```
$ontext
*Residential Electricity Consumption Model for Saudi Arabia

The model can be run for all seasons and regions at once or the user can select
a single region or season combination from the options below.
$offtext
*****************************************************************************
Option NLP=PATHNLP;
Option limrow=000;
Option limcol=000;
Option decimals=6;
Option savepoint=0;
*****************************************************************************
Scalars runAllseasons set to 1 to run for all seasons sequentially /1/
        runSummer set to 1 to run for Summer only /0/
        runWinter set to 1 to run for Winter only /0/
        runSprfall set to 1 to run for Spring and fall only /0/

        runAllregions set to 1 to run for all regions sequentially /1/
        runCent set to 1 to run for COA only /0/
        runWest set to 1 to run for WOA only /0/
        runSout set to 1 to run for SOA only /0/
        runEast set to 1 to run for EOA only /0/;
*****************************************************************************
Sets
Hour hours in a day /hr0*hr24/

season seasons used in defining parameters /Summ,Wint,
                                            Spfa spring and fall consolidated/
seasonuse(season) seasons used for model run - dynamic set

Daytype type of day /wday weekdays
                     wendhol weekends and holidays/

*Materials below are listed in order from external surface (top) to interior surface (bottom):
*Wall/roof design now based on analysis of Al-Sanea et al. (2005) for Saudi Arabia:
m materials /cemplaster1 cement plaster
             concrete1 concrete
             PolySt polystyrene insulation
             concrete2 concrete
             cemplaster2 cement plaster/
*/
concrete(m) concrete layers /concrete1
                             concrete2/

cemplaster(m) cement plaster layers /cemplaster1
                                     cemplaster2/
*/
surface surface /eastern,western,northern,southern,roof/
walls(surface) wall surfaces /eastern,western,northern,southern/

*length=south/north-facing sides; width:east/west-facing sides.
dim dimensions /l length,w width,h height/


IHGcomp internal heat gain components /fridge,freezer,dishwasher,washer,dryer,
                                       waterheater,waterpump,stoven,conelec,
                                       otherapp,people,lightingincand,
                                       lightingCFL,lightingLFL,lightingLED,lightingHal/

Equipment(IHGcomp) IHG components classified as equipment /Fridge refrigerator
                                                           Freezer
                                                           Waterheater
                                                           Waterpump water pump (typically outside th»
e zone i.e. no heat gain contribution)
                                                           Dishwasher
                                                           Washer washing machine
                                                           Dryer clothes dryer
                                                           Stoven stove and oven
                                                           Conelec consumer electronics
                                                           Otherapp other appliances/

withoutpump(equipment) all equipment without water pump /fridge,freezer,waterheater,
                                     dishwasher,washer,dryer,stoven,conelec,otherapp/

```

```
Equipdiscretion(equipment) appliances used for discretionary purposes
                                  /Dishwasher,Washer,Dryer,Stoven,Conelec,Otherapp/

IHGlights(IHGcomp) lighting heat gains /lightingincand,lightingCFL,lightingLFL,
                                       lightingLED,lightingHal/

bulbtech lighting technologies /incand incandescent lamps
                               CFL compact fluorescent lamps
                               LFL linear fluorescent lamps
                               LED light emitting diodes
                               Hal halogen lamps/

fantype /supply,return/
ACtype /Window,Split,Central/
heattype /sensible,latent/

x discretized spatial dimension for heat transfer /x1*x6/

allregions all regions /Cent Riyadh,Sout Abha,West Jeddah,East Qaisumah/
r_use(allregions) dynamic set for regions

coord coordinate elements /lat latitude,long longitude/

RHsup index over which supply air humidity ratio is cycled /RH1*RH1/
Tsup index over which supply air Temperature is cycled /T1*T1/
intake index over which quantity of intake AHU air is cycled /intake1*intake1/

consbrack consumption bracket steps /b1*b8/
;
r_use(allregions)=yes;
seasonuse(season)=yes;
;
alias (surface,surface2);
alias (m,m2);
alias (hour,hour2);
alias (hour,hour3);
*******************************************************************************
*estimated using data from Saudi Aramco (2001, p. 7)
Parameter FracInsulate(allregions) fraction of residences of this type that are insulated
/Cent 0.269
 West 0.320
 Sout 0.130
 East 0.281/
;
Parameters Numberofresidences(allregions) number of the residential type considered in all regions in»
 units;
Numberofresidences('Cent')=(299243+59410+24404)*FracInsulate('Cent');
Numberofresidences('West')=(15112+100888+26149)*FracInsulate('West');
Numberofresidences('Sout')=(19902+12308+8943+58526)*FracInsulate('Sout');
Numberofresidences('East')=(161911+23328+14381)*FracInsulate('East');
*Numberofresidnces(allregions)=1;

Parameter dt time step for FDM discretization in hours;
dt=1;

Scalars
sboltzconst Stefan-Boltzmann constant in kJ*K^-4*m^-2*sec^-1 /5.67e-11/
Patm atmospheric pressure in kPa /101.325/
*Source of enthalpy (McQuiston et al. (2005) page 66)
enthalpysatv0C enthalpy of saturated vapor at 0 degrees C in kJ per kgv /2501.3/
*The specific heat is treated as a constant as it does not change significantly
*in the temperature ranges being considered.
Cpvapor specific heat at constant volume for vapor in kJ per kg per K /1.864/
R_air ideal gas constant for dry air in kJ per kg per K /0.287058/
R_vapor ideal gas constant for water vapor in kJ per kg per K /0.461/
*The specific heat is treated as a constant as it does not change significantly in the temperature
*ranges being considered.
Cpair specific heat for air in kJ per kg per K /1.006/
*Sources for fan characteristics: Nilsson (1995, p.3), Santos and Leal (2005, p.113), and
*Engdahl and Johansson (2004, p. 213).
fanefficiency effective efficiency of the fans taking into account motor and flow efficiencies /1/;

*fanSFP may already account for efficiency. for right now, we use 1 for fanefficiency.
Parameter fanSFP(fantype,allregions) fanSFP for supply and return fans in air conditioning system in »
 kW per cubic meter per second;
```

```
fanSFP(fantype,allregions)=0.6;
fanSFP(fantype,'Sout')=0.7;
fanSFP(fantype,'East')=0.5;
fanSFP(fantype,'West')=0.4;
fanSFP('return',allregions)=0;
*Split and window units have one fan. Central ACs may have two.

Table Daysinseason(season,daytype) number of days in a season by type
      wday wendhol
Summ  61   32
Wint  64   26
Spfa  123  59
;

Parameter Monthsinseason(season) number of months in a season;
Monthsinseason('Summ')=3;
Monthsinseason('Wint')=3;
Monthsinseason('Spfa')=6;

Parameter ACH(allregions) air changes per hour for the zone;
ACH(allregions)=0.70;
ACH('West')=0.55;
ACH('Sout')=0.90;
ACH('East')=0.65;

*****************************************************************************
*************Indoor Properties (often times desired properties)***************
*****************************************************************************
*Specified based on ASHRAE Standard 55-2010 for indoor thermal comfort.
Parameter Tindoor(hour,season,allregions) indoor dry bulb temperature in K;
Tindoor(hour,'Summ','Cent')=273.15+25;
Tindoor(hour,'Wint','Cent')=273.15+21;
Tindoor(hour,'Spfa','Cent')=273.15+22;

Tindoor(hour,'Summ','East')=273.15+25;
Tindoor(hour,'Wint','East')=273.15+21;
Tindoor(hour,'Spfa','East')=273.15+22;

Tindoor(hour,'Summ','Sout')=273.15+22.5;
Tindoor(hour,'Wint','Sout')=273.15+20.5;
Tindoor(hour,'Spfa','Sout')=273.15+21.5;

Tindoor(hour,'Summ','West')=273.15+27;
Tindoor(hour,'Wint','West')=273.15+26;
Tindoor(hour,'Spfa','West')=273.15+26;

*****************************************************************************
*Price-response section, dealing with adjusting indoor zone temperature based on
*real-time pricing and household's tolerance for discomfort:

Scalar discomforttoleranceindex tolerance for discomfort >0 is tolerant- 0 is neutral- and <0 is into»
    lerant /0/
Scalar elecpricethreshold threshold for price increase in the form of ratio of maximum and minimum pr»
    ices to warrant price response /2/
**********************
Scalar thermostatresolution instrumental resolution of thermostat in degrees K or C /0.1/;

Parameter elecprice(hour,season,allregions) price of electricity in USD per kWh;
elecprice(hour,season,allregions)=0.03;
*elecprice(hour,season,allregions)$(ord(hour)>18 and ord(hour)<=21)=0.04;
*elecprice(hour,season,allregions)$(ord(hour)>=13 and ord(hour)<=18)=0.06;

Parameter Tindoormax(hour,season,allregions) maximum indoor temperature allowed by household in Kelvi»
    n;
Tindoormax(hour,season,allregions)=Tindoor(hour,season,allregions)+1;

Parameter numberofsetpoints(hour,season,allregions) number of set point temperatures between max and »
    min temperature;
numberofsetpoints(hour,season,allregions)=(Tindoormax(hour,season,allregions)-Tindoor(hour,season,all»
    regions))/thermostatresolution+1;

Parameter dailypricerange(season,allregions) range between maximum and minimum electricity prices for»
     a given day in USD per kWh;
dailypricerange(season,allregions)=smax(hour,elecprice(hour,season,allregions))-smin(hour,elecprice(h»
    our,season,allregions));
```

```
216
217 *The last element of the set j is equal to the value of numberofsetpoints(hour,season,allregions);
218 Set j progression through set-points /j0*j11/;
219
220 Parameter setpointpricerange(j,hour,season,allregions) price range for themostate control;
221 setpointpricerange(j,hour,season,allregions)$(ord(j)=1)=smin(hour2,elecprice(hour2,season,allregions)»
    );
222
223 Loop(j$(discomforttoleranceindex=0 and ord(j)>1),
224 setpointpricerange(j,hour,season,allregions)=setpointpricerange(j-1,hour,season,allregions)+dailypric»
    erange(season,allregions)/numberofsetpoints(hour,season,allregions)
225      );
226
227 Loop(j$(discomforttoleranceindex<>0 and ord(j)>1),
228 setpointpricerange(j,hour,season,allregions)=setpointpricerange(j-1,hour,season,allregions)
229     +dailypricerange(season,allregions)*(2**(discomforttoleranceindex*((ord(j)-1)-1))*(1-2**discomfor»
    ttoleranceindex)/(1-2**(discomforttoleranceindex*numberofsetpoints(hour,season,allregions))))
230     );
231 setpointpricerange(j,hour,season,allregions)$(discomforttoleranceindex<0 and setpointpricerange(j,hou»
    r,season,allregions)>=smin(hour2,elecprice(hour2,season,allregions))+dailypricerange(season,allregion»
    s)/numberofsetpoints(hour,season,allregions)*(card(j)-2))=smax(hour2,elecprice(hour2,season,allregion»
    s));
232
233 Tindoor(hour,season,allregions)$(smax(hour2,elecprice(hour2,season,allregions))>=elecpricethreshold*s»
    min(hour2,elecprice(hour2,season,allregions)))=
234 thermostatresolution*(smin(j$(ord(j)>1 and (elecprice(hour,season,allregions)<=setpointpricerange(j,h»
    our,season,allregions)+1e-7)),(ord(j)-1)-1))+Tindoor(hour,season,allregions);
235 ********************************************************************************
236 display tindoor;
237 *abort'';
238 *Currently the relative humidity is assumed to be maintained at 50%.
239 Parameter relativehumidityin(hour,season,allregions) indoor desired relative humidity;
240 relativehumidityin(hour,season,allregions)=0.50;
241 relativehumidityin(hour,season,'West')=0.55;
242 relativehumidityin(hour,season,'Sout')=0.45;
243
244 *For a mixture of perfect gases, the humidity ratio can be written by equation 3-15
245 *on page 52 of McQuiston et al. (2005). The partial pressure of vapor in a saturated
246 *mixture is calculated by:
247 *Saturated vapor pressure(T)=611*10^((7.5*T)/(237.3+T)) where T is in Celsius and pressure in Pa.
248 *We assume the total pressure in the zone is around 1 atm.
249 Parameter humidityratioin(hour,season,allregions) humidity ratio inside zone in kgv per kga;
250 humidityratioin(hour,season,allregions)=relativehumidityin(hour,season,allregions)*0.6219
251  *(0.611*10**((7.5*(Tindoor(hour,season,allregions)-273.15))/(237.3+Tindoor(hour,season,allregions)-2»
    73.15)))
252       /(Patm-(0.611*10**((7.5*(Tindoor(hour,season,allregions)-273.15))/(237.3+Tindoor(hour,season,al»
    lregions)-273.15))));
253
254
255 Parameter densityairindoor(hour,season,allregions) density of indoor moist air in kga per cubic meter»
    ;
256 densityairindoor(hour,season,allregions)=(1+humidityratioin(hour,season,allregions))/(1+(R_vapor/R_ai»
    r)*humidityratioin(hour,season,allregions))*Patm/(R_air*Tindoor(hour,season,allregions));
257
258
259 Parameter enthalpyfgindoor(hour,season,allregions) latent heat of vaporization for vapor at indoor te»
    mperature in J per kgv;
260 *at Tindoor (from thermodynamics book, p. 760);
261 enthalpyfgindoor(hour,'Summ','Cent')=2442.3;
262 enthalpyfgindoor(hour,'Wint','Cent')=2451.8;
263 enthalpyfgindoor(hour,'Spfa','Cent')=2449.4;
264
265 enthalpyfgindoor(hour,'Summ','East')=2442.3;
266 enthalpyfgindoor(hour,'Wint','East')=2451.8;
267 enthalpyfgindoor(hour,'Spfa','East')=2449.4;
268
269 enthalpyfgindoor(hour,'Summ','Sout')=(2447+2449.4)/2;
270 enthalpyfgindoor(hour,'Wint','Sout')=(2454.1+2451.8)/2;
271 enthalpyfgindoor(hour,'Spfa','Sout')=(2451.8+2449.4)/2;
272
273 enthalpyfgindoor(hour,'Summ','West')=2437.6;
274 enthalpyfgindoor(hour,'Wint','West')=2439.9;
275 enthalpyfgindoor(hour,'Spfa','West')=2439.9;
276
277 *htranscoeffin from page 240.
