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Public Works Canada
Design & Construction
Technology

EASI PROGRAM:
ENGINEERING MANUAL

DRAFT 1

13/27

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Draft for comment

Computer-Aided Design Centre (CAD)

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1. INTRODUCTION

The EASI program (Draft 1) computes the following hourly heating/cooling loads based on a constant room temperature of 75°F:

- sensible load to return air (CL_r)
- sensible load to space (CL_s)
- latent load to space (CL_m)

These loads are saved on a loads file for subsequent use in system simulation; the report of peak heating/cooling and heating/cooling consumptions refers to only the space sensible load.

Hourly load calculations are performed for the following components:

- People
- Lights
- Infiltration
- Transmission through walls, roofs, and windows
- Solar radiation through windows

2. COOLING LOAD CALCULATIONS

These calculations are performed in imperial units (i.e., SI input is converted before calculation) and on a unitized basis (per square foot of floor area).

2.1 People

The load due to people is assumed to be instantaneous; each person contributes 250 btu/hr of sensible heat and 0.1885 lb/hr of moisture.

$CL_s = 250 * (\text{person per sq. ft.})$
$CL_m = 0.1885 * (\text{person per sq. ft.})$

2.2 Lights

The return air load due to lights is assumed to be instantaneous.

$CL_r = W * 3.413 * (\text{fraction to RA})$
where W = input to lights (watts/sq. ft.)

The remainder of heat from lights is considered in two parts. The convection portion is assumed to be instantaneous.

$CL_s = W * 3.413 * (1\text{-fraction to RA}) * (1\text{-fraction radiant})$

The calculation for the radiant portion uses the transfer function method to account for heat storage in the building mass.

$$CL_s(t) = V_1 * Q(t-1) + V_2 * Q(t-2) - W_1 * CL_s(t-1)$$

where $CL_s(t)$ - cooling load at time t
$CL_s(t-1)$ - cooling load at time (t-1)
$Q(t-1)$ - heat gain at time (t-1)
$Q(t-2)$ - heat gain at time (t-2)
V_1, V_2, W_1 - transfer function coefficients (see Table I)

The heat gain is:

$Q(_t)$ = W * 3.413 * (1-fraction to RA) * (fraction radiant)

TABLE I

Transfer Function Coefficients for Radiant Portion of Lights

	X	L	M	H	V
V_1	1	0.224	0.197	0.187	0.180
V_2	0	-.044	-.067	-.097	-.130
W_1	0	-.082	-.087	-0.91	-0.95

Note: The transfer function for radiant portion of lights is essentially the same as for solar radiation except for a delay of 1 hour; this delay makes it consistent with the equations developed by Mitalas.

2.3 Infiltration

The load due to infiltration is considered instantaneous.

The sensible load is:

$CL_s = C_p * I * (\theta_o - \theta_i)$

where C_p - specific heat of air (btu/lb°F)
I - infiltration rate (lb/hr)
θ_o - outdoor air temperature
θ_i - room air temperature

The latent load is:

$CL_m = I * (W_o - W_i)$

where W_o - humidity ratio of outdoor air (lb/hr)
W_i - humidity ratio of room air

2.4 Transmissions Through Walls, Roofs and Windows

In order to simplify the input and decrease execution time, the EASI program does not use transfer functions for calculating the heat gain through walls and roofs. More significantly, outdoor dry bulb temperature is used rather than air temperature. This may result in a significant error when transmission through the roof is a major component of load; however, in most cases the error will be relatively small.

The cooling load for transmission through walls, roofs and windows is computed using the transfer function:

$$CL_s(t) = V_o * Q(t) + V_1 * Q(t-1) - W_1 * CL_s(t-1)$$

where $CL_s(t)$ - cooling load at time (t)
$CL_s(t-1)$ - cooling load at time (t-1)
$Q(t)$ - heat gain at time (t)
$Q(t-1)$ - heat gain at time (t-1)
V_o, V_1, W_1 - transfer function coefficients (see Table II)

The heat gain is computed by:

$$Q = \text{U-value} * \text{area} * (\theta_o - \theta_i)$$

TABLE II

Transfer Function Coefficients for Transmission

	X	L	M	H	V
V_o	1	.703	.681	.676	.670
V_1	0	-.523	-.551	-.586	-.620
W_1	0	-0.82	-0.87	-0.91	-0.95

2.5 **Solar Radiation Through Windows**

The cooling load due to solar radiation is calculated using the transfer function method:

$$CL_s(t) = V_o * Q(t) + V_1 * Q(t-1) - W_1 * CL_s(t-1)$$

where $CL_s(t)$ = cooling load at time t
$CL_s(t-1)$ = cooling load at time (t-1)
$Q(t)$ = heat gain at time t
$Q(t-1)$ = heat gain at time (t-1)
V_o, V_1, W_1 = transfer function coefficients (see Table III)

The heat gain is calculated by:

$$Q(t) = A_g \cdot SC_g \cdot H$$

where A_g = area of glass
SC_g = shading coefficient of glass
H = solar radiation through standard glass (1/8" DS) for the given orientation. (The effect of cloud cover is included in H.)

TABLE III

Transfer Function Coefficients for Solar Radiation

	X	L	M	H	V
V_o	1	0.224	0.197	0.187	0.180
V_1	0	-.044	-0.067	-0.097	-0.130
W_1	0	-0.82	-0.87	-0.91	-0.95

3. SOLAR CALCULATIONS

The EASI program uses values of solar radiation (direct normal and sky diffuse) read directly from the weather file for each hour. These values are treated as if they are measured data even though they may, in fact, have been created from calculated solar and cloud cover modifier. (The Montreal and Vancouver data presently available are created using R.F. Meriwether and Associates cloud cover modifiers).

