COMPARISON OF THE BUILDING LOAD CALCULATIONS PERFORMED BY THE EXCEL MODULE "DESIGN LOADS" AND HAP-4.3 (CARRIER INC.)

This study was undertaken to validate the Excel module "DESIGN LOADS.v9.1" presenting the main component of the design system "HVAC Engineering Book". This module (hereafter referred to as E-Book) calculates building thermal and ventilation loads, and sizes HVAC system components. The study applied the software program HAP-4.3 by Carrier Inc. to validate the results produced by the module.

Input data of the sample project
Site: General Services Building, 17,600 ft^2, building floor plan and occupancy are as outlined in the guide "HVAC Engineering Book"
Site location: Toronto (Ontario)
Design outdoor air conditions: as per ASHRAE Weather Tables for Toronto area
Winter indoor conditions: dry-bulb temperature 70 ^oF, relative humidity 30% (specific humidity 32 gr/lb)
Summer indoor conditions: dry-bulb temperature 75 ^oF, relative humidity 50% (specific humidity 63 gr/lb)
HVAC system: constant air volume air-conditioning system with reheat coils and perimeter heating units

The output data calculated by the Excel module and HAP are presented below.

Hourly outdoor dry-bulb temperature profiles for summer period, ^oF

Both tools, HAP and the E-Book, use the same procedure outlined in *ASHRAE Fundamentals*, 2005, chapter 28.

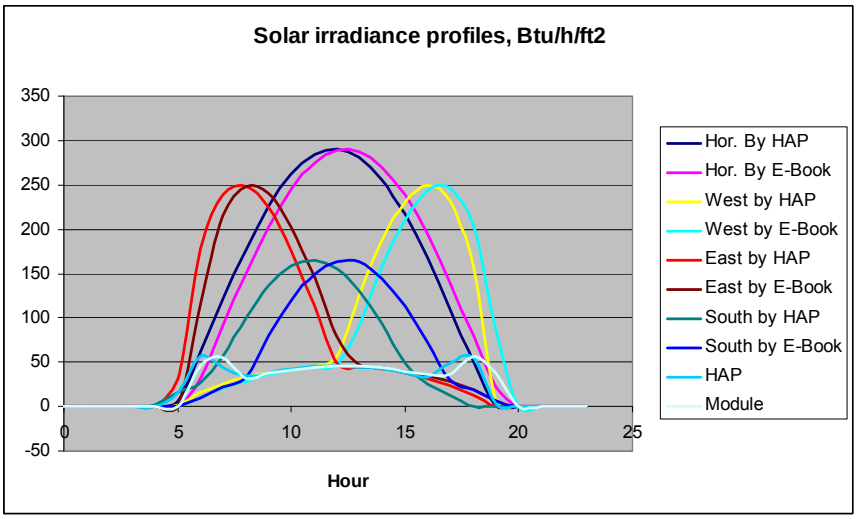
Hour	0	1	2	3	4	5	6	7	8	9	10	11
HAP	71	70	69	68	67	67	68	69	70	73	76	79
E-Book	71	70	69	69	68	68	68	69	71	73	76	80

Hour	12	13	14	15	16	17	18	19	20	21	22	23
HAP	82	85	86	87	86	85	83	80	78	76	74	72
E-Book	83	85	86	87	86	85	83	81	78	76	74	72

Judgment: In general, the calculated values are the same. The deviations are miniscule.

Hourly direct, diffusive, and reflected solar irradiance profiles, Btu/h/ft^2

Both HAP and the E-Book use the same procedure, outlined in *ASHRAE Fundamentals*, 2005, chapter 31. The chart below represents comparison of the total irradiances calculated by HAP and the E-Book for variously oriented surfaces. The E-Book code applies the solar constants published in *ASHRAE Fundamentals*, 2005 (A = 346 Btu/h/ft^2, B = 0.186, and C = 0.138). For code validation purposes, the default values were changed to match the obsolete solar constants used by the HAP code (A = 344 Btu/h/ft^2, B = 0.207, and C = 0.136) introduced by ASHRAE in 1993.



Judgment: The chart indicates that the hourly irradiance rates, including the peak values, calculated by the E-Book match the HAP and ASHRAE method. A time lag between the profiles takes place, averaged to about one and a half hours. It was not possible to trace the reason for the time lag appearance as HAP conceals the intermediate calculations.
It can be expected that use of the updated solar constants produces on average 9% higher peaks of the solar irradiances than use of the obsolete constants.