```

```
*4.15e-3 for the ceiling when heating, 1.02e-3 when cooling.
*Temperature of the ceiling surface is lower than the indoor air temperature,so
*heat flows upward. The opposite is true for the Summ.
Parameter htranscoeffin(surface) interior surface convection coefficient in kW*K^-1*m^-2;
htranscoeffin(walls)=3.18e-3;
htranscoeffin('roof')=4.15e-3;
;

*****************************************************************************
**************************Occupancy pattern**********************************
*****************************************************************************
Parameter HHsize(allregions) household size per region for the residence type under study
/Cent   7.69
 West   7.40
 Sout   7.17
 East   7.81/
;
*Defining occupancy schedule as a percentage of total household size fo weekdays and weekends:
Parameter Occupancy(daytype,hour,allregions) number of occupants throughout the day;
Occupancy('wday',hour,allregions)=1*HHsize(allregions);
Occupancy('wday',hour,allregions)$(ord(hour)<=17 and ord(hour)>=9)=0.5*HHsize(allregions);
Occupancy('wday',hour,allregions)$(ord(hour)<=23 and ord(hour)>=21)=0.8*HHsize(allregions);

Occupancy('wendhol',hour,allregions)=1*HHsize(allregions);
Occupancy('wendhol',hour,allregions)$(ord(hour)<=17 and ord(hour)>=15)=0.9*HHsize(allregions);
Occupancy('wendhol',hour,allregions)$(ord(hour)<=21 and ord(hour)>=18)=0.1*HHsize(allregions);
Occupancy('wendhol',hour,allregions)$(ord(hour)<=23 and ord(hour)>=22)=0.8*HHsize(allregions);


*****************************************************************************
**************************Residence Dimensions*******************************
*****************************************************************************
Parameter occupancydensity(allregions) number of people per square meter of living space;
occupancydensity('Cent')=1/67.7387;
occupancydensity('West')=1/57.8767;
occupancydensity('Sout')=1/51.8308;
occupancydensity('East')=1/89.8025;

Parameter totalfloorarea(allregions) estimated floor area in sq. meters;
totalfloorarea(allregions)=HHsize(allregions)/occupancydensity(allregions);

Parameter numberfloors(allregions) estimated number of floors in the entire thermal envelope for the »
   residence type;
numberfloors(allregions)=2.5;

Parameter Dimension(dim,allregions) spatial dimensions of zone in meters (see diagram);
Dimension('l',allregions)=(totalfloorarea(allregions)/numberfloors(allregions))**0.5;
Dimension('w',allregions)=Dimension('l',allregions);
*Below, assuming 10 feet per floor
Dimension('h',allregions)=numberfloors(allregions)*3.048;
display dimension,totalfloorarea;
*abort'';
Parameter zonevolume(allregions) calculates the zone air volume in cubic meters;
zonevolume(allregions)=prod(dim,Dimension(dim,allregions));
;
Parameter Surfarea(surface,allregions) surface area of walls in meters squared (see diagram);
Surfarea('western',allregions)=Dimension('w',allregions)*Dimension('h',allregions);
Surfarea('eastern',allregions)=Dimension('w',allregions)*Dimension('h',allregions);
Surfarea('northern',allregions)=Dimension('l',allregions)*Dimension('h',allregions);
Surfarea('southern',allregions)=Dimension('l',allregions)*Dimension('h',allregions);
Surfarea('roof',allregions)=Dimension('l',allregions)*Dimension('w',allregions);



*Emissivity, thermal diff, and thermal cond values from Bejan's book (p. 537 and 625)
*****************************************************************************
*********************Walls/Roof Material Properties**************************
*****************************************************************************
Parameter thermdiff(m,surface) thermal diffusivity in sq. m per second;
*thermdiff(m,surface)=4.6e-7;
*$ontext
thermdiff(cemplaster,surface)=5.8e-7;
*thermdiff('cemplaster1','roof')=1.3e-3/(0.84*2150);
thermdiff('PolySt',surface)=0.034e-3/(23*1.28);
thermdiff(concrete,surface)=6.6e-7;
```

```
*$offtext
Parameter thermcond(m,surface) thermal conductivity in kW per m per K;
*thermcond(m,surface)=0.72e-3;
*$ontext
thermcond(cemplaster,surface)=0.79e-3;
thermcond(concrete,surface)=1.28e-3;
thermcond('PolySt',surface)=0.034e-3;
*$offtext
*Emissivity and absorptivity only applicable to external material.
Parameter emissivity(m,surface) emissivity;
emissivity(m,surface)=0.90;

Parameter solabsorb(m,surface) solar absorptivity;
solabsorb(m,surface)=0.50;



*****************************************************************************
****************************Outdoor Conditions*******************************
*****************************************************************************
*Average temperatures over entire Summ period using NREL/KACST data for the year 2002.
Table Tout(hour,season,allregions) outdoor dry bulb temperature in K
            Summ.West       Wint.West       Spfa.West
hr0         303.63          295.57          299.50
hr1         302.91          294.93          298.90
hr2         302.32          294.48          298.38
hr3         301.86          294.15          297.94
hr4         301.46          293.88          297.53
hr5         301.28          293.57          297.24
hr6         301.17          293.38          297.09
hr7         302.46          293.36          297.91
hr8         304.35          295.06          300.54
hr9         306.39          297.65          303.04
hr10        308.36          299.33          305.08
hr11        309.85          300.66          306.56
hr12        310.31          301.54          307.02
hr13        310.40          301.94          306.82
hr14        310.15          301.93          306.50
hr15        310.01          301.60          306.04
hr16        309.51          301.05          305.40
hr17        309.12          300.23          304.53
hr18        308.36          299.06          303.45
hr19        307.26          298.06          302.46
hr20        306.38          297.30          301.78
hr21        305.71          296.65          301.22
hr22        305.04          296.19          300.70
hr23        304.35          295.75          300.08
hr24        303.63          295.57          299.50

+           Summ.Cent       Wint.Cent       Spfa.Cent
hr0         305.18          286.85          297.05
hr1         304.28          286.36          296.29
hr2         303.47          285.79          295.65
hr3         302.65          285.16          295.00
hr4         301.90          284.80          294.37
hr5         301.35          284.43          293.88
hr6         301.08          284.10          293.62
hr7         301.77          283.97          294.30
hr8         305.02          285.09          296.53
hr9         308.44          287.27          299.26
hr10        310.27          288.95          301.24
hr11        311.40          290.27          302.57
hr12        312.30          291.41          303.59
hr13        313.03          292.28          304.37
hr14        313.55          292.94          304.91
hr15        313.83          293.22          305.06
hr16        313.80          293.09          304.93
hr17        313.27          292.47          304.18
hr18        312.24          291.25          302.94
hr19        310.54          290.21          301.62
hr20        309.06          289.32          300.46
hr21        307.93          288.65          299.50
hr22        307.02          287.98          298.72
hr23        306.09          287.45          297.85
hr24        305.18          286.85          297.05
```

```
+          Summ.Sout      Wint.Sout     Spfa.Sout
hr0        293.50         285.76        289.60
hr1        292.86         285.34        289.10
hr2        292.35         284.95        288.59
hr3        291.99         284.60        288.05
hr4        291.45         284.20        287.48
hr5        290.78         283.93        287.06
hr6        290.66         283.75        286.76
hr7        293.37         283.88        289.08
hr8        296.77         286.06        292.35
hr9        299.07         288.07        294.69
hr10       300.65         289.71        296.16
hr11       301.70         290.90        297.21
hr12       302.25         291.62        297.82
hr13       302.19         292.05        298.25
hr14       301.60         292.11        298.17
hr15       301.07         291.79        297.62
hr16       300.14         291.25        296.86
hr17       299.07         290.33        295.66
hr18       297.95         289.04        294.17
hr19       296.65         288.19        293.00
hr20       295.91         287.56        292.19
hr21       295.40         287.06        291.43
hr22       294.65         286.54        290.71
hr23       294.12         286.11        290.08
hr24       293.50         285.76        289.60

+       Summ.East         Wint.East     Spfa.East
hr0        305.27         284.99        295.77
hr1        304.36         284.46        295.10
hr2        303.48         284.01        294.56
hr3        302.76         283.65        293.97
hr4        302.07         283.28        293.42
hr5        301.46         282.93        292.98
hr6        301.54         282.44        292.98
hr7        304.08         282.43        294.48
hr8        307.49         284.67        297.05
hr9        310.28         287.11        299.56
hr10       312.33         289.28        301.59
hr11       313.77         290.75        303.22
hr12       314.68         291.80        304.30
hr13       315.36         292.39        305.02
hr14       315.83         293.01        305.43
hr15       316.01         293.18        305.54
hr16       315.86         292.98        305.10
hr17       315.38         292.14        304.20
hr18       314.21         290.50        302.58
hr19       312.17         289.14        300.88
hr20       310.18         287.95        299.53
hr21       308.72         287.04        298.32
hr22       307.43         286.23        297.29
hr23       306.20         285.60        296.45
hr24       305.27         284.99        295.77

;
*Tout(hour,season,r_use)=Tout(hour,season,r_use)-2;
;
*Average relative humidity over entire Summ period using NREL/KACST data for the year 2002.
