Addition of Blind/Shutter Control to Transparent Multi–Layer Constructions and Other Improvements to the Solar Routines of ESPsim.

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1. Introduction

A number of enhancements and bug fixes have been implemented in the short–wave routines of ESPsim, primarily in routine MZSLGN in solar.f. The revised routines have been incorporated in version 6.20a. Corresponding changes have been made to the data input routines of ESPimp.

2. Enhancements

2.1 Blind/Shutter Control of a Transparent Multi–Layer Construction (TMC).

The facility has been added to allow replacement of the optical properties of TMCs in external surfaces, for cases where a blind/shutter is present. The way in which the modification has been implemented is that at each control period for each TMC type, a replacement set of transmission coefficients and absorptivities can be specified. The decision on whether a blind/shutter is set (i.e. when the replacement coefficients would be used) can be controlled as follows:

(i) If the activation point is set to –99, then the blind/shutter is always ON in the control period, irrespective of the 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.

At each timestep, the program calculates the radiation onto each external surface, with allowance for shading of the direct radiation if this has been specified. If the surface is a TMC, then the program determines whether the blind/shutter control is on or off according to time, radiation level and external temperature as appropriate, and sets a flag for that surface. Each surface is tested in turn. The flags are then checked at various stages in the remainder of the solar routine for selection of the appropriate transmissivity and absorptivities. This means that each TMC blind/shutter is independent of the settings of other blind/shutters.

Note that more than one surface can be assigned the same TMC type. In this case, it will inherit the same control periods, control settings and replacement properties. If this is not acceptable, the surfaces should be assigned different TMC types.

The maximum number of control periods has been set to three per day. Each control period can have a different set of replacement properties. All the control information is contained in the TMC file, the structure of which is given in the following example of file layout:

Example of TMC file layout

```
6                                                      #6 surfaces
1  0  2  0  0  0                                       #TMC types/surface
3                                                      #TMC type 1 has 3 elements
0.6100  0.5800  0.5400  0.3800  0.1700 #standard transmissivity
0.1500  0.1700  0.1900  0.2100  0.2300 #standard absorption; element 1
0.0000  0.0000  0.0000  0.0000  0.0000 #standard absorption; element 2
0.1000  0.1200  0.1400  0.1600  0.1800 #standard absorption; element 3
1                                      #control flag - blind/shutter control ON
2  0              # no. of control periods in a day; if radiation sensor then
                  # surface number (0 implies sensor every surface)
10  12                                 #start and stop hours for period 1
1  20.                                 #sensor type and activation point for period 1
0.4000  0.3500  0.3100  0.2400  0.1200 #replacement transmissivity
0.2500  0.3000  0.3200  0.3600  0.3800 #replacement absorption; element 1
0.0000  0.0000  0.0000  0.0000  0.0000 #replacement absorption; element 2
0.1500  0.1500  0.1600  0.1600  0.1800 #replacement absorption; element 3
0                                      #replacement thermophysical properties index
14  17                                 #start and stop hours for period 2
0  200.                                #sensor type and activation point for period 2
0.2000  0.1500  0.1300  0.1100  0.1000 #replacement transmissivity
0.3500  0.3700  0.3900  0.4100  0.4300 #replacement absorption; element 1
0.0000  0.0000  0.0000  0.0000  0.0000 #replacement absorption; element 2
0.2500  0.2500  0.2700  0.2800  0.3000 #replacement absorption; element 3
0                                      #replacement thermophysical properties index
1                                      #TMC type 2 has 1 element
0.8000  0.7500  0.7000  0.6500  0.6000 #standard transmissivity
0.1000  0.1300  0.1600  0.1900  0.2200 #standard absorption; element 1
0                                      #control flag off for this TMC type
```

The layout is similar to the previous structure of the TMC file, but with the control flags and replacement information added. Note that the record after the replacement absorptivities contains an index pointing to replacement thermophysical properties. A value of zero indicates that thermophysical properties are not to be replaced. At present the code changes have not been implemented; so for the time being this index should be set to 0.

The appropriate routines have been modified in ESPimp so that the additional information is requested, and the input file generated for reading by ESPsim.

2.2 Blind/Shutter Control of Windows.

A few modifications were implemented here to make the treatment more consistent with that of the TMCs. Firstly, it is now possible to specify a radiation sensor on one particular external surface, as well as the previous assumption that there is a sensor on each external surface. The new structure of the blind/shutter control file is as follows:

```
  2     0          #no. of control periods in a day; if radiation sensor then
                   #surface number (0 implies sensor every surface)
  6       12       #start and stop hours for period 1
    0.600,   0.550,   0.500,   0.450,   0.400,  #replacement direct transmissivity
    0.700,   0.650,   0.600,   0.550,   0.500,  #replacement total transmissivity
    2.000,                                      #replacement U-value
1    10.000        #sensor type and activation point for period 1
 14      18        #start and stop hours for period 2
    0.400,   0.350,   0.300,   0.250,   0.200,  #replacement direct transmissivity
    0.500,   0.450,   0.400,   0.350,   0.300,  #replacement total transmissivity
    2.500,                                      #replacement U-value
0   200.000        #sensor type and activation point for period 2
```

The only difference from the previous blind/shutter control file is the first line; the additional second item specifies the sensor position in the case of a radiation sensor. The appropriate change has been implemented in ESPimp for data input.