Hourly solar-temperature profiles, ^{o}F

HAP conceals calculation of solar temperatures. For this reason, validation of the E-Book code was performed against the example on page 30.35 of *ASHRAE Fundamentals*, 2005.

Characteristic	ASHRAE	E-Book
Hour angle, HA=15 x (AST-12), degrees	34.03	34.03
Solar altitude β=arcsin β, degree	57.2	57.2
Solar azimuth Φ, degree	75.3	75.3
Solar azimuth γ=Φ-Ψ (degree):	15.3	15.3
Incident angle (degree):	58.5	58.5
Direct normal irradiance E_{DN}=[A/[exp(B/sin β)] CN, Btu/h/ft^2	278	278
Surface direct irradiance $E_{dir}=E_{DN}$ cos Θ, (Btu/h/ft^2)	145.1	145.1
Diffuse irradiance E_{dif} =DIF x Y x E_{DN} (Btu/h/ft^2)	33.1	33.1
Ground-reflected irradiance $E_r=E_{DN}$(DIF+sin β) ξ (1-cosΞ)/2, Btu/h/ft^2	27.2	27.2
Total irradiance $E_t=E_{dir}+E_{dif}+E_r$, Btu/h/ft^2	205.4	205.4
Sol-air temp $T_s=T_o+\alpha/h_o$ x $E_t-\varepsilon\Delta R/h_o$ ^{o}F	156	156

Judgment: Calculation of solar temperatures matches the ASHRAE recommendations.

Thermal conductivity of building materials, Btu-in/h/ft^2

The E-Book uses the data from *ASHRAE Fundamentals*, 2005. The source of HAP data is unknown. In general, the deviation between the data of each tool is insignificant. However, there are some exceptions. For example, the difference between the conductivities of insulation materials is shown below.

Characteristic	**HAP**	**E-Book**	**Deviation**
Batt insulation	0.32	0.31	0.01
Rigid board insulation	0.14	0.2	0.06

Judgment: It can be expected that the E-Book will produce higher transmission heat losses for roofs with board insulation.

Space ventilation air requirements

HAP	**E-Book**
Uses 62.1-2004 rates	Uses 62.1-2007 rates

Judgment: The rates are the same for the majority of occupancy categories.

Transmission heat losses through the envelope elements, Btu/h

The tables below compare the heat loss components calculated for room 120.

- Through walls, Btu/h:

HAP	E-Book
674	679

- Through windows, Btu/h:

HAP	E-Book
2843	2843

- Through roof, Btu/h:

HAP	E-Book
5371	5402

- Through infiltration, Btu/h:

HAP	E-Book
648	661

- Through slab on grade floor, Btu/h:

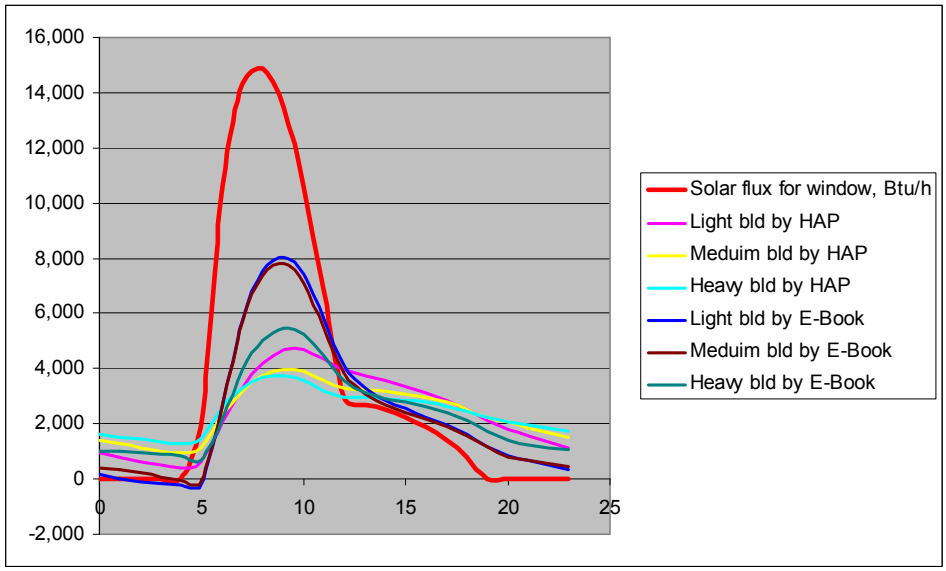
HAP	E-Book
Uses formula accounting for total resistance between indoor and outdoor air temperatures along the heat path through the slab and soil	Uses formula accounting for total resistance between indoor and soil temperatures as recommended by the latest ASHRAE handbook
328	523

Judgment: The heat losses calculated by each tool for walls, roof, and windows are the same. The indoor-to-outdoor air resistance used by HAP for calculation of the floor heat losses introduces an uncertainty, as the soil may be covered by snow, water, etc. impacting on the total thermal resistance between the indoor and outdoor air. In contrast, the E-Book code uses the ground temperature instead of the outdoor air temperature, as recommended by the latest ASHRAE Handbook Fundamentals. This approach eliminates the uncertainty.