Table relativehumidityout(hour,season,allregions) relative humidity
*relativehumidityout(hour,season,r_use)=0.8;
*$ontext
           Summ.West       Wint.West     Spfa.West
hr0        0.74            0.82          0.82
hr1        0.76            0.81          0.83
hr2        0.78            0.81          0.84
hr3        0.82            0.81          0.85
hr4        0.85            0.81          0.85
hr5        0.86            0.82          0.86
hr6        0.89            0.82          0.87
hr7        0.90            0.80          0.85
hr8        0.86            0.74          0.78
hr9        0.73            0.62          0.66
hr10       0.62            0.55          0.55
hr11       0.56            0.51          0.50
```

```
hr12       0.55             0.49           0.51
hr13       0.54             0.50           0.53
hr14       0.54             0.52           0.54
hr15       0.54             0.54           0.56
hr16       0.56             0.56           0.58
hr17       0.56             0.59           0.62
hr18       0.58             0.65           0.67
hr19       0.62             0.70           0.72
hr20       0.66             0.75           0.75
hr21       0.69             0.78           0.77
hr22       0.70             0.79           0.78
hr23       0.72             0.80           0.80
hr24       0.74             0.82           0.82
*$offtext

+          Summ.Cent        Wint.Cent      Spfa.Cent
hr0        0.20             0.62           0.40
hr1        0.21             0.64           0.41
hr2        0.22             0.66           0.42
hr3        0.23             0.69           0.44
hr4        0.24             0.70           0.45
hr5        0.25             0.72           0.47
hr6        0.26             0.74           0.48
hr7        0.27             0.75           0.48
hr8        0.25             0.72           0.45
hr9        0.20             0.64           0.39
hr10       0.17             0.58           0.35
hr11       0.16             0.53           0.31
hr12       0.15             0.49           0.29
hr13       0.14             0.47           0.28
hr14       0.14             0.44           0.27
hr15       0.13             0.43           0.27
hr16       0.13             0.43           0.27
hr17       0.13             0.45           0.28
hr18       0.14             0.47           0.29
hr19       0.15             0.51           0.31
hr20       0.16             0.53           0.33
hr21       0.17             0.56           0.35
hr22       0.18             0.58           0.36
hr23       0.19             0.60           0.38
hr24       0.20             0.62           0.40

+          Summ.Sout   Wint.Sout   Spfa.Sout
hr0        0.64        0.88        0.71
hr1        0.63        0.88        0.71
hr2        0.62        0.89        0.70
hr3        0.60        0.90        0.70
hr4        0.59        0.91        0.70
hr5        0.60        0.92        0.70
hr6        0.59        0.92        0.70
hr7        0.52        0.92        0.64
hr8        0.39        0.84        0.52
hr9        0.30        0.74        0.43
hr10       0.25        0.68        0.37
hr11       0.23        0.63        0.34
hr12       0.24        0.63        0.34
hr13       0.29        0.62        0.35
hr14       0.35        0.65        0.39
hr15       0.40        0.68        0.44
hr16       0.45        0.72        0.49
hr17       0.50        0.78        0.57
hr18       0.53        0.87        0.66
hr19       0.60        0.91        0.72
hr20       0.64        0.92        0.74
hr21       0.63        0.90        0.74
hr22       0.65        0.89        0.74
hr23       0.64        0.88        0.74
hr24       0.64        0.88        0.71

+          Summ.East       Wint.East        Spfa.East
hr0        0.20            0.70             0.44
hr1        0.22            0.72             0.46
hr2        0.23            0.73             0.47
hr3        0.24            0.74             0.49
hr4        0.25            0.76             0.50
```

```
hr5        0.26            0.77            0.51
hr6        0.26            0.79            0.51
hr7        0.24            0.79            0.49
hr8        0.21            0.72            0.45
hr9        0.18            0.62            0.40
hr10       0.16            0.54            0.36
hr11       0.15            0.49            0.33
hr12       0.14            0.45            0.30
hr13       0.13            0.43            0.28
hr14       0.13            0.41            0.28
hr15       0.12            0.40            0.27
hr16       0.12            0.41            0.28
hr17       0.12            0.43            0.29
hr18       0.13            0.49            0.32
hr19       0.14            0.55            0.35
hr20       0.15            0.58            0.36
hr21       0.17            0.62            0.39
hr22       0.18            0.65            0.41
hr23       0.19            0.68            0.43
hr24       0.20            0.70            0.44
;

Parameter humidityratioout(hour,season,allregions) humidity ratio outdoor air in kgv per kga;
humidityratioout(hour,season,allregions)=relativehumidityout(hour,season,allregions)*0.6219
 *(0.611*10**((7.5*(Tout(hour,season,allregions)-273.15))/(237.3+Tout(hour,season,allregions)-273.15)»
))
      /(Patm-(0.611*10**((7.5*(Tout(hour,season,allregions)-273.15))/(237.3+Tout(hour,season,allregio»
ns)-273.15))));

;
*SOLAR IRRADIATION CALCULATIONS:
$include solarirradmacros.gms
scalar timezone Saudi Arabian time zone in degrees W relative to Prime Meridian /315/
       greflectance ground reflectance (estimated for now) /0.2/;

*DNI data represent averages for Summ in the regions (Source: KACST/NREL)
Table DNI(hour,season,allregions) direct normal irradiance in W per sq. m
           Summ.West      Wint.West      Spfa.West
hr0        0.00           0.00           0.00
hr1        0.00           0.00           0.00
hr2        0.00           0.00           0.00
hr3        0.00           0.00           0.00
hr4        0.00           0.00           0.00
hr5        0.00           0.00           0.00
hr6        0.00           0.00           0.00
hr7        108.21         8.62           116.25
hr8        220.17         237.29         267.18
hr9        284.13         373.35         372.17
hr10       322.80         457.99         425.28
hr11       366.91         483.59         464.96
hr12       371.47         495.44         464.82
hr13       385.27         515.21         441.32
hr14       358.27         508.24         427.21
hr15       337.17         476.44         388.88
hr16       288.31         405.86         325.61
hr17       214.01         263.59         224.91
hr18       98.18          25.45          75.94
hr19       0.00           0.00           0.00
hr20       0.00           0.00           0.00
hr21       0.00           0.00           0.00
hr22       0.00           0.00           0.00
hr23       0.00           0.00           0.00
hr24       0.00           0.00           0.00

+          Summ.Cent      Wint.Cent         Spfa.Cent
hr0        0.00           0.00              0.00
hr1        0.00           0.00              0.00
hr2        0.00           0.00              0.00
hr3        0.00           0.00              0.00
hr4        0.00           0.00              0.00
hr5        0.00           0.00              0.00
hr6        126.18         0.00              69.73
hr7        428.50         179.37            345.00
hr8        616.34         417.28            537.36
hr9        701.90         540.97            630.72
```

```
hr10       758.87         591.76           691.35
hr11       790.57         632.42           726.64
hr12       787.36         672.32           726.11
hr13       769.69         669.87           698.14
hr14       731.90         643.80           640.54
hr15       660.86         544.11           551.38
hr16       549.80         440.87           413.90
hr17       343.09         198.41           162.23
hr18       82.14          0.00             16.31
hr19       0.00           0.00             0.00
hr20       0.00           0.00             0.00
hr21       0.00           0.00             0.00
hr22       0.00           0.00             0.00
hr23       0.00           0.00             0.00
hr24       0.00           0.00             0.00

+          Summ.Sout      Wint.Sout     Spfa.Sout
hr0        0.00           0.00          0.00
hr1        0.00           0.00          0.00
hr2        0.00           0.00          0.00
hr3        0.00           0.00          0.00
hr4        0.00           0.00          0.00
hr5        0.00           0.00          0.00
hr6        15.81          0.00          40.81
hr7        308.10         162.57        434.72
hr8        519.67         481.49        643.23
hr9        602.28         636.41        740.30
hr10       635.58         660.29        800.84
hr11       638.66         691.25        823.31
hr12       541.16         679.27        792.25
hr13       450.68         665.41        738.68
hr14       331.60         614.67        659.61
hr15       304.88         565.33        576.88
hr16       218.10         460.26        474.79
hr17       167.89         281.03        268.43
hr18       18.59          0.00          31.64
hr19       0.00           0.00          0.00
hr20       0.00           0.00          0.00
hr21       0.00           0.00          0.00
hr22       0.00           0.00          0.00
hr23       0.00           0.00          0.00
hr24       0.00           0.00          0.00

+       Summ.East        Wint.East        Spfa.East
hr0        0.00           0.00             0.00
hr1        0.00           0.00             0.00
hr2        0.00           0.00             0.00
hr3        0.00           0.00             0.00
hr4        0.00           0.00             0.00
hr5        0.00           0.00             0.00
hr6        169.94         0.00             56.49
hr7        436.09         80.39            233.17
hr8        602.67         294.03           370.68
hr9        681.89         371.92           461.88
hr10       743.99         404.94           502.37
hr11       768.10         433.38           533.62
hr12       761.54         447.63           537.10
hr13       750.60         404.87           507.05
hr14       721.65         406.25           462.92
hr15       663.35         334.87           408.82
hr16       560.48         270.14           295.76
hr17       391.47         99.81            122.03
hr18       122.94         0.00             27.01
hr19       0.00           0.00             0.00
hr20       0.00           0.00             0.00
hr21       0.00           0.00             0.00
hr22       0.00           0.00             0.00
hr23       0.00           0.00             0.00
hr24       0.00           0.00             0.00

;
Parameter tiltangle(surface) tilt angle for surface in degress (normal of surface relative to normal »
    of horizontal);
tiltangle(walls)=90;
tiltangle('roof')=0;
```

```
724
725 *Source: NREL/KACST(2002) for their measurement sites.
726 Table coordinates(coord,allregions) geographical coordinates in deg W for longitude and deg N for lat»
    itude
727        West   Cent   Sout   East
728 lat    21.68  24.91  18.23  28.32
729 long   320.85 313.59 317.49 313.87
730 ;
731
732 Parameter dayofyear(season) day number during the year;
733 dayofyear('Summ')=213;
734 dayofyear('Wint')=37;
735 dayofyear('Spfa')=121;
736
737 Parameter hourofday(hour) assigning numerical values to hour of day;
738 hourofday(hour)=ord(hour)-1;
739
740
741 Parameter Fsg(surface) view factor from surface to ground;
742 Fsg(surface)=(1-cos(tiltangle(surface)*pi/180))/2;
743
744 Parameter Fssky(surface) view factor from surface to sky;
745 Fssky(surface)=(1+cos(tiltangle(surface)*pi/180))/2;
746
747 Parameter C(season) ratio of diffuse irradiance to DNI (from McQuiston et al. (2005 page 187));
748 C('Summ')=0.134;
749 C('Wint')=0.103;
750 C('Spfa')=0.120;
751
752 Parameter positionofearth(season) position of earth in degrees;
753 Parameter equationoftime(season) Equation of time in minutes;
754 Parameter hourocalsolartime(hour,season,allregions) Local solar time in hours;
755 *Hour angle is angle between the projection of the vector of location-to-center of earth on
756 *the equitorial plane and the associated projection of the line from the center of the sun
757 *to the center of the earth.
758 *By convention, the hour angle is negative in the morning, zero at noon, and positive in the afternoo»
    n.
759 Parameter hourangle(hour,season,allregions) the hour angle in degrees;
760 *sol dec: Angle between the line connecting the origins of the Earth and Sun and the line projection
761 *of that line on the earth'season equitorial plane.
762 Parameter surazimuth(hour,surface,season,allregions) the surface azimuth;
763 *orientation of the aperture plane from the north
764 Parameter soldeclination(season) solar declination angle in degrees;
765 *sol alt: Angle between the sun'season rays and the projection of the rays on a horizontal surface.
766 Parameter solaltitude(hour,season,allregions) solar altitude in degrees;
767 *sol azim: Angle between horizontal projection of the sun'season rays and the horizontal direction
768 *measured from the north (clockwise direction).
769 Parameter solazimuth(hour,season,allregions) solar azimuth in degrees;
770 *solsurfazim: Absolute value of the difference between the solar azimuth (phi) and the surface azimut»
    h (psi).
771 Parameter solarsurfaceazimuth(hour,surface,season,allregions) solar surface azimuth in degrees;
772 *ang of inc: angle between sun'season rays and the normal of the surface
773 Parameter angleofincidence(hour,surface,season,allregions) the angle of incidence in degrees;
774
775
776 positionofearth(season)=earthpos(dayofyear(season));
777
778 equationoftime(season)=EOT(positionofearth(season));
779
780 hourocalsolartime(hour,season,allregions)=solhr(hourofday(hour),Dayofyear(season),coordinates('long',»
    allregions),timezone);
781
782 hourangle(hour,season,allregions)=hourang(hourocalsolartime(hour,season,allregions));
783
784 *Based on chosen diagram for zone orientation (arbitrary for horizontal surfaces);
785 surazimuth(hour,'eastern',season,allregions)=90;
786 surazimuth(hour,'western',season,allregions)=270;
787 surazimuth(hour,'northern',season,allregions)=0;
788 surazimuth(hour,'southern',season,allregions)=180;
789
790 soldeclination(season)=soldecl(positionofearth(season));
791
792 solaltitude(hour,season,allregions)=solalt(hourangle(hour,season,allregions),soldeclination(season),c»
    oordinates('lat',allregions));
793
```

```
794 solazimuth(hour,season,allregions)=solazim(hourangle(hour,season,allregions),soldeclination(season),c»
    oordinates('lat',allregions),solaltitude(hour,season,allregions));
795 solazimuth(hour,season,allregions)$(hourangle(hour,season,allregions)>0 or hourocalsolartime(hour,sea»
    son,allregions)>12)=360-solazimuth(hour,season,allregions);
796
797 solarsurfaceazimuth(hour,surface,season,allregions)=Gammasol(solazimuth(hour,season,allregions),suraz»
    imuth(hour,surface,season,allregions));
798
799 angleofincidence(hour,surface,season,allregions)=Incidence(solaltitude(hour,season,allregions),solars»
    urfaceazimuth(hour,surface,season,allregions),tiltangle(surface));
800
801
802 *The total irradiance is now calculated as a function of DNI.
803 Parameter directirradiance(hour,surface,season,allregions) the direct irradiance in kW per sq. m;
804 directirradiance(hour,'northern',season,allregions)=DNI(hour,season,allregions)*COS(angleofincidence(»
    hour,'northern',season,allregions)*pi/180)$(solaltitude(hour,season,allregions)>0 and (solazimuth(hou»
    r,season,allregions)<90 or solazimuth(hour,season,allregions)>270));
805 directirradiance(hour,'southern',season,allregions)=DNI(hour,season,allregions)*COS(angleofincidence(»
    hour,'southern',season,allregions)*pi/180)$(solaltitude(hour,season,allregions)>0 and (solazimuth(hou»
    r,season,allregions)>90 and solazimuth(hour,season,allregions)<270));
806 directirradiance(hour,'eastern',season,allregions)=DNI(hour,season,allregions)*COS(angleofincidence(h»
    our,'eastern',season,allregions)*pi/180)$(solaltitude(hour,season,allregions)>0 and (solazimuth(hour,»
    season,allregions)>0 and solazimuth(hour,season,allregions)<180));
807 directirradiance(hour,'western',season,allregions)=DNI(hour,season,allregions)*COS(angleofincidence(h»
    our,'western',season,allregions)*pi/180)$(solaltitude(hour,season,allregions)>0 and (solazimuth(hour,»
    season,allregions)>180 and solazimuth(hour,season,allregions)<360));
808 directirradiance(hour,'roof',season,allregions)=DNI(hour,season,allregions)*COS(angleofincidence(hour»
    ,'roof',season,allregions)*pi/180)$(solaltitude(hour,season,allregions)>0);
809
810 directirradiance(hour,surface,season,allregions)=directirradiance(hour,surface,season,allregions)*1e-»
    3;
811
812
813 Parameter diffuseirradiance(hour,surface,season,allregions) the diffuse irradiance in kW per sq. m;
814 diffuseirradiance(hour,surface,season,allregions)=Fssky(surface)*C(season)*DNI(hour,season,allregions»
    )*1e-3;
815
816 Parameter reflectedirradiance(hour,surface,season,allregions) the reflected irradiance in kW per sq. »
    m;
817 reflectedirradiance(hour,surface,season,allregions)=greflectance*Fsg(surface)*(C(season)+sin(solaltit»
    ude(hour,season,allregions)*pi/180))*DNI(hour,season,allregions)*1e-3;
818
819
820 *Total irradiance is the sum of direct, diffuse, and reflected irradiation, depending on tilt angle o»
    f surface.