The blind/shutter control possibilities are now the same as those described above for the TMC. As in the case of the TMC blind/shutter, the position of the window blind/shutter is calculated at each timestep, according to the time, the calculated solar radiation incident on each external surface, and the external temperature as appropriate. Flags are set for each external surface containing a window, and these flags are tested at various points in the rest of the routine in order to determine the correct set of properties to be used for the window.

The blind/shutter settings can thus be independent (in the case where there is a radiation sensor on each surface) with some blinds being ON, others being OFF. The setting of flags at the start of the routine for indicating blind/shutter positions has removed one problem with the old code, where it was possible for a blind/shutter at a particular window to be on and off at the same timerow (i.e. the blind was assumed to be on at some points in the routine, and off at other points).

The previous possibility of modifying the properties of internal windows has been retained. If the replacement U–value is set to be negative, then all internal windows are given the replacement set of properties. It is assumed that adjacent zones are given the same set of replacement properties for these windows, and that control periods are the same; this is not checked. 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.

Note one important difference between the treatment of windows and TMCs is that only one set of replacement properties are allowed per zone in the case of windows. Therefore all windows will have the same set of replacement properties. This is not a restriction in the case of TMCs.

2.3 TMC absorptivities.

The absorptivities of the elements of a TMC are relative (i.e. the absorptivity of element 2 is relative to the flux on the outside of the TMC, not to the flux that has passed through element 1, etc). It is assumed that shortwave flux is approaching from the external boundary of the zone. For flux inside the zone hitting a TMC, the relative absorptivities need to be reversed. This was not done in the old code. In the new code the absorptivities are reversed in an approximate manner. Rather than work from first principles (taking into account density, angle of incidence etc), the assumption is made that the reflectivity is the same in both directions. This leads to comparatively simple equations for reversing the absorptivities, as follows:
To convert relative to absolute absorptivities:

$$\alpha_1 = \alpha_1'$$

$$\alpha_k = 1 - \left\{ \frac{1 - \sum_{i=1}^{k} \alpha_i'}{\prod_{i=1}^{(k-1)} (1-\alpha_i)} \right\}$$

$$\text{for } k = 2,n,1 \quad (n>1)$$

To convert absolute to relative (reversed) absorptivities:

$$\alpha_n'' = \alpha_n$$

$$\alpha_k'' = 1 - \sum_{i=k+1}^{n} \alpha_i'' - \prod_{i=k}^{n} (1-\alpha_i)$$

$$\text{for } k = n-1, 1, -1$$

where

n	number of elements
α_i	absolute absorptivity
α_i'	relative absorptivity
α_i''	relative **reversed** absorptivity

If necessary this reversal could be done in a more rigorous manner, at some loss in terms of runtime.

2.4 Doors.

In the old code:

```
QDOOR(ICOMP)=X2*ZDA(ICOMP)*0.75
QIREF=QIREF+QDOOR(ICOMP)*0.3/0.7
```

where QDOOR() is the radiation absorbed by all the doors in the zone from the diffuse radiation (X2) transmitted by a particular window/TMC, ZDA() is the total door area of the zone, and QIREF is the reflected flux. Note that QDOOR() is not summed correctly for the addition of flux from each window and TMC; also, the sum of the absorbed and reflected fractions is greater than 1. However, QDOOR() was not used in the rest of ESPsim, so effectively this absorbed shortwave was lost.

In the new code, QDOOR() is calculated as follows:

```
      IF(NDOORS(ICOMP,K).GT.0)THEN
        DO 91 KK=1,NDOORS(ICOMP,K)
          QDOOR(ICOMP)=QDOOR(ICOMP)+X2*DA(ICOMP,K,KK)*0.75
          QIREF=QIREF+X2*DA(ICOMP,K,KK)*0.25
91      CONTINUE
      ENDIF
```

where DA() are the individual door areas.

Modifications have been made in routine MZDCON of subsys.f, so that the "sol–air" temperature, and therefore door conduction, is altered according to the levels of incident flux. The modifications have been implemented for flux impinging upon the door surfaces of the zone (QDOOR()), and for the fluxes impinging upon the other side of the doors. In the case of an external door, the relevant solar flux absorbed on the external surface is used; for an adjacent zone the relevant value of QDOOR() is used.

Note that doors are treated as resistances, with no heat storage. Also, it is assumed that any **direct** radiation impinges upon the the opaque surfaces and/or windows/TMCs, rather than the doors. It is important to note that for a more rigorous treatment where door areas are significant, the doors should be defined as separate constructions.

2.5 Reflected Diffuse Radiation.

In the old code, the reflected diffuse radiation (from opaque surfaces, windows, TMCs, doors) is added together (augmented by a an additional factor accounting for re–reflections from windows) and distributed to all OPAQUE surfaces, according to an area/absorptivity weighting. This has led to problems in zones with a high proportion of glazing.

