting on a specified flow component which is used to define one or more connections. In the latter case, it is possible to actuate all the connections defined by the controlled component or to restrict the action to a sub-set. Supported definitions are as follows.



Examples:





Note that it is not possible to apply control to component types 220, 230, 240 and 250 when actuating a component. Instead the control action must be applied to a connection.

Controller types

The following controller types are available for flow control.

index	Sensed property	Actuated property
1	temperature	flow rate
3	enthalpy	flow rate
5	1st phase	flow rate
7	2nd phase	flow rate
9	additional plt output	flow rate
11	relative humidity	flow rate
24	temperature difference	flow rate
25	absolute temperature difference	flow rate
26	pressure	flow rate
27	pressure difference	flow rate
28	absolute pressure difference	flow rate
29	absolute mass flow rate	flow rate
30	wind speed	flow rate
31	wind direction	flow rate
32	diffuse horizontal solar radiation	flow rate
33	direct normal solar radiation	flow rate
34	relative humidity of outdoor air	flow rate

Control Laws

The following control laws are available for selection.

Law	Definition
0	ON/OFF controller. It can be used with any mass flow component in order to open or shut it. If sensing value is greater than set point open it otherwise close it. Supplementary data 1 - Signal set point 2 - =1 direct control =-1 inverted control
1	LINEAR controller with hysteresis. Generally for using in conjunction with components type 410 and 420. Supplementary data 1 - signal lower limit Sl (?) 2 - relative position H/H100 at Sl (-) 3 - signal upper limit Su (?) 4 - relative position H/H100 at Su (-) 5 - dS to overcome hysteresis (?)

10 Site obstructions file (optional)

Before *ish* can be used to predict time-series shading for transfer to a zone shading/insolation file for use by *bps*, it is first necessary to establish, within *esp-r*, a description of the various site and facade obstructions which will cause the shading. This description is held in the site obstructions file. This is the file which is transferred to *ish* in addition to a zone geometry file. The following table details file contents.

Record	Description of fields
1	Site latitude and longitude difference.
2	Total number of site obstruction blocks.
3 $\rightarrow$ I	For each obstruction block in turn: x, y and z coordinates of block origin, block length, width and height, and orientation angle.
I+1	Opaque surface x and z grid interval, transparent surface x and z grid interval.

Table 24 Contents of the *site obstructions* file.

Important points to note include:

- Site latitude is +ve if north, -ve if south of the equator. Longitude difference is relative to some local time zone and is +ve if east, -ve if west of the reference meridian.
- Site obstructions are restricted to the REC shape type defined in section 2. This means that complex obstructions will require decomposition prior to geometry specification. The requested data have the same meaning as set out for zone geometry definition.
- Note that the geometry specification *must* be expressed relative to the same coordinate system as used for zone description.
- The record I+1 entry allows the user to control the accuracy level of *ish*'s predictions by allowing the user to specify the grid sizes for opaque and transparent surfaces. Specifying 20,20,10,10, for example, will result in 400 opaque surface grid cells and 100 grid cells for each window. Accuracy levels will then be high but at the expense of *ish* computing time. *Ish* has a minimum acceptable grid corresponding to a record I+1 entry of 5,5,4,4.
- Note that *ish* is equipped to perform shading prediction for individual windows subjected to overhangs and side fins. In this case no site obstruction file is required.

Figure 18 shows an example site obstructions file.

```
# site obstruction file defined in ../zones/reception.obs
# associated with zone geometry file ../zones/reception.geo
 0. 0.   # dummy values for site position
    8    # no obstruction blocks
# origin  X    Y    Z   width   depth   height  angle  descr  matr
   -4.900   -7.000   0.000   5.800   1.000   2.950   0.000  blk_1   extern_wall  # block  1
    1.200   -7.000   0.000   3.600   1.000   2.950   0.000  blk_2   extern_wall  # block  2
    5.200   -7.000   0.000   3.600   1.000   2.950   0.000  blk_3   extern_wall  # block  3
    9.100   -7.000   0.000  10.800   1.000   2.950   0.000  blk_4   extern_wall  # block  4
   -4.900   -7.000   3.100   5.800   1.000   2.900   0.000  xblk_1  extern_wall  # block  5
    1.200   -7.000   3.100   3.600   1.000   2.900   0.000  xblk_2  extern_wall  # block  6
    5.200   -7.000   3.100   3.600   1.000   2.900   0.000  xblk_3  extern_wall  # block  7
```

```
    9.100   -7.000    3.100   10.800    1.000    2.900    0.000  xblk_4   extern_wall  # block  8
# grid opq X  opq Z  win X  win Z
    20    20     5     5
```

Figure 18 Example site obstructions file listing.