821 Parameter totalirrad(hour,season,surface,allregions) total solar irradiance on a surface in kW per sq»
    r meter;
822 totalirrad(hour,season,surface,allregions)= directirradiance(hour,surface,season,allregions)
823                                  +diffuseirradiance(hour,surface,season,allregions)
824                                  +reflectedirradiance(hour,surface,season,allregions);
825
826 *totalirrad(hour,season,'west',allregions)=diffuseirradiance(hour,'west',season,allregions);
827 *totalirrad(hour,season,'east',allregions)$(ord(hour)>=17)=diffuseirradiance(hour,'east',season,allre»
    gions);
828
829 *Currently using historical Weibull averages from Rehman et al. (1994) using their
830 *scale and shaper parameters;
831 Parameter windspeed(hour,season,allregions) wind speed in meters per second at a height of around 10 »
    meters;
832 *Using Riyadh averages for central:
833 windspeed(hour,'Summ','Cent')=3.85*gamma(1+1/1.93);
834 windspeed(hour,'Wint','Cent')=3.92*gamma(1+1/1.92);
835 windspeed(hour,'Spfa','Cent')=3.48*gamma(1+1/1.88);
836 *Using Jeddah averages for west:
837 windspeed(hour,'Summ','West')=3.94*gamma(1+1/2.45);
838 windspeed(hour,'Wint','West')=4.30*gamma(1+1/2.13);
839 windspeed(hour,'Spfa','West')=4.01*gamma(1+1/2.20);
840 *Using Najran averages for south:
841 windspeed(hour,'Summ','Sout')=3.71*gamma(1+1/2.43);
842 windspeed(hour,'Wint','Sout')=2.87*gamma(1+1/2.00);
843 windspeed(hour,'Spfa','Sout')=2.89*gamma(1+1/2.18);
844 *Using Dhahran averages for east:
845 windspeed(hour,'Summ','East')=4.88*gamma(1+1/2.33);
846 windspeed(hour,'Wint','East')=4.92*gamma(1+1/2.47);
847 windspeed(hour,'Spfa','East')=5.04*gamma(1+1/2.28);
```

```
848
849
850 Parameter Tground(hour,season,allregions) ground temperature in K;
851 Tground(hour,season,allregions)=300;
852
853 *Below correlation for the outdoor heat transfer coefficient was established by
854 *Jayamaha et al. (1996) for wind speeds ranging from 0 to 4 meters/sec.
855 Parameter htranscoeffout(hour,season,surface,allregions) exterior surface convection coefficient in k»
    W*K^-1*m^-2;
856 htranscoeffout(hour,season,surface,allregions)=(1.444*windspeed(hour,season,allregions)+4.955)*1e-3;
857
858
859 Parameter densityairout(season,hour,allregions) density of moist air in kga per cubic meter;
860 densityairout(season,hour,allregions)=(1+humidityratioout(hour,season,allregions))/(1+(R_vapor/R_air)»
    *humidityratioout(hour,season,allregions))*Patm/(R_air*Tout(hour,season,allregions));
861
862 Parameter infilvolflowrate(allregions) infiltration volumetric flow rate in cubic meters per second;
863 infilvolflowrate(allregions)=ACH(allregions)*zonevolume(allregions)/3600;
864
865
866
867 *****************************************************************************
868 *******************************Lighting**************************************
869 *****************************************************************************
870 *Source for minimum illumination: Jefferis (2013, p. 360).
871 Scalar illuminatemin minimum illumination in lumens per sq. meter /130/;
872
873 Parameter bulbefficacy(bulbtech) bulb efficacy in lumens per kW
874 /incand 16e3
875  CFL    70e3
876  LFL    92e3
877  LED    80e3
878  Hal    21e3/
879 ;
880 Parameter bulbpowerrating(bulbtech) bulb power ratings in kW per bulb
881 /incand 50e-3
882  CFL    23e-3
883  LFL    26e-3
884  LED    20e-3
885  Hal    40e-3/
886 ;
887 *Based on Anwar's calculations using imports data. Only available at the national level.
888 Parameter bulbmarketshare(bulbtech) bulb fraction market share in the residential sector
889 /incand 0.42
890  CFL    0.095
891  LFL    0.36
892  LED    0.00
893  Hal    0.125/
894 ;
895 Parameter bulbsusedfrac(allregions) fraction of lights used by region;
896 bulbsusedfrac(allregions)=0.40;
897 bulbsusedfrac('Sout')=0.37;
898 bulbsusedfrac('West')=0.35;
899 *Here we can use either the illumination requirement data or directly input number of bulbs:
900 *I assume that 50% of the lights are turned on at any one time:
901 Parameter Lightingschedule(bulbtech,season,daytype,hour,allregions) number of lights throughout the d»
    ay;
902 Lightingschedule(bulbtech,season,daytype,hour,allregions)$(solaltitude(hour,season,allregions)<=5 and»
     (ord(hour)<=23 and ord(hour)>12))=
903 illuminatemin*bulbmarketshare(bulbtech)*Surfarea('roof',allregions)*numberfloors(allregions)*
904 (1/bulbefficacy(bulbtech))*(1/bulbpowerrating(bulbtech))*bulbsusedfrac(allregions);
905
906 Parameter LightingscheduleOutdoor(bulbtech,season,daytype,hour,allregions) number of lights used outs»
    ide ie without heat gain contribution;
907 Lightingscheduleoutdoor('Incand',season,daytype,hour,allregions)$(solaltitude(hour,season,allregions)»
    <=3)=2;
908
909 *****************************************************************************
910 *************************Equipment and Appliances****************************
911 *****************************************************************************
912 Parameter spaceheatingsaturation(allregions) percentage of households with electrical space heating
913 /Cent 0.15
914  Sout 0.30
915  West 0.00
916  East 0.05/
```

```
;
*Except for the water pump, equipment power draws below are from Gottwalt et al. (2011).
*Using the other equipment's power values, the water pump draw is estimated from
*the assumed operation schedule below and the amount of electricity consumed by appliances
*as cited by The Brattle Group (2011). The water heater power draw is estimated
*the same way, using its electricity consumption value cited by The Brattle Group.
*Consumer electronics are estimated the same way as the water heaters, and they include
*TVs,laptops,desktops, and DVD/BD players.
Parameter equippowerrating(equipment,allregions) equipment operational power loads in kW;
*some equipment is assumed to use 50% of its rated power consumption on average:
equippowerrating('fridge',allregions)=140e-3;
equippowerrating('freezer',allregions)=106e-3;
equippowerrating('dishwasher',allregions)=530e-3;
equippowerrating('washer',allregions)=600e-3;
equippowerrating('dryer',allregions)=1410e-3;
equippowerrating('stoven',allregions)=(1840)*1e-3;
equippowerrating('conelec',allregions)=519.23e-3;
equippowerrating('otherapp',allregions)=500e-3;
equippowerrating('waterpump',allregions)=1112.7e-3;
equippowerrating('waterheater',allregions)=3214e-3;

*above values are multiplied by the number of residences per envelope:
equippowerrating(equipment,allregions)=1*equippowerrating(equipment,allregions);

;
*Equipment saturation levels below from Dubai Press Club (2012, p. 159-161) and CDSI (2004-2012)
*Also assumes that imports constitute nearly 65% of stock:
Parameter equipsaturation(equipment) saturation levels in households for appliances in percent
/fridge      0.93
 freezer     0.46
 dishwasher  0.045
 washer      0.635
 dryer       0.069
 stoven      1.95
 conelec     3.711
 otherapp    1.00
 waterpump   0.92
 waterheater 1.59/
;

Parameter equipmentschedule(equipment,season,daytype,hour) use of equipment throughout the day;
*For national analysis, these values represent fraction of households for any given hour
*when they are awake (estimated from 7 AM to 10 PM) except for fridge, freezer, and water pump:
equipmentschedule(equipment,season,daytype,hour)=0;
*$ontext
equipmentschedule('fridge',season,daytype,hour)=1;
equipmentschedule('freezer',season,daytype,hour)=1;
equipmentschedule('waterpump',season,daytype,hour)=1/(card(hour)-1);
equipmentschedule('dishwasher',season,daytype,hour)$(ord(hour)>=8 and ord(hour)<=23)=1/(23-8);
*I assume the washer and dryer are run every other day (hence the 50% multiplier):
equipmentschedule('washer',season,daytype,hour)$(ord(hour)>=8 and ord(hour)<=23)=0.5*1/(23-8);
equipmentschedule('dryer',season,daytype,hour)$(ord(hour)>=8 and ord(hour)<=23)=0.5*1/(23-8);
equipmentschedule('stoven',season,daytype,hour)$(ord(hour)>=8 and ord(hour)<=23)=1/(23-8);
equipmentschedule('conelec',season,'wday',hour)$(ord(hour)>=14 and ord(hour)<=23)=1/(23-14);
equipmentschedule('conelec',season,'wendhol',hour)$(ord(hour)>=9 and ord(hour)<=23)=1/(23-9);
equipmentschedule('otherapp',season,daytype,hour)$(ord(hour)>=8 and ord(hour)<=23)=1/(23-8);
*In the summmer, I assume only a fraction of water heaters is used:
equipmentschedule('waterheater',season,daytype,hour)$(ord(hour)>=8 and ord(hour)<=23)=0.33*1/(23-8);
equipmentschedule('waterheater','Wint',daytype,hour)$(ord(hour)>=8 and ord(hour)<=23)=1/(23-8);
*$offtext
*************************************************************************
$ontext
This section deals with a household's price response to price changes throughout
the day. It is only activated if the ratio of the maximum and minimum prices observed
in a 24-hour-period is 2 or higher. Only discretionary uses are included.
$offtext
$INCLUDE Appliances_priceresponse.gms
display equipmentschedule;
*abort'';
*************************************************************************
;
*While sensible heat gains are divided into radiative and convective components,
*latent heat gains are assumed to instantaneously contribute to cooling load (p. 223, McQuiston et al»
.)
Parameter Internalheatgain(hour,season,daytype,IHGcomp,heattype,allregions) internal heat gains in kW»
```

```
;
*For equipment, it is assumed that that 50% of the total nameplate input ratings
*contribute to heat gain (page 225 of McQuiston et al.):
Internalheatgain(hour,season,daytype,equipment,'sensible',allregions)$(withoutpump(equipment))=
0.5*equipsaturation(equipment)*equipmentschedule(equipment,season,daytype,hour)*equippowerrating(equi»
pment,allregions);


*From Table 8-2 (p. 222) for seated people doing very light work :
*72 W/adult and 45 W/adult for sensible and latent heat types, respectively.
Internalheatgain(hour,season,daytype,'people','sensible',allregions)=72e-3*Occupancy(daytype,hour,all»
regions);
Internalheatgain(hour,season,daytype,'people','latent',allregions)=45e-3*Occupancy(daytype,hour,allre»
gions);

Internalheatgain(hour,season,daytype,'lightingincand','sensible',allregions)=bulbpowerrating('incand'»
)*Lightingschedule('incand',season,daytype,hour,allregions);
Internalheatgain(hour,season,daytype,'lightingCFL','sensible',allregions)=bulbpowerrating('CFL')*Ligh»
tingschedule('CFL',season,daytype,hour,allregions);
Internalheatgain(hour,season,daytype,'lightingLFL','sensible',allregions)=bulbpowerrating('LFL')*Ligh»
tingschedule('LFL',season,daytype,hour,allregions);
Internalheatgain(hour,season,daytype,'lightingLED','sensible',allregions)=bulbpowerrating('LED')*Ligh»
tingschedule('LED',season,daytype,hour,allregions);
Internalheatgain(hour,season,daytype,'lightingHal','sensible',allregions)=bulbpowerrating('Hal')*Ligh»
tingschedule('Hal',season,daytype,hour,allregions);

*Fraction values from Table 8-20 (p. 263) and page. 224.
Parameter Fracconv(IHGcomp) fraction of internal heat gains (above) that is convective;
Fracconv(equipment)=0.8;
Fracconv('people')=0.3;
Fracconv('lightingincand')=0.2;
Fracconv('lightingcfl')=0.33;
Fracconv('lightinglfl')=0.33;
Fracconv('lightinghal')=0.2;

Parameter Fracrad(IHGcomp) fraction of internal heat gains (above) that is radiative;
Fracrad(equipment)=0.2;
Fracrad('people')=0.7;
Fracrad('lightingincand')=0.8;
Fracrad('lightingcfl')=0.67;
Fracrad('lightinglfl')=0.67;
Fracrad('lightinghal')=0.8;
;



*****************************************************************************
*************************************Windows*********************************
*****************************************************************************
$ontext
We here define the properties of solar heat gain and conduction through fenestrations.
The current system represented is a 1/4-in. uncoated double glazing system (ID 5b).
We can change properties by selecting other systems from table 7-3 on page 200
(McQuiston et al. (2005)).
$offtext
Scalar diffusesolartransmit from table 7-3 pg 200 /0.75/
*Above transmittance value is for single-glazed windows^^
       solarabsorbfloor solar absorptivity of the floor /0.8/
       Uglazing overall heat transfer coefficient for windows in kW per sq. m per K (Table 5-7 page 1»
46) /1e-3/
       convectivecomponentwindows convective component of heat transfer through windows (page 268) /0»
.37/

Parameter Indoorshadingtransmit(allregions) if no internal shading value is unity;
Indoorshadingtransmit(allregions)=0.5;
Indoorshadingtransmit('West')=0.6;
Indoorshadingtransmit('Sout')=0.4;

Parameter totglazingarea(surface,allregions) total glazing area for each surface in sq. m;
totglazingarea(surface,allregions)=0.15*surfarea(surface,allregions);

*To redefine solid wall material used for conduction calculations by netting out
*windows:
Surfarea(surface,allregions)=Surfarea(surface,allregions)-totglazingarea(surface,allregions);

```

```
1055
1056 Parameter diffuseSHG(hour,surface,season,allregions) transmitted diffuse solar radiation in kW per sq»
      meter;
1057 diffuseSHG(hour,surface,season,allregions)=
1058 Indoorshadingtransmit(allregions)*diffusesolartransmit*diffuseirradiance(hour,surface,season,allregio»
     ns)*totglazingarea(surface,allregions);
1059
1060 *The following is a curve-fit of data on page 200, table 7-3. Estimated using Eviews.