In the new code, the reflected diffuse is distributed to all surfaces, namely opaque surfaces, TMCs, windows and doors. Losses to adjacent zones are taken into account. Since this redistribution also results in a proportion that is reflected, the reflected diffuse element is treated iteratively. In order to avoid any significant time penalties, the following criteria are set to stop the iteration:

(i) If the remaining unallocated flux is less than 1% of the incoming flux to the zone or less than $0.1W/m^2$, the iteration is stopped

(ii) If iterations exceed the set number of 8, then a warning is issued if unallocated flux exceeds 2% of the incoming flux to the zone or $0.2W/m^2$.

In both cases, any remaining flux is assigned to all opaque surfaces according to an area/absorptivity weighting. A test was carried out to ensure that the time penalty was not significant. The four–zone problem described in Section 4.4 was simulated with old and new versions of the solar algorithm; increased simulation time was negligible.

This enhancement could make a large difference, particularly when there are large glazing areas, and when default insolation type 3 (spread to all surfaces) is selected. In the old code direct flux with this insolation type was only distributed to opaque surfaces; in the new code it is distributed to all surfaces.

2.6 Directly Insolated Windows.

A maximum of two surfaces can be insolated at any one timestep. If a shading/insolation file is used, then one of these surfaces can be specified to have insolated windows. The same applies to default insolation in the old code. A modification has been made in the case of default insolation to allow both surfaces to have directly insolated windows. Proportions of the incoming direct flux are allocated on an area–weighted basis. This option can be specified in the geometry file by giving the fourth item of default insolation data as a negative quantity (as described in the manual).

2.7 Structure of the Code.

The code has been streamlined, sectioned and commented so that the sequential logic is easier to follow. The only 'jump' in the new code is for the case when the sun is not up, for which the majority of the code is bypassed.

The code for calculating the absorptivities and transmissions through a TMC has been separated from the main routine (MZSLGN), and replaced by a new routine (MZTMCA).

2.8 Enhanced trace facility.

When the trace option is selected for this routine (option 'S'), the summed totals of the distribution of flux within a zone are given, as in the following example listing:

```
ENERGY DISTRIBUTION OF SOLAR PENETRATING ZONE (W)
Q from adjacent zones=    206.798
Q from outside=    1014.58
total solar inputs to zone=    1221.37

Q to adjacent zones=    162.781
Q lost through ext windows and TMCs=    47.8508
Q absorbed in TMCs=    366.810
Q absorbed in opaque walls=    494.166
Q absorbed in doors=    25.6843
Q in air point=    114.297
Q remainder (allocated to opaque walls)=    9.78498
total solar distributed=    1221.37
```

3. Bug Fixes

3.1 Flux transfers to adjacent zones. In routine MZSOLR of solar.f, the variables DIRT, DIFT, AIRT are updated with the results of routine MZSLGN calculations. The assignment was:

```
DIRT(ICPLE,ISCPLE)=DIRT(ICPLE,ISURF)+QLOSSD(ICOMP,ISURF)
DIFT(ICPLE,ISCPLE)=DIFT(ICPLE,ISURF)+QLOSSF(ICOMP,ISURF)
AIRT(ICPLE,ISCPLE)=AIRT(ICPLE,ISURF)+QLOSSA(ICOMP,ISURF)
```

but it should be:

```
DIRT(ICPLE,ISCPLE)=DIRT(ICPLE,ISCPLE)+QLOSSD(ICOMP,ISURF)
DIFT(ICPLE,ISCPLE)=DIFT(ICPLE,ISCPLE)+QLOSSF(ICOMP,ISURF)
AIRT(ICPLE,ISCPLE)=AIRT(ICPLE,ISCPLE)+QLOSSA(ICOMP,ISURF)
```

As far as can be ascertained, the first terms on the RHS of the revised equations will be zero, since they are always reset to zero in routine MZSLGN after the internal flux has been distributed. However, the old code could lead to incorrect levels of radiation being transferred to another zone.

3.2 Window re–reflections. In the old code, the variable ZAREF was used to collect the products of the window area and the reflected component, for reassignment of the re–reflected diffuse radiation. However, the external windows were summed twice; internal windows were not included. This is not a problem in the new code – the method of reassignment of reflected diffuse has been changed (see Section 2.5).

3.3 Corruption of shading pointer. In the old code, there is a flag JJ2 to indicate whether or not there is shading for the current surface, and a corresponding pointer JJ1 which points to the shading factor, which is used to modify the transmission of direct radiation through the window. Later on in the routine, JJ2 is used to flag whether or not there are any insolated windows within the zone, with a corresponding pointer JJ1 specifying the insolated proportion in the shading/insolation file. Under certain circumstances the second set of JJ1,JJ2, which are set within the 'window' loop, can overwrite the first set which are set outside this loop, so that for the second, third, fourth, etc window in a surface, the shading factors will be incorrect.

This has been corrected by using different variables for the two sets of flags/pointers.