11 Operation of esp-r.

esp-r employs interactive dialogue techniques to prompt a user for information, applying range checks to each reply. Many data items have defaults invoked by simply selecting the appropriate button. In some cases a repeat facility is active. This allows previously entered data to be recalled for current use. For example, if a construction is the same as the previous one. The default and repeat facilities are signalled when active.

esp-r also offers a range of editing options to permit interactive modifications to any previously generated disk file. In most cases two editing levels exists. The first allows global changes to a file; for example respecifying all window dimensions in a zone geometry file or all constructions in a zone constructions file. The second facilitates specific file modification; to respecify one window for example or change a zone's orientation. It is left to the user to decide on the target file corresponding to each design modification. For example: the system configuration can be relocated geographically, zones or plant components repositioned, or zones earth banked by editing the system configuration file; zone shape and window specifications can be changed by editing the zone geometry file; thermophysical properties can be redefined via the zone constructions file; zone operation via the zone operations file; shading altered by changing the shading/insolation file; leakage via the leakage distribution file or air flow directly via the zone operations file or air flow file; and so on.

Sub-section 4.2 details the operational features of *esp-r*.

12 Adaptive Gridding

12.1 Linear Thermal Conductivity

Via this option, the thermal conductivity of any layer of any surface, except air gaps, can be defined to be linear function of temperature and/ or moisture content. All the required data for such a definition will be provided by the primitive construction database to the zone construction file without any additional effort by the user. Note that you should take particular care in defining the layers within partitions, otherwise the scheme will warn the user of mis-matching linear thermal conductivity definitions. These thermal definitions will remain in effect until exiting from the Simulator, (re)loading a configuration file, or changing them via this option.

12.2 Nonlinear Thermophysical Properties

This option can be used to define the thermophysical properties of layers (except air gaps), to be polynomial functions of temperature. There are two ways of specifying these functions: the user may enter the required information within the Simulator or supply a "system thermal configuration file". The latter may be created after entering data manually and is useful if multiple simulations are anticipated. The following table details the contents of the system thermal configuration file .

Table 3.20 contents of the system thermal configuration file

Record	Description of Fields
1	Number of thermal functions
For each thermal function cycle to record 5	
2	Thermal function number
3	Thermal actuator location
4	Number of thermal equations
For each thermal equation cycle to record 5	
5	Thermal equation number, thermal property type, lower and higher mean temperatures ,and eight thermal coefficients, (A, a, B, b, C, c, D, d), respectively .

Important points to note include;

- Each thermal function contains one thermal actuator location and up to nine thermal equations.
- Thermal actuator location: indices to zone, surface and layer. If any of these are zero then it means all the selections available at its level (i.e. 1 3 0 means all the layers in the 3rd surface of the 1st zone).
- The thermal equation describes the change in thermal property value by the following equation:

$$\Delta P = A\,\Delta T^{a} + B\,\Delta T^{b} + C\,\Delta T^{c} + D\,\Delta T^{d}$$

- Thermal property type is used to define the thermophysical property whose value changes as a function of temperature will be estimated by the associated coefficients

in the thermal equation.The following types are active: 1-thermal conductivity, 2-density, 3-heat capacity.

- Each thermal equation is valid for the layers, defined by thermal actuator location, whose mean temperature is equal to or higher than the lower temperature range, and lower than higher temperature range .
- This type is also equipped with a code for detecting the illegal statements such as mis-matching definitions of partitions from each sides, un-acceptable temperature range, ... etc.
- if thermal conductivity of any layer is defined by both types of thermal definitions the linear thermal conductivity is assumed for that layer because of the more flexibility available at the linear conductivity menu for defining the types of layer's materials ; however the other two properties will not be affected .
- The thermal equations can be save in a thermal equations data file (an example is shown below) as a data base from which the user can pull as many equation as required for completing thermal functions which in turn make up the system thermal configuration .

```
 2        # TOTAL THERMAL FUNCTIONS
 1        # thermal function No.
 1  4  2   # thermal actuator location
 2        # Total thermal equations
# No T  MIN(Temp.)MAX      A       a       B       b       C       c       D       d
  1  1  -30.00   25.00  0.001000   1.00  0.000034   2.00  0.000000   0.00  0.000000   0.00
  2  1   25.00  100.00  0.000100   1.00  0.000008   2.25  0.000000   0.00  0.000000   0.00
 2        # thermal function No.
 2  1  1   # thermal actuator location
 2        # Total thermal equations
# No T  MIN(Temp.)MAX      A       a       B       b       C       c       D       d
  1  1  -20.00  125.00  0.001000   1.00  0.000600   2.09  0.000005   3.00  0.000000   0.00
  2  2  -80.00  200.00  0.000010   1.20  0.000003   2.07  0.000000   0.00  0.000000   0.00
```