1061 *Assuming single-glazed window:
1062 Parameter directsolartransmit(hour,surface,season,allregions) transmittance of direct solar irradianc»
     e;
1063 directsolartransmit(hour,surface,season,allregions)=-2.12e-4*sqr(angleofincidence(hour,surface,season»
     ,allregions))
1064 +1.1155e-2*angleofincidence(hour,surface,season,allregions)+0.805248;
1065
1066 directsolartransmit(hour,surface,season,allregions)$((angleofincidence(hour,surface,season,allregions»
     )>90 or angleofincidence(hour,surface,season,allregions)<0))=0;
1067
1068
1069 Parameter sunlitarea(surface,allregions) sunlit portion of the fenestration in sq. meters;
1070 sunlitarea(surface,allregions)=totglazingarea(surface,allregions)*0.7;
1071
1072
1073 Parameter directSHG(hour,surface,season,allregions) transmitted direct solar radiation in kW per sq. »
     meter;
1074 directSHG(hour,surface,season,allregions)=
1075 Indoorshadingtransmit(allregions)*directsolartransmit(hour,surface,season,allregions)*directirradianc»
     e(hour,surface,season,allregions)*sunlitarea(surface,allregions);
1076
1077 ********************************************************************************
1078 Parameter COP(season,daytype,hour,allregions) coefficient of performance of HVAC unit;
1079 *Have to set a dummy for now (this is redefined later):
1080 COP(season,daytype,hour,allregions)=1;
1081
1082 *Going through the return fan does not change the humidity ratio:
1083 Parameter humidityratio3(hour,season,allregions) humidity ratio at state 3;
1084 humidityratio3(hour,season,allregions)=humidityratioin(hour,season,allregions);
1085
1086 *Parameters used in conjunction with iterating over many supply air properties:
1087 Parameter Monthlyelectricityconsumed(RHsup,Tsup,intake,season,allregions) in kWh per month;
1088 Parameter Monthlyelectricitycost(RHsup,Tsup,intake,season,allregions) in SAR per month;
1089 Parameter TemperatureinHVACrun(Tsup,season,daytype,hour,allregions) to take into account iteration;
1090 Parameter humidityratioinHVACrun(RHsup,season,daytype,hour,allregions) to take into account iteration»
     ;
1091 Parameter MassintakeAHUrun(intake,season,daytype,hour,allregions) to take into account iteration;
1092 Parameter savemassintakeAHU(season,daytype,hour,allregions) initial iteration point for outside air q»
     uantity;
1093 Parameter savehumidityratioinHVAC(season,daytype,hour,allregions) initial iteration point for supply »
     air humidityratio;
1094 Parameter saveTemperatureinHVAC(season,daytype,hour,allregions) initial iteration point for supply ai»
     r temperature;
1095 Parameter TotalPowerExcel(season,daytype,hour,allregions,consbrack) to format the total power correct»
     ly for Excel use;
1096
1097 Parameter upconsumptionlevel(consbrack) upper consumption levels in each bracket in kWh;
1098 upConsumptionlevel('b1')=2000;
1099 upConsumptionlevel('b2')=4000;
1100 upConsumptionlevel('b3')=6000;
1101 upConsumptionlevel('b4')=7000;
1102 upConsumptionlevel('b5')=8000;
1103 upConsumptionlevel('b6')=9000;
1104 upConsumptionlevel('b7')=10000;
1105 upConsumptionlevel('b8')=+inf;
1106
1107 Parameter electariff(consbrack) electricity price in SAR per kWh corresponding to each bracket;
1108 electariff('b1')=5;
1109 electariff('b2')=10;
1110 electariff('b3')=12;
1111 electariff('b4')=15;
1112 electariff('b5')=20;
1113 electariff('b6')=22;
1114 electariff('b7')=24;
1115 electariff('b8')=26;
1116 electariff(consbrack)=electariff(consbrack)/100;
1117
```

```
Scalar elecfixedtariff fixed charge for meter reading in SAR /15/;
*****************************************************************************
Variables
ctot objective value (total cost)

Heatfluxint(x,season,daytype,hour,surface,allregions) heat flux at internal surface in kW per sq. met»
er
Heatfluxext(x,season,daytype,hour,surface,allregions) heat flux at exterior surface in kW per sq. met»
er
masswaterAHU(season,daytype,hour,allregions) mass flow rate of added or removed water from air in kg »
per sec
Qcooling(season,daytype,hour,allregions) cooling load in kW
Qcoil(season,daytype,hour,allregions) heat transefer rate from or to coil in kW

;
Positive Variables
Temperature(x,season,daytype,hour,m,surface,allregions) temperature in Kelvin in spatial dimension an»
d time of day
L(m,surface) thickness of materials within walls or roof in meters
dx(m,surface) spatial step for FDM scheme in meters
massinHVAC(season,daytype,hour,allregions) mass flow rate into zone in kg per sec
massoutHVAC(season,daytype,hour,allregions) mass flow rate of return air in kg per second
enthalpyinHVAC(season,daytype,hour,allregions) enthalpy of supply air in kJ per kga
massexhaustAHU(season,daytype,hour,allregions) mass flow rate of air going to atmosphere in kg per se»
c
massintakeAHU(season,daytype,hour,allregions) mass flow rate coming into AHU from atmosphere in kg pe»
r sec
massrecircAHU(season,daytype,hour,allregions) mass flow rate of recirculated air in kg per sec
TotalHVACpower(season,daytype,hour,allregions) total power consumption of HVAC system in kW
humidityratio6(season,daytype,hour,allregions) humidity ratio before coil in kg of vapor per kg of ai»
r
humidityratioinHVAC(season,daytype,hour,allregions) humidity ratio after coil in kg of vapor per kg o»
f air
temperatureinHVAC(season,daytype,hour,allregions) supply air temperature in degrees C
enthalpy7(season,daytype,hour,allregions) enthalpy of air after passing through coil in kJ per kga
enthalpy3(season,daytype,hour,allregions) enthalpy of air after passing through return fan in kJ per »
kga
enthalpy6(season,daytype,hour,allregions) enthalpy of air before passing through return fan kJ per kg»
a
Lightingpower(season,daytype,hour,allregions) power consumption by lighting in kW
Equipmentpower(season,daytype,hour,allregions) power consumption by equipment in kW
Totalpower(season,daytype,hour,allregions) total power consumption in kW

Qcoilminus(season,daytype,hour,allregions)
Qcoilplus(season,daytype,hour,allregions)


Negative Variables
Wfansup(season,daytype,hour,allregions) power required from supply fan in kW
Wfanret(season,daytype,hour,allregions) power required from return fan in kW
;

;
Equation
objective objective function to solve NLP

spacestepbal(m,surface) used to define spatial step for FDM discretization for each each layer
Temperatureprofile(x,season,daytype,hour,m,surface,allregions) used to generate temperature profiles »
inside walls
boundarycondition1(x,season,daytype,hour,m,surface,allregions) used to define flux BCs at external su»
rfaces
boundarycondition2(x,season,daytype,hour,m,surface,allregions) used to define flux BCs at internal su»
rfaces
intermediateBC1(season,daytype,hour,m,surface,allregions) used to define temperature BCs at interface»
s
intermediateBC2(season,daytype,hour,m,surface,allregions) used to define derivative BCs at interfaces
Energyextbal(x,season,daytype,hour,m,surface,allregions) used to compute the heat flux at exterior su»
rface
Energyintbal(x,season,daytype,hour,m,surface,allregions) used to compute the heat flux at interior su»
rface
Zoneenergybal1(season,daytype,hour,allregions) energy balance for the zone air used to compute coolin»
g load
Zoneenergybal2(season,daytype,hour,allregions) energy balance for the zone air used to compute coolin»
g load
Zonemassbal(season,daytype,hour,allregions) mass balance for zone air
```

```
AHUmassbal2(season,daytype,hour,allregions) mass balance for return portion of AHU
AHUmassbal3(season,daytype,hour,allregions) mass balance for supply portion of AHU
Supplytempcalc(season,daytype,hour,allregions) used to calculate supply air temperature
*AHUenergybalcoil(season,daytype,hour,allregions) air energy balance using cooling coil as control vo»
lume
*AHUenergybalfansup(season,daytype,hour,allregions) air energy balance using supply fan as control vo»
lume
AHUenergybalmixing(season,daytype,hour,allregions) air energy balance using mixing box as control vol»
ume
AHUvapormassbalmixing(season,daytype,hour,allregions) vapor mass balance using mixing box as control »
volume
AHUvapormassbalcoilfansup(season,daytype,hour,allregions) vapor mass balance using cooling coil and s»
upply fan as control volume
AHUenergybalcoilfansup(season,daytype,hour,allregions) air energy balance using cooling coil and supp»
ly fan as control volume
*AHUrecircreq(season,daytype,hour,allregions) temporary replacement to AHUenergybalmixing
AHUenergybalfanret(season,daytype,hour,allregions) air energy balance using return fan as control vol»
ume
SFPfanretreq(season,daytype,hour,allregions)
SFPfansupreq(season,daytype,hour,allregions)
HVACpowerbal(season,daytype,hour,allregions) to calculate total power consumption for HVAC use
Lightingpowercons(season,daytype,hour,allregions) to calculate lighting power consumption
Equipmentpowercons(season,daytype,hour,allregions) to calculate equipment power consumption
Totpowercons(season,daytype,hour,allregions) to aggregate total power consumption in the household
Qcoildecomp(season,daytype,hour,allregions) used in the linearization of abs(qcoil)
Qcoilprod(season,daytype,hour,allregions) used in the liearization of abs(qcoil)
;

*Specifying material thicknesses in meters:
L.fx(cemplaster,surface)=0.020;
L.fx('concrete1',surface)=0.130;
L.fx('PolySt',surface)=0.025;
L.fx('concrete2',surface)=0.130;
$ontext
L.fx('cemplaster1','roof')=0.010;
L.fx('concrete1','roof')=0.025;
L.fx('airspace','roof')=0.025;
L.fx('concrete2','roof')=0.100;
L.fx('cemplaster2','roof')=0.020;
$offtext
dx.l(m,surface)=0.1;


enthalpy3.lo(season,daytype,hour,allregions)=(     (Cpair*(Tindoor(hour,season,allregions)-273.15)
+humidityratioin(hour,season,allregions)*(Cpvapor*(Tindoor(hour,season,allregions)-273.15)+enthalpysa»
tv0C)) );
*enthalpy3.up(season,daytype,hour,r_use)=enthalpy3.lo(season,daytype,hour,r_use)+5;

*enthalpy7.lo(season,daytype,hour,r_use)=enthalpyinHVAC.lo(season,daytype,hour,r_use)-0;
*enthalpy7.up(season,daytype,hour,r_use)=enthalpyinHVAC.up(season,daytype,hour,r_use);

*enthalpy6.lo(season,daytype,hour,r_use)=2;
*enthalpy6.up(season,daytype,hour,r_use)=enthalpy7.up(season,daytype,hour,r_use)+5;

$ontext
massinHVAC.up(season,daytype,hour,r_use)=1.8;
massinHVAC.lo(season,daytype,hour,r_use)=0;
massoutHVAC.up(season,daytype,hour,r_use)=massinHVAC.up(season,daytype,hour,r_use)+infilvolflowrate;
massoutHVAC.lo(season,daytype,hour,r_use)=0;
massrecircAHU.up(season,daytype,hour,r_use)=massoutHVAC.up(season,daytype,hour,r_use);
massrecircAHU.lo(season,daytype,hour,r_use)=0;
$offtext

massintakeAHU.fx(season,daytype,hour,allregions)=0;

$offorder
;
*****************************************************************************
objective.. ctot=e=0;
*sum((seasonuse,daytype,hour,r_use),Totalpower(seasonuse,daytype,hour,r_use));
*****************************************************************************
$ontext
This section deals with the solution of the transient heat equation through a wall/roof
and the associated energy balances that complete the problem formulation. An implicit
backward in time and centered in space finite difference scheme is used to avoid
```

```
instability when misspecifying the time step.
$offtext
spacestepbal(m,surface).. dx(m,surface)-L(m,surface)/(card(x)-1)=e=0;

Temperatureprofile(x,seasonuse,daytype,hour,m,surface,r_use)$(ord(x)>1 and ord(x)<card(x))..
( Temperature(x,seasonuse,daytype,hour,m,surface,r_use)*sqr(dx(m,surface))
  +(thermdiff(m,surface)*dt*3600)*Temperature(x+1,seasonuse,daytype,hour+1,m,surface,r_use)
  -(sqr(dx(m,surface))+2*(thermdiff(m,surface)*dt*3600))*Temperature(x,seasonuse,daytype,hour+1,m,surface,r_use)
  +(thermdiff(m,surface)*dt*3600)*Temperature(x-1,seasonuse,daytype,hour+1,m,surface,r_use) )$(ord(hour)<card(hour))
+
( Temperature(x,seasonuse,daytype,hour,m,surface,r_use)
  -Temperature(x,seasonuse,daytype,'hr0',m,surface,r_use) )$(ord(hour)=card(hour))
=e=0;


*Boundary condition on external surfaces:
boundarycondition1(x,seasonuse,daytype,hour,m,surface,r_use)$(ord(x)=1 and ord(m)=1)..