3.4 Incorrect TMC nodal assignments. In the old code, when the diffuse is assigned to 'other' surfaces (i.e. not the directly insolated ones), if the surface is a TMC, nodal flux additions are:

```
INODE=(2*NE+1)+2
DO 90 L=1,NE
LL=NE+1-L
INODE=INODE-2
.......
QTMCA(K,INODE,2)=QTMCA(K,INODE,2)+DFAB*0.25
QTMCA(K,INODE+1,2)=QTMCA(K,INODE+1,2)+DFAB*0.5
QTMCA(K,INODE+2,2)=QTMCA(K,INODE+2,2)+DFAB*0.25
.......
```

The nodal assignments should be QTMCA(,INODE,),QTMCA(,INODE–1,) and QTMCA(,INODE–2,). This has been corrected.

3.5 Diffuse flux hitting TMC and transmitted to adjacent zone. In the old code, for a directly insolated internal TMC, part of the flux hitting the TMC was transferred through to the next zone using the variables QLOSSD() for direct and QLOSSF() for diffuse. For diffuse radiation hitting other internal TMCs, however, flux passed through to the adjacent zone was not added to the variable QLOSSF(). This has been corrected.

3.6 Diffuse flux allocation to windows in directly insolated surfaces. A maximum of two internal surfaces can be directly insolated at any particular timestep. Only one of these surfaces can have insolated windows (but see Section 2.6 above). In the old code, the insolated surfaces were dealt with first, tracking both direct and diffuse fluxes as appropriate.

Then the other surfaces were dealt with in turn for the diffuse component. For the case where there are two insolated surfaces, and windows in both, the diffuse flux was not allocated to the windows in the second of these surfaces. This has been fixed.

3.7 Directly insolated surface flux allocations . For default insolation for two surfaces, suppose the proportions for allocating the direct radiation to the two surfaces are calculated as P1 and P2 (based on their relative surface areas). In the old code, proportion P1 is used as the multiplier for both surfaces. This would explain the recently reported bug that if the default insolated surfaces are, say, 3 and 6, then the results are different from those resulting from the specification of 6 and 3. The magnitude of the error will depend on the relative areas of the two surfaces. In the new code the proportions are correctly assigned.

A related minor bug occurs in the case of default insolation on two surfaces, neither of which contain an insolated window. In this case the proportions were calculated, in the old code, as ratios of the opaque surface areas to the combined surface areas. The ratios used should be the surface area (opaque + window) divided by the combined area. Another related bug was present for the case of doors in a surface containing directly insolated windows. In this case the flux for the doors was allocated to the windows. Both these bugs have been corrected.

4. Testing

4.1 Checks on the Implementation of the New Routine.

The new routine was first tested on a single zone model with windows and TMCs. Detailed tracing in the solar routine was used to check that fluxes were distributed correctly.

The main testing was carried out on a four–zone model with internal and external windows, TMCs and doors (described below in Section 4.4) External absorbed fluxes were checked, but no checks were carried out here on the calculation of the incident flux calculations (i.e. on routines MZSANG, MZSINT, MZSCAI or MZSRAD). For each zone, fluxes entering through each window were calculated by detailed tracing within the routine. Energy balances were used to confirm that all flux was distributed. The routine was checked for blind/shutter control of windows and TMCs, for default insolation and the use of shading/insolation files.

Checks were carried out on the iterative treatment of the diffuse flux. A maximum of four iterations were found to be necessary for the four–zone model (for which opaque surfaces had absorptivities of 0.6). This was also true even for the case of default insolation type 3, when all direct is treated as diffuse.

It is difficult to quantify the magnitude of the effect of the modifications because it is very dependent on the particular model chosen. However, several test simulations were carried out in an attempt to estimate the effect of the changes introduced. These are described in the following sections.

4.2 ESP test configuration.

This is the simulation exercise described in the ESP manual. It consists of a three–zone problem with no internal windows, no TMCs, no blind/shutter control and no shading. The expectation would therefore be of negligible differences between simulations using the old and new routines. The simulations were carried out as specified in the manual, for the summer's day of 17 July, using the 'clm67' climate data set. The following table gives the predicted air temperatures in the main office, Zone 1.

Output for July 7 for Zone 1

Time (Hrs)	Air temperature (Deg. C.) ESPsim6.19b	Air temperature (Deg. C.) ESPsim6.20a
0.5	28.76	28.78
1.5	28.47	28.49
2.5	28.27	28.29
3.5	28.18	28.20
4.5	28.04	28.07