Figure 3.16 System thermal configuration file

```
# cement block conductivity
  1  1  -30.00   35.00  0.001040   1.00  0.000034   2.00  0.000000   0.00  0.000000   0.00
# cement block conductivity
  2  1   35.00  100.00  0.000100   1.03  0.000028   2.20  0.000000   0.00  0.000000   0.00
# cement block density
  3  2  -45.00  100.00  0.000004   1.00  0.000002   2.00  0.000000   0.00  0.000000   0.00
# cement block heat capacity
  4  3  -40.00   75.00  0.000035   1.00  0.000005   2.03  0.000000   0.00  0.000000   0.00
```

Figure 3.17 Thermal equations data file

Appendix

Representative data for building energy analysis

Table A1 Casual gains.

From people					
Degree of activity	Typical application	*Wperson*$^{-1}$ Sensible	Latent	Radiant portion	Conv po
Sedentary	Offices Restaurant	95	45	0.2	
Light work	Factory	125	100	0.2	
Heavy work	Factory	180	255	0.2	
From lights					
Type	Illumination lux	*Wm*$^{-2}$ Sensible		Radiant portion	Conv po
Tungsten	200	25-35		0.8	
	400	50-80		0.8	
Fluorescent	200	10		0.6	
65W white	400	15-20		0.6	
	1000	35-55		0.6	
Fluorescent	200	15-20		0.6	
65W deluxe	400	30-45		0.6	
From other sources [see IHVE (now CIBSE) Guide Book A 1970, section					
Source				Radiant portion	Conv po
High temp.				0.8	
Medium temp.				0.4	
Low temp.				0.2	

Miscellaneous ..... Source	Wm^{-2} (of net useful area)
General office areas	25
Word processing	45
Computer rooms >200m^2	550
Computer rooms <200m^2	350-550
Classrooms	10-25
Terminal rooms 50-250	
Copying	175
Vending	20
Mailrooms	20
Conference rooms	10
Storage areas	5
	$m^2\ person^{-1}$
General office	10
Managers office	14
Secretary office	7
Terminal room	9
Word processing	10
Cafeteria	3
Conference rooms	2
Laboratory	25
Classrooms	2
Store areas	100

Table A2 Overall resistances of cavities.

Thickness (mm)	emissivity	Surface Resistance ($m^2°C/W$) f Down	Up
Unventilated cavities			
5	high	0.11	
	low	0.18	
20	high	0.21	
	low	1.06	
High emissivity planes and corrugated sheets in contact.		0.11	
Low emissivity multiple foil insulation with air space on one side.		1.76	
Ventilated cavities 20mm minimum			
Airspace in cavity wall.			0.18
As previous but with high emissivity surfaces.			0.11
Airspace between high emissivity surfaces, one corrugated with unsealed joints.			0.88
As previous but with plane surface of low emissivity.			0.26
Airspace behind tiles on tile-hung wall.			0.12
Airspace between tiles and roofing felt on pitched roof.			0.12
Loftspace between flat ceiling and unsealed pitched tile roof.			0.11
As previous but with sealed roof.			0.18
Loftspace between flat ceiling and sealed pitched roof, surfaces of high emissivity.			0.25

Table A3 Thermophysical properties of materials.