Temperature(x+1,seasonuse,daytype,hour,m,surface,r_use)
 -(1+(dx(m,surface))*htranscoeffout(hour,seasonuse,surface,r_use)/thermcond(m,surface))*Temperature(x,seasonuse,daytype,hour,m,surface,r_use)
 +dx(m,surface)*htranscoeffout(hour,seasonuse,surface,r_use)/thermcond(m,surface)*Tout(hour,seasonuse,r_use)
*Solar radiation terms:
 +solabsorb(m,surface)*dx(m,surface)/thermcond(m,surface)*totalirrad(hour,seasonuse,surface,r_use)
*Surface radiation terms:
 +emissivity(m,surface)*sboltzconst*dx(m,surface)/thermcond(m,surface)*(Fsg(surface)*(Tground(hour,seasonuse,r_use)**4-Temperature(x,seasonuse,daytype,hour,m,surface,r_use)**4)
                              +Fssky(surface)*(  (Tout(hour,seasonuse,r_use)-6*cos(tiltangle(surface)*pi/180/2))**4
                                                  -Temperature(x,seasonuse,daytype,hour,m,surface,r_use)**4))=e=0;


*Boundary condition on interior surfaces (to account for the difference between external
*and internal surface area differences, we subtract out the effect of thicknesses):
*Also, latent heat is estimated to become an instanteous component of the cooling load
boundarycondition2(x,seasonuse,daytype,hour,m,surface,r_use)$(ord(x)=card(x) and ord(m)=card(m))..
(1+(dx(m,surface))*htranscoeffin(surface)/thermcond(m,surface))*Temperature(x,seasonuse,daytype,hour,m,surface,r_use)
 -(dx(m,surface))*htranscoeffin(surface)/thermcond(m,surface)*Tindoor(hour,seasonuse,r_use)
*Radiative component of internal heat gains:
 +dx(m,surface)/thermcond(m,surface)*(
   sum((IHGcomp),Internalheatgain(hour,seasonuse,daytype,IHGcomp,'sensible',r_use)*Fracrad(IHGcomp))
        /sum(surface2,surfarea(surface2,r_use)
                      -(dimension('w',r_use)*sum(m2,L(m2,'roof'))+dimension('h',r_use)*sum(m2,L(m2,'southern'))+dimension('h',r_use)*sum(m2,L(m2,'northern'))-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'northern'))-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'southern')))$(ord(surface2)<=2)
                      -(dimension('h',r_use)*sum(m2,L(m2,'eastern'))+dimension('h',r_use)*sum(m2,L(m2,'western'))+dimension('l',r_use)*sum(m2,L(m2,'roof'))-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'western'))-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'eastern')))$(ord(surface2)=3 or ord(surface2)=4)
                      -(dimension('l',r_use)*sum(m2,L(m2,'northern'))+dimension('l',r_use)*sum(m2,L(m2,'southern'))+dimension('w',r_use)*sum(m2,L(m2,'western'))+dimension('w',r_use)*sum(m2,L(m2,'eastern'))-sum(m2,L(m2,'northern'))*sum(m2,L(m2,'western'))-sum(m2,L(m2,'northern'))*sum(m2,L(m2,'eastern'))-sum(m2,L(m2,'southern'))*sum(m2,L(m2,'western'))-sum(m2,L(m2,'southern'))*sum(m2,L(m2,'eastern')))$(ord(surface2)=card(surface2))  )
                                    )
*Solar thermal radiation transmitted through windows:
 +dx(m,surface)/thermcond(m,surface)*(   (diffuseSHG(hour,surface,seasonuse,r_use)
                                   +(1-solarabsorbfloor)*directSHG(hour,surface,seasonuse,r_use))/sum(surface2,surfarea(surface2,r_use)
                      -(dimension('w',r_use)*sum(m2,L(m2,'roof'))+dimension('h',r_use)*sum(m2,L(m2,'southern'))+dimension('h',r_use)*sum(m2,L(m2,'northern'))-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'northern'))-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'southern')))$(ord(surface2)<=2)
                      -(dimension('h',r_use)*sum(m2,L(m2,'eastern'))+dimension('h',r_use)*sum(m2,L(m2,'western'))+dimension('l',r_use)*sum(m2,L(m2,'roof'))-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'western'))-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'eastern')))$(ord(surface2)=3 or ord(surface2)=4)
                      -(dimension('l',r_use)*sum(m2,L(m2,'northern'))+dimension('l',r_use)*sum(m2,L(m2,'southern'))+dimension('w',r_use)*sum(m2,L(m2,'western'))+dimension('w',r_use)*sum(m2,L(m2,'eastern'))-sum(m2,L(m2,'northern'))*sum(m2,L(m2,'western'))-sum(m2,L(m2,'northern'))*sum(m2,L(m2,'eastern'))-sum(m2,L(m2,'southern'))*sum(m2,L(m2,'western'))-sum(m2,L(m2,'southern'))*sum(m2,L(m2,'eastern')))$(ord(surface2)=card(surface2)) )
                                    )
 -Temperature(x-1,seasonuse,daytype,hour,m,surface,r_use)=e=0;
```

```
1292
1293
1294 *currently assuming perfect interfaces (look into capture resistances?)
1295 intermediateBC1(seasonuse,daytype,hour,m,surface,r_use)$(ord(m)<card(m))..
1296 sum(x$(ord(x)=card(x)),Temperature(x,seasonuse,daytype,hour,m,surface,r_use))
1297  -sum(x$(ord(x)=1),Temperature(x,seasonuse,daytype,hour,m+1,surface,r_use))=e=0;
1298
1299
1300
1301 intermediateBC2(seasonuse,daytype,hour,m,surface,r_use)$(ord(m)<card(m))..
1302 thermcond(m,surface)/dx(m,surface)*(  sum(x$(ord(x)=card(x)),Temperature(x,seasonuse,daytype,hour,m,s»
     urface,r_use))
1303                                -sum(x$(ord(x)=card(x)-1),Temperature(x,seasonuse,daytype,hour,m,surface»
     ,r_use))  )
1304  -thermcond(m+1,surface)/dx(m+1,surface)*(  sum(x$(ord(x)=2),Temperature(x,seasonuse,daytype,hour,m+1»
     ,surface,r_use))
1305                                     -sum(x$(ord(x)=1),Temperature(x,seasonuse,daytype,hour,m+1,surface»
     ,r_use))  )=e=0;
1306
1307 *************************
1308 *To calculate the conduction heat flux on external and interior surfaces:
1309 Energyextbal(x,seasonuse,daytype,hour,m,surface,r_use)$(ord(x)=1 and ord(m)=1)..
1310 Heatfluxext(x,seasonuse,daytype,hour,surface,r_use)
1311  -htranscoeffout(hour,seasonuse,surface,r_use)*(Tout(hour,seasonuse,r_use)-Temperature(x,seasonuse,da»
     ytype,hour,m,surface,r_use))
1312  -solabsorb(m,surface)*totalirrad(hour,seasonuse,surface,r_use)
1313  -emissivity(m,surface)*sboltzconst*(Fsg(surface)*(Tground(hour,seasonuse,r_use)**4-Temperature(x,sea»
     sonuse,daytype,hour,m,surface,r_use)**4)
1314                                +Fssky(surface)*(  (Tout(hour,seasonuse,r_use)-6*cos(tiltangle(surface)*»
     pi/180/2))**4
1315                                          -Temperature(x,seasonuse,daytype,hour,m,surface,r_use)**4))=e»
     =0;
1316
1317
1318
1319 Energyintbal(x,seasonuse,daytype,hour,m,surface,r_use)$(ord(x)=card(x) and ord(m)=card(m))..
1320 Heatfluxint(x,seasonuse,daytype,hour,surface,r_use)
1321  -htranscoeffin(surface)*(Temperature(x,seasonuse,daytype,hour,m,surface,r_use)-Tindoor(hour,seasonus»
     e,r_use))
1322  -sum((IHGcomp),Internalheatgain(hour,seasonuse,daytype,IHGcomp,'sensible',r_use)*Fracrad(IHGcomp))
1323         /sum(surface2,surfarea(surface2,r_use)
1324                        -(dimension('w',r_use)*sum(m2,L(m2,'roof'))+dimension('h',r_use)*sum(m2,L(m2,'s»
     outhern'))+dimension('h',r_use)*sum(m2,L(m2,'northern'))-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'northern')»
     )-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'southern')))$(ord(surface2)<=2)
1325                        -(dimension('h',r_use)*sum(m2,L(m2,'eastern'))+dimension('h',r_use)*sum(m2,L(m2»
     ,'western'))+dimension('l',r_use)*sum(m2,L(m2,'roof'))-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'western'))-s»
     um(m2,L(m2,'roof'))*sum(m2,L(m2,'eastern')))$(ord(surface2)=3 or ord(surface2)=4)
1326                        -(dimension('l',r_use)*sum(m2,L(m2,'northern'))+dimension('l',r_use)*sum(m2,L(m»
     2,'southern'))+dimension('w',r_use)*sum(m2,L(m2,'western'))+dimension('w',r_use)*sum(m2,L(m2,'eastern»
     '))-sum(m2,L(m2,'northern'))*sum(m2,L(m2,'western'))-sum(m2,L(m2,'northern'))*sum(m2,L(m2,'eastern'))»
     -sum(m2,L(m2,'southern'))*sum(m2,L(m2,'western'))-sum(m2,L(m2,'southern'))*sum(m2,L(m2,'eastern')))$(»
     ord(surface2)=card(surface2)))
1327  -(diffuseSHG(hour,surface,seasonuse,r_use)+(1-solarabsorbfloor)*directSHG(hour,surface,seasonuse,r_u»
     se))
1328         /sum(surface2,surfarea(surface2,r_use)
1329                        -(dimension('w',r_use)*sum(m2,L(m2,'roof'))+dimension('h',r_use)*sum(m2,L(m2,'s»
     outhern'))+dimension('h',r_use)*sum(m2,L(m2,'northern'))-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'northern')»
     )-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'southern')))$(ord(surface2)<=2)
1330                        -(dimension('h',r_use)*sum(m2,L(m2,'eastern'))+dimension('h',r_use)*sum(m2,L(m2»
     ,'western'))+dimension('l',r_use)*sum(m2,L(m2,'roof'))-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'western'))-s»
     um(m2,L(m2,'roof'))*sum(m2,L(m2,'eastern')))$(ord(surface2)=3 or ord(surface2)=4)
1331                        -(dimension('l',r_use)*sum(m2,L(m2,'northern'))+dimension('l',r_use)*sum(m2,L(m»
     2,'southern'))+dimension('w',r_use)*sum(m2,L(m2,'western'))+dimension('w',r_use)*sum(m2,L(m2,'eastern»
     '))-sum(m2,L(m2,'northern'))*sum(m2,L(m2,'western'))-sum(m2,L(m2,'northern'))*sum(m2,L(m2,'eastern'))»
     -sum(m2,L(m2,'southern'))*sum(m2,L(m2,'western'))-sum(m2,L(m2,'southern'))*sum(m2,L(m2,'eastern')))$(»
     ord(surface2)=card(surface2)))=e=0;
1332
1333 *************************
1334 $ontext
1335 Energy balance for the zone air (calculation the cooling load):
1336 Qcooling<0 means heat transfer out of system (cooling)
1337 Qcooling>0 means heat transfer into system (heating)
1338 $offtext
1339
1340 *Applying first law using zone as the control volume:
```

```
Zoneenergybal1(seasonuse,daytype,hour,r_use)..
 Qcooling(seasonuse,daytype,hour,r_use)
*Infiltration component (sensible and latent, respectively, all convective)
 +infilvolflowrate(r_use)*densityairout(seasonuse,hour,r_use)*Cpair*(Tout(hour,seasonuse,r_use)-Tindoor(hour,seasonuse,r_use))
 +infilvolflowrate(r_use)*densityairout(seasonuse,hour,r_use)*(humidityratioout(hour,seasonuse,r_use)-humidityratioin(hour,seasonuse,r_use))*enthalpyfgindoor(hour,seasonuse,r_use)
*Convective internal sensible and latent heat gain components
 +sum((IHGcomp),Internalheatgain(hour,seasonuse,daytype,IHGcomp,'sensible',r_use)*Fracconv(IHGcomp))
 +sum((IHGcomp),Internalheatgain(hour,seasonuse,daytype,IHGcomp,'latent',r_use))
*Heat transferred from walls and roof (convection)
*(to account for the difference between external
*and internal surface area differences, we subtract out the effect of thicknesses)
 +sum((surface,m,x)$(ord(m)=card(m) and ord(x)=card(x)),
    (surfarea(surface,r_use)-(dimension('w',r_use)*sum(m2,L(m2,'roof'))+dimension('h',r_use)*sum(m2,L(m2,'southern'))+dimension('h',r_use)*sum(m2,L(m2,'northern'))-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'northern'))-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'southern')))$(ord(surface)<=2)
                              -(dimension('h',r_use)*sum(m2,L(m2,'eastern'))+dimension('h',r_use)*sum(m2,L(m2,'western'))+dimension('l',r_use)*sum(m2,L(m2,'roof'))-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'western'))-sum(m2,L(m2,'roof'))*sum(m2,L(m2,'eastern')))$(ord(surface)=3 or ord(surface)=4)
                              -(dimension('l',r_use)*sum(m2,L(m2,'northern'))+dimension('l',r_use)*sum(m2,L(m2,'southern'))+dimension('w',r_use)*sum(m2,L(m2,'western'))+dimension('w',r_use)*sum(m2,L(m2,'eastern'))-sum(m2,L(m2,'northern'))*sum(m2,L(m2,'western'))-sum(m2,L(m2,'northern'))*sum(m2,L(m2,'eastern'))-sum(m2,L(m2,'southern'))*sum(m2,L(m2,'western'))-sum(m2,L(m2,'southern'))*sum(m2,L(m2,'eastern')))$(ord(surface)=card(surface)))*htranscoeffin(surface)*(Temperature(x,seasonuse,daytype,hour,m,surface,r_use)-Tindoor(hour,seasonuse,r_use)))
*Heat transferred through windows (convective component); used Equations 7-33 8-66 of McQuiston et al. (2005)
 +sum(surface,Uglazing*(Tout(hour,seasonuse,r_use)-Tindoor(hour,seasonuse,r_use))*totglazingarea(surface,r_use)*convectivecomponentwindows)
=e=0;



Zoneenergybal2(seasonuse,daytype,hour,r_use)..