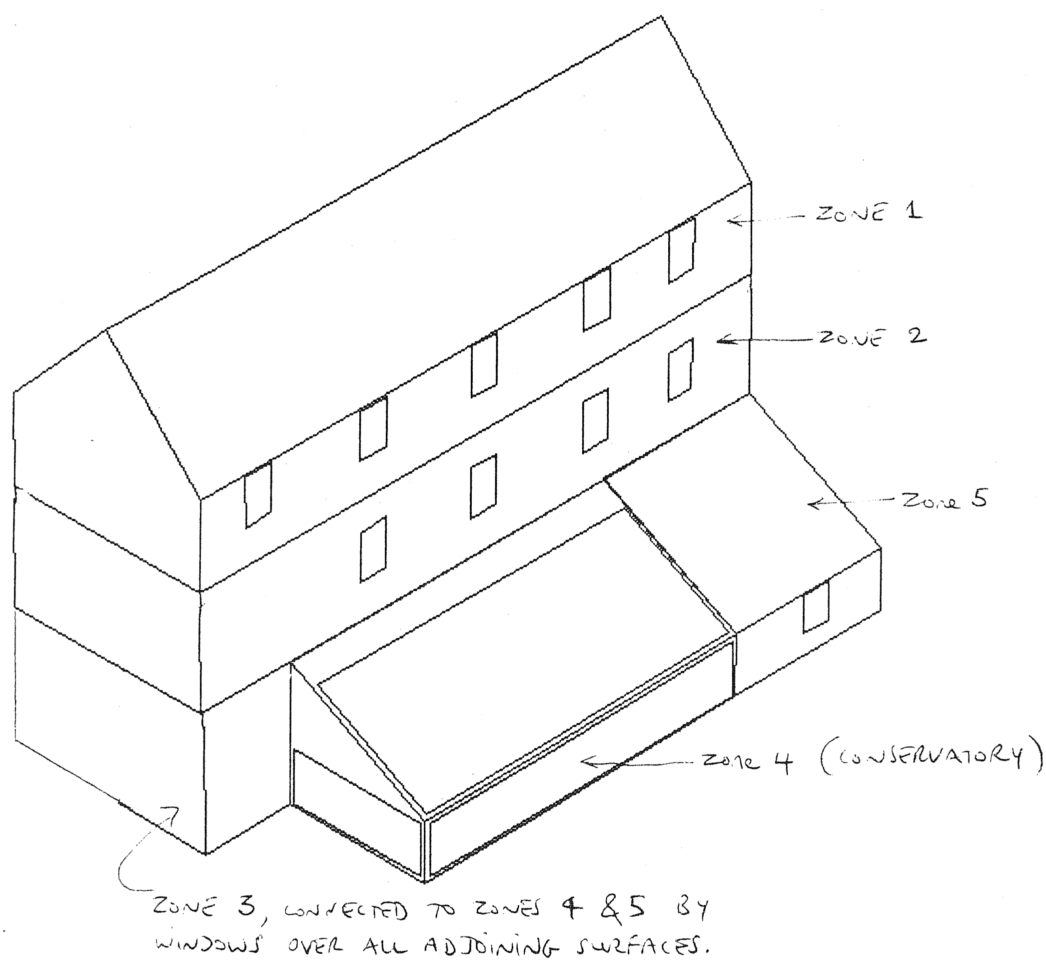
Output for July 7 for Zone 1

Time (Hrs)	Air temperature (Deg. C.) ESPsim6.19b	Air temperature (Deg. C.) ESPsim6.20a
5.5	28.05	28.11
6.5	28.41	28.50
7.5	28.93	29.04
8.5	29.63	29.73
9.5	30.60	30.71
10.5	31.49	31.60
11.5	32.05	32.15
12.5	32.46	32.60
13.5	32.67	32.94
14.5	32.51	32.86
15.5	32.13	32.50
16.5	31.83	32.27
17.5	31.57	31.98
18.5	31.14	31.38
19.5	30.53	30.62
20.5	29.99	30.03
21.5	29.72	29.76
22.5	29.58	29.62
23.5	29.34	29.37

As can be seen, differences in temperature prediction are very small. The differences that do occur can be ascribed to the change in treatment of the reflected diffuse radiation, and to the treatment of doors.

4.2 Large house with Conservatory.

This simulation problem was chosen from a previous case study, in order to investigate the effect of changes on a conservatory, where solar radiation is of particular importance. The building is depicted in the diagram below:



The south–facing conservatory consists predominantly of clear double–glazing, and is connected to Zone 3 in the main body of the house by a large window. Simulations were undertaken using a climate data set representative of the Glasgow climate, for a single day (13 July) after a suitable start–up period. From the hours of 07:00 to 17:00, an infiltration rate of 5 ach and a ventilation rate of 7 ach from Zone 3 was assumed for the conservatory. Direct insolation was assumed to fall upon the floor in the all the main rooms, including the conservatory.

This test was carried out in order to investigate specifically the effect of the changes in the solar routines. Thus the floors of Zones 3, 4 and 5 were connected to a zone at a constant temperature (a type 2 connection, with a temperature of 12°C). This ensured that the effects of another change between versions 19b and 20a of ESPsim, that of the change in the external convection coefficient for the ground connection, did not influence the results.

Selected results are given in Table 1. As can be seen, the changes in the solar routine has had very little impact on the air temperatures in Zones 1 and 3, with differences generally less than 1°C.

In the conservatory, differences in predictions are greater, with air temperatures about 4°C lower at the hottest part of the day. The decrease in temperatures probably results from the increase in flux losses from the windows, due to the more accurate treatment of the reflected diffuse component in the new solar routine. There may also be a small change in the flux transferred to the adjacent Zone 3.

The absolute values of the predicted temperatures are obviously dependent upon the parameters chosen for the simulations, particularly with regard to the infiltration and ventilation exchanges. However, the results do give an idea of the magnitude of the effect of changes in the solar routines on predicted temperatures in a highly glazed zone such as a conservatory.