Material	Conductivity ($W/m°C$)	Density (kg/m^3)	Specific heat ($J/kg°C$)	Emiss.	Solar absorptivity
ASBESTOS					
Cement	0.36	1500.00	1000.00	0.90	0.60
Sheet	0.36	700.00	1050.00	0.96	0.60
ASPHALT & BITUMEN					
Asphalt	0.50	1700.00	1000.00	0.90	0.90
Bitumen felt	0.50	1700.00	1000.00	0.90	0.90
Roofing felt	0.19	960.00	837.00	0.90	0.90
Asphalt mastic	1.15	2325.00	837.00	0.90	0.90
BRICK					
Outer leaf	0.84	1700.00	800.00	0.93	0.70
Inner leaf	0.62	1700.00	837.00	0.93	0.70
Insulating	0.27	700.00	837.00	0.93	0.70
CARPET					
Wilton	0.06	183.00	1360.00	0.90	0.60
Felt underlay	0.04	160.00	1360.00	0.90	0.65
Rubber underlay	0.10	400.00	1360.00	0.90	0.65
CONCRETE					
Heavy	1.40	2100.00	653.00	0.90	0.65
Light	0.38	1200.00	653.00	0.90	0.65
Aerated	0.16	500.00	840.00	0.90	0.65
Aerated block	0.24	750.00	1000.00	0.90	0.65
Refactory insulating	0.25	10.00	837.00	0.90	0.65
Vermiculite aggregate	0.17	450.00	837.00	0.90	0.65
INSULATION					
Fibreboard	0.06	300.00	1000.00	0.90	0.50
Woodwool	0.10	500.00	1000.00	0.90	0.50
Glasswool	0.04	250.00	840.00	0.90	0.30
Urea Formaldehyde	0.03	30.00	1764.00	0.90	0.50
Thermalite	0.19	753.00	837.00	0.90	0.70
Polyurethane board	0.03	30.00	837.00	0.90	0.50
Polystyrene	0.03	25.00	1000.00	0.90	0.30
Siporex	0.12	550.00	1004.00	0.90	0.40
METAL					
Copper	200.00	8900.00	418.00	0.72	0.65
Aluminium	160.0	2800.00	896.00	0.22	0.20
Steel	50.00	7800.00	502.00	0.12	0.20
PLASTER					
Dense	0.50	1300.00	1000.00	0.91	0.50
Light	0.16	600.00	1000.00	0.91	0.50
Gypsum	0.42	1200.00	837.00	0.91	0.50

Material	Conductivity ($W/m°C$)	Density (kg/m^3)	Specific heat ($J/kg°C$)	Emiss.	Solar absorptivity
Perlite	0.08	400.00	837.00	0.91	0.50
Vermiculite	0.20	720.00	837.00	0.91	0.50
Gypsum board	0.16	950.00	840.00	0.91	0.50
Perlite board	0.18	800.00	837.00	0.91	0.60
SCREEDS & RENDERS					
Light concrete	0.41	1200.00	840.00	0.90	0.80
Cast concrete	1.28	2100.00	1007.00	0.90	0.65
Granolithic	0.87	2085.00	837.00	0.90	0.65
White render	0.50	1300.00	1000.00	0.91	0.50
STONE					
Sandstone	1.83	2200.00	712.00	0.90	0.60
Red granite	2.90	2650.00	900.00	0.90	0.55
White marble	2.77	2600.00	802.00	0.90	0.45
TILES					
Clay	0.85	1900.00	837.00	0.90	0.60
Concrete	1.10	2100.00	837.00	0.90	0.65
Slate	2.00	2700.00	753.00	0.85	0.85
Plastic	0.50	1050.00	837.00	0.90	0.40
Rubber	0.30	1600.00	2000.00	0.94	0.82
Cork	0.08	530.00	1800.00	0.90	0.60
Asphalt/asbestos	0.55	1900.00	837.00	0.90	0.70
PVC/asbestos	0.85	2000.00	837.00	0.90	0.60
WOOD					
Block	0.16	800.00	2093.00	0.90	0.65
Flooring	0.14	600.00	1210.00	0.91	0.65
Hardboard (medium)	0.08	600.00	2000.00	0.91	0.70
Hardboard (standard)	0.13	900.00	2000.00	0.91	0.70
Cork board	0.04	160.00	1888.00	0.90	0.60
Chip board	0.15	800.00	2093.00	0.91	0.65
Oak (radial)	0.19	700.00	2390.00	0.90	0.65
Weatherboard	0.14	650.00	2000.00	0.91	0.65
Fir (20 perc moist)	0.14	419.00	2720.00	0.90	0.65

These are the materials held in the *primitive constructions' database*. Note that the reference codes are not given here since these will change as new materials are added. Current database contents, and the active reference codes, can be listed via *con*.