  Qcooling(seasonuse,daytype,hour,r_use)
 +massoutHVAC(seasonuse,daytype,hour,r_use)*(Cpair*(Tindoor(hour,seasonuse,r_use)-273.15)
                                +humidityratioin(hour,seasonuse,r_use)*(Cpvapor*(Tindoor(hour,seasonuse,r_use)-273.15)+enthalpysatv0C))
 -massinHVAC(seasonuse,daytype,hour,r_use)*enthalpyinHVAC(seasonuse,daytype,hour,r_use)=e=0;



**********Mass Balances*********
*Mass balance for the zone air, accounting for infiltration:
Zonemassbal(seasonuse,daytype,hour,r_use)..
* infilvolflowrate*densityairout(seasonuse,hour,r_use)
 +massinHVAC(seasonuse,daytype,hour,r_use)
 -massoutHVAC(seasonuse,daytype,hour,r_use)=e=0;


*To calculate supply air temperature:
Supplytempcalc(seasonuse,daytype,hour,r_use)..
  temperatureinHVAC(seasonuse,daytype,hour,r_use)*(cpair+cpvapor*humidityratioinHVAC(seasonuse,daytype,hour,r_use))
 -enthalpyinHVAC(seasonuse,daytype,hour,r_use)
 +humidityratioinHVAC(seasonuse,daytype,hour,r_use)*enthalpysatv0C=e=0;


*Air mass balance for return portion of AHU:
AHUmassbal2(seasonuse,daytype,hour,r_use).. massoutHVAC(seasonuse,daytype,hour,r_use)
 -massexhaustAHU(seasonuse,daytype,hour,r_use)
 -massrecircAHU(seasonuse,daytype,hour,r_use)=e=0;


*Air mass balance for supply portion of AHU:
AHUmassbal3(seasonuse,daytype,hour,r_use).. -massinHVAC(seasonuse,daytype,hour,r_use)
 +massintakeAHU(seasonuse,daytype,hour,r_use)
 +massrecircAHU(seasonuse,daytype,hour,r_use)=e=0;


*Vapor mass balacne for mixing box:
AHUvapormassbalmixing(seasonuse,daytype,hour,r_use)..
  massintakeAHU(seasonuse,daytype,hour,r_use)*humidityratioout(hour,seasonuse,r_use)
 +massrecircAHU(seasonuse,daytype,hour,r_use)*humidityratio3(hour,seasonuse,r_use)
```

```
 -massinHVAC(seasonuse,daytype,hour,r_use)*humidityratio6(seasonuse,daytype,hour,r_use)=e=0;

*Vapor mass balacne for coil/supply fan control volume. Positive if added, negative if removed.
AHUvapormassbalcoilfansup(seasonuse,daytype,hour,r_use)..
  masswaterAHU(seasonuse,daytype,hour,r_use)
 +massinHVAC(seasonuse,daytype,hour,r_use)*humidityratio6(seasonuse,daytype,hour,r_use)
 -massinHVAC(seasonuse,daytype,hour,r_use)*humidityratioinHVAC(seasonuse,daytype,hour,r_use)=e=0;


*Using a control volume that encompasses both the coil and the supply fan:
AHUenergybalcoilfansup(seasonuse,daytype,hour,r_use)..
  Qcoil(seasonuse,daytype,hour,r_use)
 -Wfansup(seasonuse,daytype,hour,r_use)
 -massinHVAC(seasonuse,daytype,hour,r_use)*enthalpyinHVAC(seasonuse,daytype,hour,r_use)
 +massinHVAC(seasonuse,daytype,hour,r_use)*enthalpy6(seasonuse,daytype,hour,r_use)=e=0;


*$ontext
*Using mixing box as control volume:
AHUenergybalmixing(seasonuse,daytype,hour,r_use).. massrecircAHU(seasonuse,daytype,hour,r_use)*enthal»
py3(seasonuse,daytype,hour,r_use)
 +massintakeAHU(seasonuse,daytype,hour,r_use)*(Cpair*(Tout(hour,seasonuse,r_use)-273.15)
                                +humidityratioout(hour,seasonuse,r_use)*(Cpvapor*(Tout(hour,seasonuse,»
r_use)-273.15)+enthalpysatv0C))
 -massinHVAC(seasonuse,daytype,hour,r_use)*enthalpy6(seasonuse,daytype,hour,r_use)=e=0;
*$offtext
*As zero mass intake from outside is presently enforced, the following equation
*is a simplification of the above AHUenergybalmixing constraint, which is commented out.
*AHUrecircreq(seasonuse,daytype,hour,r_use).. enthalpy3(seasonuse,daytype,hour,r_use)
* -enthalpy6(seasonuse,daytype,hour,r_use)=e=0;



*Using area around return fan as control volume:
AHUenergybalfanret(seasonuse,daytype,hour,r_use).. Wfanret(seasonuse,daytype,hour,r_use)
 -massoutHVAC(seasonuse,daytype,hour,r_use)*(Cpair*(Tindoor(hour,seasonuse,r_use)-273.15)
                                +humidityratioin(hour,seasonuse,r_use)*(Cpvapor*(Tindoor(hour,seasonus»
e,r_use)-273.15)+enthalpysatv0C))
 +massoutHVAC(seasonuse,daytype,hour,r_use)*enthalpy3(seasonuse,daytype,hour,r_use)=e=0;



*by convention, work down on the system (air in this case) is negative:
SFPfanretreq(seasonuse,daytype,hour,r_use).. -Wfanret(seasonuse,daytype,hour,r_use)
 -fanSFP('return',r_use)*massoutHVAC(seasonuse,daytype,hour,r_use)/densityairindoor(hour,seasonuse,r_»
use)=e=0;


*Assuming the air density here is equal to 1.23 kg/cubic meter.
SFPfansupreq(seasonuse,daytype,hour,r_use).. -Wfansup(seasonuse,daytype,hour,r_use)
 -fanSFP('supply',r_use)*massinHVAC(seasonuse,daytype,hour,r_use)/1.265=e=0;



*Summing up total electric power used to meet cooling load:
HVACpowerbal(seasonuse,daytype,hour,r_use).. TotalHVACpower(seasonuse,daytype,hour,r_use)
 -(Qcoilplus(seasonuse,daytype,hour,r_use)+Qcoilminus(seasonuse,daytype,hour,r_use))/COP(seasonuse,da»
ytype,hour,r_use)
 +(Wfansup(seasonuse,daytype,hour,r_use)+Wfanret(seasonuse,daytype,hour,r_use))/fanefficiency=e=0;


*To calculate direct power consumption by equipment (still need to develop);
Equipmentpowercons(seasonuse,daytype,hour,r_use).. Equipmentpower(seasonuse,daytype,hour,r_use)
 -sum(equipment,equipsaturation(equipment)*equipmentschedule(equipment,seasonuse,daytype,hour)*equipp»
owerrating(equipment,r_use))=e=0;


*To calculate direct power consumption by lights (still need to develop):
Lightingpowercons(seasonuse,daytype,hour,r_use).. Lightingpower(seasonuse,daytype,hour,r_use)
 -sum(bulbtech,bulbpowerrating(bulbtech)*lightingschedule(bulbtech,seasonuse,daytype,hour,r_use))
 -sum(bulbtech,bulbpowerrating(bulbtech)*lightingscheduleOutdoor(bulbtech,seasonuse,daytype,hour,r_us»
e))=e=0;


*Summing total power consumption seasonuseally:
```

```
Totpowercons(seasonuse,daytype,hour,r_use).. Totalpower(seasonuse,daytype,hour,r_use)
 -TotalHVACpower(seasonuse,daytype,hour,r_use)
 -Lightingpower(seasonuse,daytype,hour,r_use)
 -Equipmentpower(seasonuse,daytype,hour,r_use)=e=0;

$ontext
*Old constraints that used separate control volumes for supply fan and coil:

*Using area around coil as the control volume:
AHUenergybalcoil(seasonuse,daytype,hour,r_use).. Qcoil(seasonuse,daytype,hour,r_use)
 -massinHVAC(seasonuse,daytype,hour,r_use)*enthalpy7(seasonuse,daytype,hour,r_use)
 +massinHVAC(seasonuse,daytype,hour,r_use)*enthalpy6(seasonuse,daytype,hour,r_use)=e=0;


*Using area around supply fan as control volume:
AHUenergybalfansup(seasonuse,daytype,hour,r_use).. Wfansup(seasonuse,daytype,hour,r_use)
 -massinHVAC(seasonuse,daytype,hour,r_use)*enthalpy7(seasonuse,daytype,hour,r_use)
 +massinHVAC(seasonuse,daytype,hour,r_use)*enthalpyinHVAC(seasonuse,daytype,hour,r_use)=e=0;
$offtext

*The following two equation are used to represent the absolute value function
*as a differentiable formulation:
Qcoildecomp(seasonuse,daytype,hour,r_use).. Qcoil(seasonuse,daytype,hour,r_use)
 +Qcoilminus(seasonuse,daytype,hour,r_use)
 -Qcoilplus(seasonuse,daytype,hour,r_use)=e=0;

Qcoilprod(seasonuse,daytype,hour,r_use)..