4.3 Office Block.

A further comparison was carried out on an office block modelled as a single zone, containing a large area of glazing. The clear double glazing was modelled as a TMC. Again, the simulations were carried out for a summer period, and a typical day's results are shown in the following table:

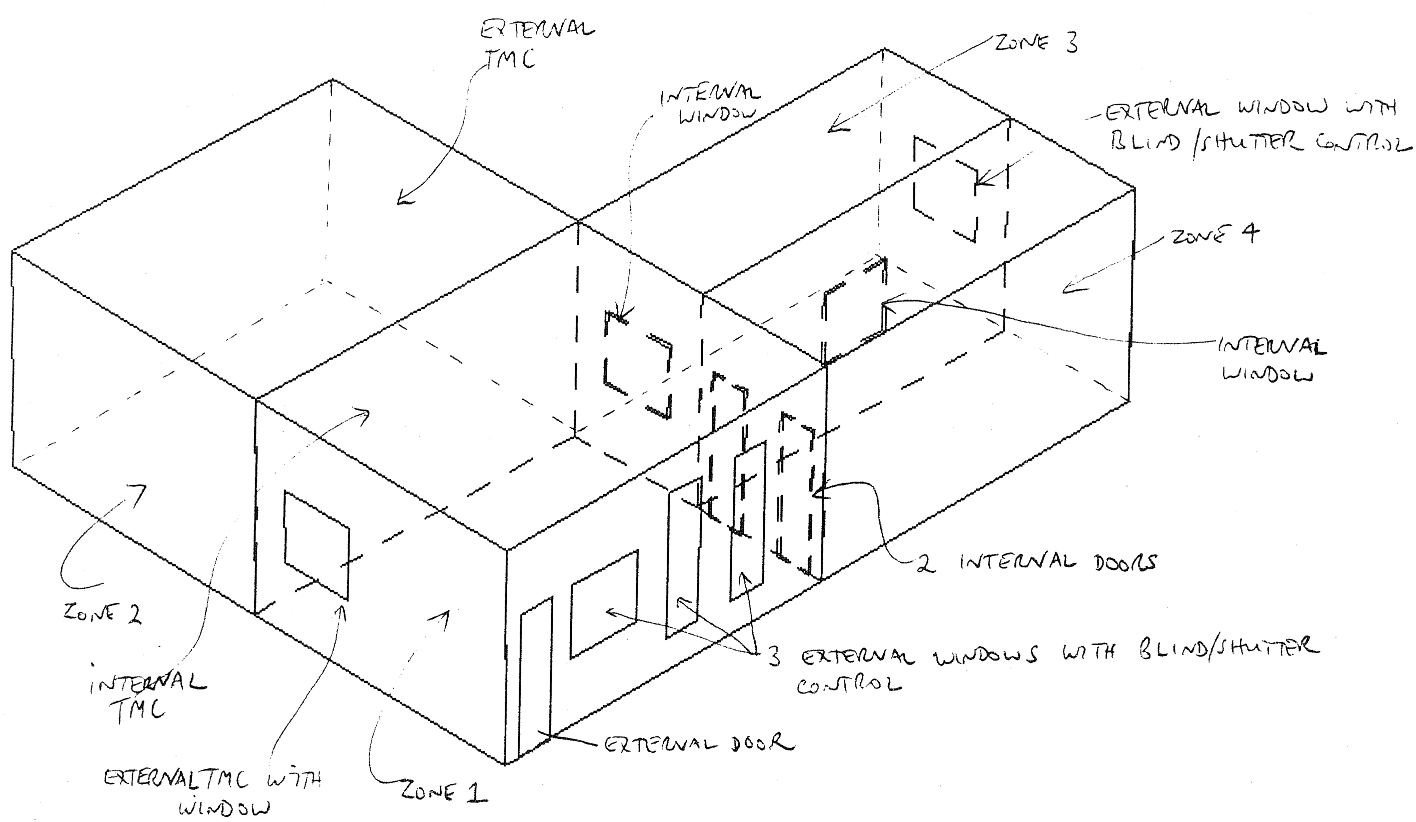
Output for July 16 for Zone 1

Time (Hrs)	Air temperature (Deg. C.) ESPsim6.19b	Air temperature (Deg. C.) ESPsim6.20a
0.5	27.99	26.14
1.5	27.86	26.04
2.5	27.65	25.84
3.5	27.38	25.61
4.5	27.23	25.48
5.5	27.27	25.51
6.5	27.58	25.77
7.5	26.22	24.71
8.5	25.25	24.16
9.5	27.01	25.85
10.5	28.10	26.80
11.5	28.80	27.42
12.5	29.25	27.83
13.5	29.19	27.81
14.5	29.23	27.90
15.5	29.03	27.75
16.5	28.95	27.71
17.5	30.16	28.60
18.5	31.80	29.79
19.5	31.09	29.16
20.5	29.79	27.97
21.5	29.37	27.53
22.5	28.88	27.10
23.5	28.48	26.70

There was no ground connection in the model so the differences in the two predictions derive from differences in the solar treatment. The reduced air temperatures predicted by simulation with the new solar routine, lower by about 1.5°C, are thought to result primarily from the improved treatment of the reflected diffuse component.