The value of solar radiation through standard glass, H, is calculated each hour:

$$H = \alpha * I_s + \beta * I_n$$

where I_s = sky diffuse radiation
I_n = direct normal radiation
α = modifier, for particular azimuth and tilt, to be applied to sky diffuse
β = modifier, for particular azimuth and tilt, to be applied to direct normal

The factors α and β are functions of the geometry; they are calculated for only 1 day, the 21st of the month. Note that the effect of shading devices, if any, is also included in β .

The derivation of α and β factors is given in Appendix I.

4. CONDENSED WEATHER DATA

The EASI program performs hourly calculations for seven days to represent each month. Monthly consumptions are obtained by multiplying by the ratio (no. of days in month/7).

The seven days representing each month are chosen to give approximately the same values for peaks and comsumptions as the full year analysis. Indications are that this results in errors of less than 5%. The advantages are that computation time is reduced by a factor of 4, and the size of weather and loads files is also reduced by a factor of 4. This makes floppy disk storage practical for these files.

5. REFERENCE SYSTEM

The purpose of the reference system model is to provide some indication of the cooling which would be required when outdoor air is used for "free-cooling".

The system chosen is basically an ideal variable air volume system which maintains room conditions without using "reheat". This system is one which provides the necessary cooling by adjusting the flow of supply air, f_s, which is assumed to be at a constant condition of θ_s (60°F) and h_s (25 btu/lb).

$$f_s = \frac{CL_s}{\rho * c_p * 60 * (\theta_r - \theta_s)}$$

The amount of mechanical cooling required by this system, R, depends upon the outdoor air conditions:

- If outdoor air temperature θ_{oa}, is less than or equal to θ_s then the supply air condition can be maintained by mixing without any refrigeration; $R = 0$.
- If outdoor air temperature, θ_{oa}, is greater than θ_s then mechanical cooling is required.
- If outdoor air dewpoint is less than or equal to the supply air dewpoint then only sensible cooling is required. The amount of sensible cooling is:

  $$R = \rho * c_p * 60 * f_s * (\theta_{oa} - \theta_s)$$

  where ρ = density of air
  c_p = specific heat of air

  $$R = \frac{(\theta_{oa} - \theta_s)}{(\theta_r - \theta_s)} * CL_s$$

- If outdoor air dewpoint is greater than supply air dewpoint, and outdoor enthalpy, h_{oa}, is less than or equal to room enthalpy, h_r, then outdoor air must be cooled to the supply condition. The cooling required in this case is:

  $$R = \rho * 60 * f_s * (h_{oa} - h_s)$$

  combining equations

  $$R = \frac{(h_{oa} - h_s)}{c_p * (\theta_r - \theta_s)} * CL_s$$

- If outdoor air enthalpy, h_{oa}, is greater than room enthalpy, h_r, then room air is recirculated and cooled rather than cooling outside air (except for outdoor air which is included as ventilation/infiltration air). In this case the mechanical cooling required is equal to the space load, or

  $$R = CL_s$$

Derivation of Solar Modifiers α and β

The solar heat gain through glass is the sum of transmitted radiation plus the inward flowing fraction of radiation absorbed in the glass; both direct and diffuse components must be considered:

H = (direct transmitted + direct absorbed) * SHRAT +
(diffuse transmitted + diffuse absorbed)

where SHRAT is ratio of unshaded area/total area for windows with shading devices (1. for unshaded window).

Direct transmitted = direct * transmittance of glass for direct absorptance.

Direct absorbed = direct * absorptance of glass for direct * inward flowing fraction.

Diffuse transmitted = diffuse * transmittance for diffuse.

Diffuse absorbed = diffuse * absorptance for diffuse * inward flowing fraction.

For standard glass (1/8" DS):
inward flowing fraction = 0.2673796
transmittance for diffuse (T_d) = 0.7990111
absorptance for diffuse (A_d) = 0.0543594

Transmittance and absorbance of glass for direct solar are functions of the cosine of the incident angle, ϕ:

$$A_d = \sum_{j=0}^{5} a_j \cos^j (\phi)$$

$$T_d = \sum_{j=0}^{5} t_j \cos^j (\phi)$$

The values of a_j and t_j for standard glass are given in Table IV.

TABLE IV

Values of a_j and t_j for Standard Glass

j	a_j	t_j
0	0.01154	-0.00885
1	0.77674	2.71235
2	-3.94657	-0.62062
3	8.57881	-7.07329
4	-8.38135	9.75995
5	3.01188	-3.89922

The direct solar component is:

$$\text{direct} = I_n \cos(\phi)$$

The diffuse solar component is:

$$\text{diffuse} = Y * I_s + Z * \text{ground brightness}$$ where

I_s = Sky brightness

Y = 0.45 if $\cos(n) < -.2$
otherwise

$y = .55 + .437 + \cos\phi + .313 \cos^2\phi$

$$Z = \frac{1 + \cos(180 - \text{tilt angle})}{2}$$

ground brightness = ROG * ($I_s + I_n$ * sin (altitude angle))

where ROG - ground reflectivity.

Substituting into equation 1 and regrouping terms:

$$H = \alpha I_s + \beta I_n$$

where α = 0.8135456 * (Y + Q * ROG)

β = (0.8135456 * Z * ROG * sin (altitude angle) + FUNCT ($\cos(\phi)$) * SHRAT

where FUNCT = (A_d + .267396 * T_d) * $\cos(\phi)$

SHRAT is calculated using the subroutine SHADOW from ASHRAE Energy Calculations 1.