  Qcoilminus(seasonuse,daytype,hour,r_use)*Qcoilplus(seasonuse,daytype,hour,r_use)=e=0;
;
*****************************************************************************
Model Residential /objective,spacestepbal,temperatureprofile,boundarycondition1,
boundarycondition2,intermediateBC1,intermediateBC2,Energyextbal,Energyintbal,
Zoneenergybal1,zoneenergybal2,zonemassbal,AHUmassbal2,AHUmassbal3,Supplytempcalc,
AHUenergybalmixing,AHUvapormassbalmixing,AHUvapormassbalcoilfansup,AHUenergybalcoilfansup,
AHUenergybalfanret,SFPfanretreq,SFPfansupreq,HVACpowerbal,Lightingpowercons,
Equipmentpowercons,Totpowercons,Qcoildecomp,Qcoilprod/;

Model Qsystemcheck /objective,spacestepbal,temperatureprofile,boundarycondition1,
boundarycondition2,intermediateBC1,intermediateBC2,Energyextbal,Energyintbal,
Zoneenergybal1/;
*Residential.optfile=1;

*8 GB of memory:
Residential.workspace=8192;
Qsystemcheck.workspace=8192;
*Use all available CPU cores:
Residential.threads=0;
Qsystemcheck.threads=0;
*Scaling to improve performance:
Residential.scaleopt=1;
Qsystemcheck.scaleopt=1;
*Solvelink set to 5 to use RAM exclusively:
*Residential.solvelink=5;
*Qsystemcheck.solvelink=5;

$ontext
AHUenergybalcoil.scale(seasonuse,daytype,hour,r_use)=1e-1;
Qcoil.scale(seasonuse,daytype,hour,r_use)=1e1;
HVACpowerbal.scale(seasonuse,daytype,hour,r_use)=1e-2;
$offtext

r_use(allregions)=no;
r_use('Cent')$((runCent=1 and runAllregions<>1) or runAllregions=1)=yes;
r_use('West')$(runWest=1 and runAllregions<>1)=yes;
r_use('Sout')$(runSout=1 and runAllregions<>1)=yes;
r_use('East')$(runEast=1 and runAllregions<>1)=yes;

Loop(Allregions$((r_use(allregions) and runallregions<>1) or runallregions=1),

seasonuse(season)=no;
seasonuse('Summ')$((runSummer=1 and runAllseasons<>1) or runAllseasons=1)=yes;
seasonuse('Wint')$(runWinter=1 and runAllseasons<>1)=yes;
seasonuse('Spfa')$(runSprfall=1 and runAllseasons<>1)=yes;

Loop(season$((seasonuse(season) and runallseasons<>1) or runallseasons=1),
```

```
1544
1545 *Different scaling requirements by seasons:
1546 If(ord(season)=1,
1547 Temperature.scale(x,season,daytype,hour,m,surface,allregions)=1e2;
1548 Temperatureprofile.scale(x,season,daytype,hour,m,surface,allregions)=1e-2;
1549 intermediateBC2.scale(season,daytype,hour,m,surface,allregions)=1e-2;
1550 AHUenergybalfanret.scale(season,daytype,hour,allregions)=1e1;
1551 AHUenergybalcoilfansup.scale(season,daytype,hour,allregions)=1e2;
1552 AHUenergybalmixing.scale(season,daytype,hour,allregions)=1e3;
1553 AHUvapormassbalmixing.scale(season,daytype,hour,allregions)=1e1;
1554 AHUvapormassbalmixing.scale(season,daytype,hour,'Sout')=1e1;
1555 );
1556
1557 If(ord(season)=2,
1558 Temperature.scale(x,seasonuse,daytype,hour,m,surface,allregions)=1e2;
1559 Temperatureprofile.scale(x,seasonuse,daytype,hour,m,surface,allregions)=1e-2;
1560 intermediateBC2.scale(seasonuse,daytype,hour,m,surface,allregions)=1e-2;
1561 AHUenergybalfanret.scale(seasonuse,daytype,hour,allregions)=1e1;
1562 AHUenergybalcoilfansup.scale(seasonuse,daytype,hour,allregions)=1e2;
1563 AHUenergybalmixing.scale(seasonuse,daytype,hour,allregions)=1e3;
1564 AHUvapormassbalmixing.scale(seasonuse,daytype,hour,allregions)=1e1;
1565 );
1566
1567 If(ord(season)=3,
1568 Temperature.scale(x,seasonuse,daytype,hour,m,surface,allregions)=1e2;
1569 Temperatureprofile.scale(x,seasonuse,daytype,hour,m,surface,allregions)=1e-2;
1570 intermediateBC2.scale(seasonuse,daytype,hour,m,surface,allregions)=1e-2;
1571 AHUenergybalfanret.scale(seasonuse,daytype,hour,allregions)=1e1;
1572 AHUenergybalcoilfansup.scale(seasonuse,daytype,hour,allregions)=1e2;
1573 AHUenergybalmixing.scale(seasonuse,daytype,hour,allregions)=1e3;
1574 AHUvapormassbalmixing.scale(seasonuse,daytype,hour,allregions)=1e1;
1575 );
1576
1577
1578 Solve Qsystemcheck using NLP minimizing ctot;
1579
1580 *Specifying supply air properties here (we can specify these exogenously or fix other variables and l»
     et them be determined):
1581
1582 humidityratioinHVAC.fx(seasonuse,daytype,hour,allregions)$(Qcooling.l(seasonuse,daytype,hour,allregio»
     ns)<0)=0.0050;
1583 humidityratioinHVAC.fx(seasonuse,daytype,hour,'West')$(Qcooling.l(seasonuse,daytype,hour,'West')<0)=0»
     .0050;
1584 humidityratioinHVAC.fx(seasonuse,daytype,hour,'Sout')$(Qcooling.l(seasonuse,daytype,hour,'Sout')<0)=0»
     .0075;
1585 humidityratioinHVAC.fx(seasonuse,daytype,hour,'Cent')$(Qcooling.l(seasonuse,daytype,hour,'Cent')<0)=0»
     .0060;
1586 humidityratioinHVAC.fx(seasonuse,daytype,hour,allregions)$(Qcooling.l(seasonuse,daytype,hour,allregio»
     ns)>0)=0.0105;
1587
1588 temperatureinHVAC.fx(seasonuse,daytype,hour,allregions)$(Qcooling.l(seasonuse,daytype,hour,allregions»
     )<0)=Tindoor(hour,seasonuse,allregions)-273.15-12;
1589 temperatureinHVAC.fx(seasonuse,daytype,hour,'Sout')$(Qcooling.l(seasonuse,daytype,hour,'Sout')<0)=Tin»
     door(hour,seasonuse,'Sout')-273.15-10;
1590 temperatureinHVAC.fx(seasonuse,daytype,hour,'Cent')$(Qcooling.l(seasonuse,daytype,hour,'Cent')<0)=Tin»
     door(hour,seasonuse,'Cent')-273.15-12;
1591 temperatureinHVAC.fx(seasonuse,daytype,hour,allregions)$(Qcooling.l(seasonuse,daytype,hour,allregions»
     )>0)=Tindoor(hour,seasonuse,allregions)-273.15+17;
1592
1593
1594 *COP is not the same for cooling and heating. Below, we define the cooling COP as a given
1595 *and the heating COP is related using the first law of thermodynamics:
1596 COP(seasonuse,daytype,hour,'Cent')$(Qcooling.l(seasonuse,daytype,hour,allregions)<0)=7/3.412;
1597 COP(seasonuse,daytype,hour,'West')$(Qcooling.l(seasonuse,daytype,hour,allregions)<0)=7.9/3.412;
1598 COP(seasonuse,daytype,hour,'Sout')$(Qcooling.l(seasonuse,daytype,hour,allregions)<0)=6/3.412;
1599 COP(seasonuse,daytype,hour,'East')$(Qcooling.l(seasonuse,daytype,hour,allregions)<0)=7.4/3.412;
1600 COP(seasonuse,daytype,hour,allregions)$(Qcooling.l(seasonuse,daytype,hour,allregions)>0)=COP(seasonus»
     e,daytype,hour,allregions)+1;
1601
1602
1603 saveTemperatureinHVAC(seasonuse,daytype,hour,allregions)=temperatureinHVAC.l(seasonuse,daytype,hour,a»
     llregions);
1604 savehumidityratioinHVAC(seasonuse,daytype,hour,allregions)=humidityratioinHVAC.l(seasonuse,daytype,ho»
     ur,allregions);
1605 savemassintakeAHU(seasonuse,daytype,hour,allregions)=massintakeAHU.l(seasonuse,daytype,hour,allregion»
```

```
s);
1606
1607
1608 Loop((intake,RHsup,Tsup),
1609 *To step forward the supply air properties and the quantity of mass intake:
1610 humidityratioinHVAC.fx(seasonuse,daytype,hour,allregions)$(Qcooling.l(seasonuse,daytype,hour,allregio»
     ns)<0)=savehumidityratioinHVAC(seasonuse,daytype,hour,allregions)+0.00000*(ord(RHsup)-1);
1611 humidityratioinHVAC.fx(seasonuse,daytype,hour,allregions)$(Qcooling.l(seasonuse,daytype,hour,allregio»
     ns)>0)=savehumidityratioinHVAC(seasonuse,daytype,hour,allregions)+0.00000*(ord(RHsup)-1);
1612
1613 temperatureinHVAC.fx(seasonuse,daytype,hour,allregions)$(Qcooling.l(seasonuse,daytype,hour,allregions»
     )<0)=saveTemperatureinHVAC(seasonuse,daytype,hour,allregions)+(ord(Tsup)-1)/2;
1614 temperatureinHVAC.fx(seasonuse,daytype,hour,allregions)$(Qcooling.l(seasonuse,daytype,hour,allregions»
     )>0)=saveTemperatureinHVAC(seasonuse,daytype,hour,allregions)-(ord(Tsup)-1)/2;
1615
1616 massintakeAHU.fx(seasonuse,daytype,hour,allregions)=savemassintakeAHU(seasonuse,daytype,hour,allregio»
     ns)+(ord(intake)-1)/20;
1617
1618
1619 humidityratioinHVACrun(RHsup,seasonuse,daytype,hour,allregions)=humidityratioinHVAC.l(seasonuse,dayty»
     pe,hour,allregions);
1620 TemperatureinHVACrun(Tsup,seasonuse,daytype,hour,allregions)=temperatureinHVAC.l(seasonuse,daytype,ho»
     ur,allregions);
1621 MassintakeAHUrun(intake,seasonuse,daytype,hour,allregions)=massintakeAHU.l(seasonuse,daytype,hour,all»
     regions);
1622
1623
1624 Solve Residential using NLP minimizing ctot;
1625
1626 *The total power consumption calculated takes off the power that would be
1627 *required for heating for houses that do not have electric space heaters(based
1628 *on saturation levels defined earlier):
1629 TotalPowerExcel(season,daytype,hour,allregions,'b1')=
1630 (Totalpower.l(season,daytype,hour,allregions)
1631   -(TotalHVACpower.l(season,daytype,hour,allregions)*(1-spaceheatingsaturation(allregions)))$(Qcoolin»
     g.l(season,daytype,hour,allregions)>0))*Numberofresidences(allregions);
1632
1633 *To report average monthly electricity consumption every season (currently not
1634 *accounting for HVAC power used for heating, assuming no heating power use):
1635 Monthlyelectricityconsumed(RHsup,Tsup,intake,season,allregions)=sum((daytype,hour),( Totalpower.l(sea»
     son,daytype,hour,allregions)
1636                                                                                -(TotalHVACpower.»
     l(season,daytype,hour,allregions)*(1-spaceheatingsaturation(allregions)))$(Qcooling.l(season,daytype,»
     hour,allregions)>0)
1637                                                                                )*Daysinseason(se»
     ason,daytype)/Monthsinseason(season));
1638
1639 *To report the associated average monthly cost every season based on current
1640 *electricity tariffs:
1641 Monthlyelectricitycost(RHsup,Tsup,intake,season,allregions)=elecfixedtariff
1642 +(electariff('b1')*monthlyelectricityconsumed(RHsup,Tsup,intake,season,allregions))$(upconsumptionlev»
     el('b1')>=monthlyelectricityconsumed(RHsup,Tsup,intake,season,allregions))
1643 +sum(consbrack$(upconsumptionlevel(consbrack)<=monthlyelectricityconsumed(RHsup,Tsup,intake,season,al»
     lregions) and monthlyelectricityconsumed(RHsup,Tsup,intake,season,allregions)<=upconsumptionlevel(con»
     sbrack+1)), electariff(consbrack)*(monthlyelectricityconsumed(RHsup,Tsup,intake,season,allregions)-up»
     consumptionlevel(consbrack)))
1644 +sum(consbrack$(upconsumptionlevel(consbrack)<=monthlyelectricityconsumed(RHsup,Tsup,intake,season,al»
     lregions)), electariff(consbrack)*(upconsumptionlevel(consbrack)-upconsumptionlevel(consbrack-1))) ;
1645
1646 execute_unload 'PowerLoad.gdx' TotalPowerExcel;
1647 If( (ord(season)=card(season) and ord(allregions)=card(allregions)),
1648 execute 'gdxxrw.exe PowerLoad.gdx o=PowerLoadVillasInsulate.xlsm Par=TotalPowerExcel rng=TotPower!A2:»
     Z1000';
1649    );
1650 *To reset values for next loop run:
1651 Totalpower.l(season,daytype,hour,allregions)=0;
1652 TotalHVACpower.l(season,daytype,hour,allregions)=0;
1653 Qcooling.l(season,daytype,hour,allregions)=0;
1654
1655     );
1656
1657 *To move the solve to the next season:
1658 seasonuse(season)=no;
1659 seasonuse(season+1)$(runallseasons=1)=yes;
1660
```

```
);

*To move the solve to the next region:
r_use(allregions)=no;
r_use(allregions+1)$(runallregions=1)=yes;

);
*****************************************************************************
$INCLUDE Residential_Display_Variables.gms
*****************************************************************************
;
$ontext
****Exporting to Excel using GDX utilities:
*Unloading to GDX file
execute_unload 'results.gdx' Qsystem Texternalroof HVACpower distance
Tempprofile directirradiance diffuseirradiance reflectedirradiance totalirrad
Totalpower Tinternalroof Qcoil Tindoorrun humidityratioinHVACrun TemperatureinHVACrun
Monthlyelectricityconsumed MassintakeAHUrun ;

*Writing parameters and variables to Excel files from GDX file
*Results.xlsx; used to graphically present some of the main results
execute 'gdxxrw.exe results.gdx o=Residential_Results.xlsx par=Qsystem rng=SysLoad!A1:AZ9999'
execute 'gdxxrw.exe results.gdx o=Residential_Results.xlsx par=Texternalroof rng=RoofExtT!A1:AZ9999'
execute 'gdxxrw.exe results.gdx o=Residential_Results.xlsx par=HVACpower rng=HVACpower!A1:AZ9999'
execute 'gdxxrw.exe results.gdx o=Residential_Results.xlsx var=Totalpower rng=TotPower!A1:AZ9999'
execute 'gdxxrw.exe results.gdx o=Residential_Results.xlsx par=Tinternalroof rng=RoofIntT!A1:AZ9999'
execute 'gdxxrw.exe results.gdx o=Residential_Results.xlsx var=Qcoil rng=Qcoil!A1:AZ9999'
execute 'gdxxrw.exe results.gdx o=Residential_Results.xlsx par=Tindoorrun rng=TindRun!A1:AZ9999';

*WallTemp.xlsx; used to graphically present the temperature profiles through walls and roof
execute 'gdxxrw.exe results.gdx o=WallTemp.xlsx par=distance'
execute 'gdxxrw.exe results.gdx o=WallTemp.xlsx par=Tempprofile rng=Sheet3!I1:L1251';

*Radiation.xlsx; used to graphically present solar irradiation profiles
execute 'gdxxrw.exe results.gdx o=Radiation.xlsx par=directirradiance'
execute 'gdxxrw.exe results.gdx o=Radiation.xlsx par=diffuseirradiance'
execute 'gdxxrw.exe results.gdx o=Radiation.xlsx par=reflectedirradiance'
execute 'gdxxrw.exe results.gdx o=Radiation.xlsx par=totalirrad';

*Supplyair.xlsx used to show results over a range of supply air properties:
execute 'gdxxrw.exe results.gdx o=Supplyair.xlsx par=temperatureinHVACrun'
execute 'gdxxrw.exe results.gdx o=Supplyair.xlsx par=humidityratioinHVACrun rng=Sheet3!G1:M251'
execute 'gdxxrw.exe results.gdx o=Supplyair.xlsx par=massintakeAHUrun rng=Sheet3!O1:S251'
execute 'gdxxrw.exe results.gdx o=Supplyair.xlsx par=Monthlyelectricityconsumed rng=Sheet3!U1:Z30';
$offtext


execute_unload 'results.gdx' Regelecconsump natelecconsumplight NatelecconsumpAPP;
execute 'gdxxrw.exe results.gdx o=regionalconsumpvillasInsulate.xlsx par=regelecconsump'
execute 'gdxxrw.exe results.gdx o=regionalconsumpvillasInsulate.xlsx par=natelecconsumpLight rng=Shee»
t3!K1:Q20'
execute 'gdxxrw.exe results.gdx o=regionalconsumpvillasInsulate.xlsx par=NatelecconsumpAPP rng=Sheet3»
!R1:Z20';

```