4.4 Four–Zone Test Configuration

This model was constructed in order to permit comprehensive testing of the solar routine, and cannot be considered a 'typical' problem. The layout is shown in the following diagram.



The model contains internal and external windows, TMCs and doors, and blind/shutter control of windows. For this exercise, blind/shutter control of TMCs was not used, in order that the predictions of the simulations with the old and new solar routines could be compared.

Tables 2 and 3 summarise some of the results from the simulations. Mean air temperatures do not differ by more than 5% between the two simulations. Zone 2 shows the greatest differences in air temperature, with the new routine predicting up to 4.5°C higher temperatures than the old routine in the late afternoon. This is thought to result partly from increased flux transfer from Zone 1 which receives radiation through its west–facing TMC in the afternoon.

4.5 Conclusions from Tests .

The conclusion is drawn that the effects of the changes are minor for rooms with a low proportion of glazing, but that for conservatories the effect of the change in the solar distribution routine can be important. Note that this work has not included checks on the calculation of the incident flux magnitudes, as derived in routines MZSANG, MZSINT, MZSCAI and MZSRAD.

5. Suggestions for Further Improvements

5.1 ESPins and TMCs. Modify ESPins so that it works with non–rectangular surfaces; then modify solar.f of ESPsim so that the insolated data files can be applied to TMCs.

5.2 Insolated surfaces. Modify ESPins and solar.f of ESPsim so that it is possible to directly insolate more than 2 surfaces at any one time.

5.3 Internal TMC property replacement. Allow modification to the properties of an internal TMC, depending on time control.

5.4 Diffuser. Add option of a "diffuser" to a TMC (and window) – if the blind/shutter control is ON, the transmission/absorptivities would be replaced AND all direct would be treated as diffuse for internal distribution.

5.5 Insulated blinds. Modifications are to be made to allow replacement of the thermophysical properties as well as the optical properties. Although this is not yet implemented, provision has been made in the TMC file structure for an index pointing to the relevant replacement properties.

5.6 Enable long–wave exchange between elements of a TMC.

5.7 Add shading of diffuse radiation.

5.8 Add view factors to the distribution of diffuse.

Summary output for zone 1
Period : Day 13 of month 7

Time (Hrs)	Plant (Kw)	ESPsim6.19b Air temp. (Deg. C.)	ESPsim6.20a Air temp. (Deg. C.)
0.50	0.	21.36	20.92
1.50	0.	19.57	19.20
2.50	0.	18.12	17.79
3.50	0.	16.84	16.55
4.50	0.	15.74	15.48
5.50	0.	15.09	14.84
6.50	0.	14.98	14.70
7.50	0.	15.43	15.13
8.50	0.	16.72	16.38
9.50	0.	19.02	18.58
10.50	0.	22.76	22.25
11.50	0.	26.73	26.16
12.50	0.	29.22	28.58
13.50	0.	31.11	30.39
14.50	0.	32.50	31.71
15.50	0.	32.97	32.18
16.50	0.	33.28	32.53
17.50	0.	34.61	33.78
18.50	0.	35.01	34.08
19.50	0.	32.42	31.61
20.50	0.	29.71	29.06
21.50	0.	27.55	26.98
22.50	0.	25.21	24.73
23.50	0.	23.17	22.76
Summary output for zone 3			
0.50	0.	29.00	27.86
1.50	0.	27.96	27.07
2.50	0.	27.21	26.39
3.50	0.	26.69	25.92
4.50	0.	26.22	25.47
5.50	0.	25.77	25.05
6.50	0.	25.52	24.83
7.50	0.	26.24	25.48
8.50	0.	27.06	26.25
9.50	0.	27.49	26.72
10.50	0.	29.66	28.64
11.50	0.	32.71	31.73
12.50	0.	35.92	35.25
13.50	0.	38.94	38.16
14.50	0.	40.62	39.76
15.50	0.	41.17	40.26
16.50	0.	41.07	40.06
17.50	0.	39.71	38.83
18.50	0.	37.92	37.07
19.50	0.	37.23	36.16
20.50	0.	35.71	34.55
21.50	0.	34.26	33.03
22.50	0.	33.17	31.83
23.50	0.	31.83	30.34
Summary output for zone 4			
0.50	0.	29.71	27.35
1.50	0.	28.39	26.23
2.50	0.	27.56	25.56
3.50	0.	26.80	24.92
4.50	0.	26.02	24.26
5.50	0.	25.75	24.06
6.50	0.	25.87	24.18
7.50	0.	25.46	23.86
8.50	0.	26.05	24.42
9.50	0.	29.50	27.43
10.50	0.	34.85	32.10
11.50	0.	40.01	36.56
12.50	0.	43.55	39.67
13.50	0.	45.94	41.83
14.50	0.	46.90	42.73
15.50	0.	46.94	42.84
16.50	0.	46.36	42.43
17.50	0.	46.60	42.51
18.50	0.	45.36	41.24
19.50	0.	41.69	38.12
20.50	0.	39.26	36.05
21.50	0.	36.99	34.02
22.50	0.	34.98	32.19
23.50	0.	33.35	30.67