Table A4 Properties of selected window arrangements.*1

Window arrangement	Thickness & type (mm)	Light transmittance*2	Direct transmittance*2	Total transmittance	U-value ($Wm^{-2}{}^{\circ}C^{-1}$)
SINGLE GLAZING					
without blinds:					
Clear float	4	0.89	0.82	0.86	5.4
	6	0.87	0.78	0.83	5.4
	10	0.84	0.70	0.78	5.3
	12	0.82	0.67	0.76	5.2
Spectrafloat	6 bronze	0.51	0.54	0.66	5.4
Antisun	6 green	0.72	0.46	0.62	5.4
	6 blue	0.54	0.46	0.62	5.4
	4 bronze	0.61	0.58	0.70	5.4
	6 bronze	0.50	0.46	0.62	5.4
	10 bronze	0.33	0.29	0.51	5.3
	12 bronze	0.27	0.23	0.47	5.2
	4 grey	0.55	0.55	0.68	5.4
	6 grey	0.42	0.42	0.60	5.4
	10 grey	0.25	0.25	0.49	5.3
	12 grey	0.19	0.19	0.45	5.2
Reflectafloat	6 silver	0.33	0.43	0.53	5.4
with internal venetian blinds:					
Clear float	6		0.09	0.47	
	12		0.08	0.46	
Spectrafloat	6 bronze		0.06	0.43	
Antisun	6 green		0.05	0.42	
	6 blue		0.05	0.42	
	6 grey		0.05	0.43	
	10 grey		0.03	0.39	
	12 grey		0.02	0.38	
	6 bronze		0.05	0.42	
	10 bronze		0.03	0.40	
	12 bronze		0.03	0.39	
Reflectafloat	6 silver		0.06	0.37	
DOUBLE GLAZING					
without blinds:					
6mm clear inner pane:					
Clear float	4 (+4mm inner)	0.80	0.67	0.75	2.8
	6	0.76	0.61	0.72	2.8

Window arrangement	Thickness & type (mm)	Light transmittance*2	Direct transmittance*2	Total transmittance	U-value ($Wm^{-2}°C^{-1}$)
	10	0.73	0.55	0.66	2.7
Spectrafloat	6 bronze	0.45	0.42	0.54	2.8
Antisun	6 bronze	0.44	0.36	0.49	2.8
	10 bronze	0.29	0.23	0.38	2.7
	6 grey	0.37	0.33	0.46	2.8
Insulight HP	6	0.44	0.24	0.33	1.6
	10	0.42	0.22	0.31	1.6
6mm Kappafloat (Champagne) inner pane:					
Clear float	4 (+4mm inner)	0.63	0.50	0.66	1.9
	6	0.60	0.46	0.63	1.9
	10	0.57	0.41	0.58	1.8
6mm Kappafloat (Neutral) inner pane:					
Clear float	4 (+4mm inner)	0.76	0.52	0.65	1.8
	6	0.74	0.50	0.62	1.8
	10	0.72	0.45	0.57	1.8
with venetian blinds between panes + 6mm clear inner:					
Clear float	6		0.07	0.25	
Spectrafloat	6 bronze		0.05	0.23	
Antisun	6 bronze		0.04	0.23	
with internal venetian blinds + 6mm clear float inner:					
Clear float	6		0.07	0.47	
Spectrafloat	6 bronze		0.05	0.38	

*1 Data from: Glass and Transmission Properties of Windows, 7th Edition, Pilkington Environmental Advisory Service, February 1988.

*2 For normal incidence.

ESP-r requires the direct and total transmittance for each of 5 angles of incidence: 0° (normal), 40°, 55°, 70° and 80°. These data can be obtained from *win* on input of the normal incidence values as given in the previous table. The following table gives values for some typical window arrangements. A reasonable

estimate of the effect of angle of incidence of any particular glass can be made by substituting the tabulated values of direct and total transmittance for the values at normal incidence, and calculating values at other incidence angles using ratios obtained from the following table.

Table A5 Window properties as a function of incidence angle.

Window arrangement	**Direct transmittance for .....**					**Total transmittance for .....**				
	0°	40°	55°	70°	80°	0°	40°	55°	70°	80°
4mm clear float	0.82	0.81	0.75	0.59	0.36	0.86	0.85	0.80	0.65	0.42
6mm clear float	0.78	0.76	0.72	0.58	0.35	0.83	0.81	0.77	0.64	0.40
6mm Antisun (green)	0.46	0.44	0.40	0.30	0.16	0.62	0.61	0.57	0.47	0.31
6mm clear float	0.09	0.08	0.08	0.07	0.04	0.47	0.43	0.40	0.33	0.23
+ internal blind										
6mm clear float	0.61	0.58	0.54	0.38	0.17	0.72	0.70	0.66	0.50	0.25
+ 6mm clear float										
6mm Antisun (grey)	0.33	0.30	0.26	0.18	0.09	0.46	0.43	0.38	0.28	0.16
+ 6mm clear float										
6mm Antisun (bronze)	0.04	0.04	0.04	0.04	0.03	0.35	0.33	0.32	0.28	0.20
+ 6mm clear float										
+ internal blind										
6mm clear float	0.07	0.06	0.06	0.05	0.03	0.25	0.23	0.21	0.17	0.11
+ 6mm clear float										
+ blind between panes										