Table 1: Output from simulations of Section 4.2

solar routine comparison

OLD SOLAR ROUTINE

Air temperature information (Deg.C)

Zone	Maximum value	Minimum value	Mean value
1	36.171	20.050	27.910
	@17, 7,17.50	@17, 7, 4.50	
2	33.709	20.428	28.370
	@17, 7,10.50	@17, 7, 4.50	
3	23.480	18.574	21.215
	@17, 7,18.50	@17, 7, 4.50	
4	22.840	18.267	20.317
	@17, 7,20.50	@17, 7, 7.50	

Surface solar energy absorption (KW)

Zone	External surface			Internal surface			Air point		
	Mx val	Mn val	Me val	Mx val	Mn val	Me val	Mx val	Mn val	Me val
1	11.683	0.	4.158	1.54	0.	0.65	0.163	0.	0.044
	17 711.517 7 1.5			17 714.517 7 1.5			17 711.517 7 1.5		
2	11.422	0.	4.525	0.65	0.	0.28	0.	0.	0.
	17 713.517 7 1.5			17 710.517 7 1.5			17 7 1.517 7 1.5		
3	6.619	0.	2.496	0.26	0.	0.10	0.053	0.	0.013
	17 710.517 7 1.5			17 7 9.517 7 1.5			17 7 9.517 7 1.5		
4	9.943	0.	3.416	0.00	0.	0.00	0.001	0.	0.000
	17 710.517 7 1.5			17 7 9.517 7 1.5			17 7 9.517 7 1.5		
All	38.374	0.	14.595	2.27	0.	1.03	0.206	0.	0.057
	17 710.517 7 1.5			17 713.517 7 1.5			17 710.517 7 1.5		

Summary output for zone 2
Period : Day 17 of month 7

Time (Hrs)	Plant (Kw)	Air temp. (Deg. C.)
0.50	0.	21.96
1.50	0.	21.52
2.50	0.	21.10
3.50	0.	20.70
4.50	0.	20.43
5.50	0.	20.84
6.50	0.	22.58
7.50	0.	25.58
8.50	0.	29.04
9.50	0.	31.95
10.50	0.	33.71
11.50	0.	33.60
12.50	0.	32.11
13.50	0.	31.41
14.50	0.	31.75
15.50	0.	32.12
16.50	0.	32.50
17.50	0.	32.76
18.50	0.	32.46
19.50	0.	31.49
20.50	0.	30.20
21.50	0.	29.00
22.50	0.	28.13
23.50	0.	27.51

Table 2: Output from Section 4.4; old solar routine

NEW SOLAR ROUTINE

Air temperature information (Deg.C)

Zone	Maximum value	Minimum value	Mean value
1	38.416	19.580	28.223
	@17, 7,17.50	@17, 7, 4.50	
2	37.297	20.307	29.645
	@17, 7,17.50	@17, 7, 4.50	
3	23.510	18.411	21.109
	@17, 7,18.50	@17, 7, 5.50	
4	22.766	18.114	20.181
	@17, 7,20.50	@17, 7, 7.50	

Surface solar energy absorption (KW)

Zone	External surface			Internal surface			Air point		
	Mx val	Mn val	Me val	Mx val	Mn val	Me val	Mx val	Mn val	Me val
1	11.683	0.	4.158	1.37	0.	0.57	0.163	0.	0.044
	17 711.517 7 1.5			17 714.517 7 1.5			17 711.517 7 1.5		
2	11.422	0.	4.525	0.59	0.	0.28	0.	0.	0.
	17 713.517 7 1.5			17 713.517 7 1.5			17 7 1.517 7 1.5		
3	6.619	0.	2.496	0.28	0.	0.11	0.052	0.	0.016
	17 710.517 7 1.5			17 7 9.517 7 1.5			17 7 9.517 7 1.5		
4	9.943	0.	3.416	0.01	0.	0.00	0.001	0.	0.000
	17 710.517 7 1.5			17 7 9.517 7 1.5			17 7 9.517 7 1.5		
All	38.374	0.	14.595	2.13	0.	0.96	0.207	0.	0.060
	17 710.517 7 1.5			17 714.517 7 1.5			17 710.517 7 1.5		

Summary output for zone 2
Period : Day 17 of month 7

Time (Hrs)	Plant (Kw)	Air temp. (Deg. C.)
0.50	0.	22.06
1.50	0.	21.56
2.50	0.	21.08
3.50	0.	20.63
4.50	0.	20.31
5.50	0.	20.71
6.50	0.	22.48
7.50	0.	25.52
8.50	0.	29.13
9.50	0.	32.27
10.50	0.	34.28
11.50	0.	34.32
12.50	0.	32.95
13.50	0.	32.80
14.50	0.	34.13
15.50	0.	35.41
16.50	0.	36.53
17.50	0.	37.30
18.50	0.	36.57
19.50	0.	34.34
20.50	0.	32.01
21.50	0.	30.31
22.50	0.	29.08
23.50	0.	28.12

Table 3: Output from Section 4.4; new solar routine