Window heat gain rates, Btu/h

HAP	E-Book
Calculates window heat gain rates for the single glass reference window de-rated by the window shade coefficient	Calculates the window heat gain rates using hourly solar heat gain coefficients set by the latest ASHRAE Handbook Fundamentals for different window systems

The cooling load profiles calculated by the E-Book and HAP for unshaded windows in room 120 with light, medium, and heavy weighted structures are shown below.

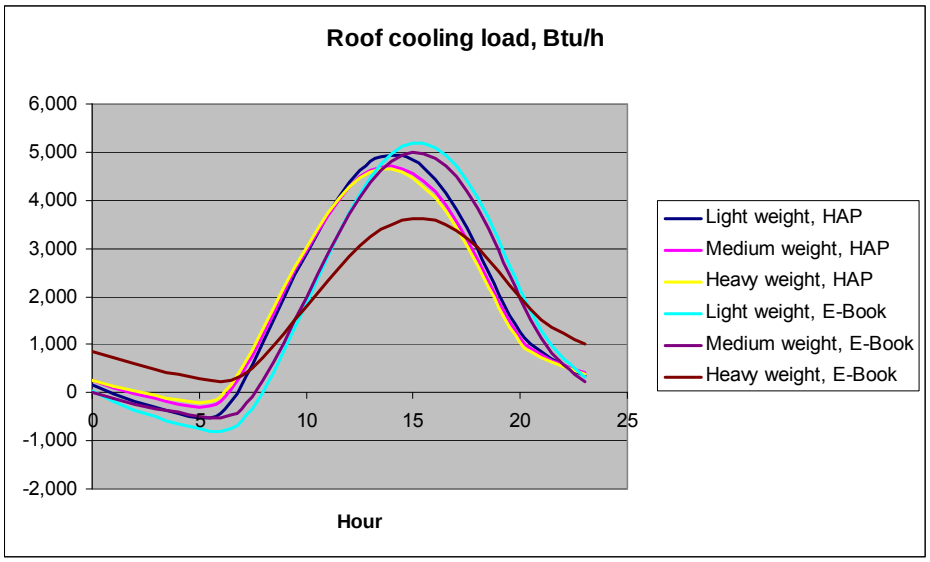


Judgment: The HAP method, using the reference single glass concept and the shade coefficient, is outdated and no longer supported by ASHRAE. The E-Book, using the latest ASHRAE achievements, produces more reliable results.
For windows with external shades, the E-Book calculates the moving shaded window area as recommended by chapter 31 of *ASHRAE Fundamentals*, 2005. The E-Book's code assumes that the shades interrupt only the direct radiation, and that the diffusive and reflected radiations reach the window uninterrupted. Potentially, this assumption could result in the overestimation of the total window heat gain rate. This assumption is suggested by *ASHRAE Fundamentals*, 2005 for overhangs and fins, taking into account possible exceptions, for example increased reflectivity of the ground.

Roof cooling loads, Btu/h

HAP	E-Book
Applies obsolete TF method	Applies new CTS/RTS methods recommended by ASHRAE

The load profiles calculated by each tool for room 120 are presented below. The calculations are done for light, medium, and heavy weighted structures.



Judgment: The TF method used by HAP calculates the current hour cooling load based on the cooling loads from previous hours. This assumption introduces uncertainty that may potentially be accumulated during hour-to-hour incremental calculations. The TF method distinguishes only the weight of the building and disregards the room's interior finish, which significantly impacts on the radiant heat transfer among the room's interior components. RTS and CTS methods use the 24-hour radiant cooling load profiles predefined for different classes of construction. The classes account for the weight of the building, the finish of the interior, and the percent of windows. As RTS/CTS methods have no time dependence and allow for various interior finishes, these methods are more adequate and reliable than the TF method, which was developed for yearly energy simulations rather than for the HVAC design.

Heat gain rates from people, Btu/h

The occupancy categories used by HAP do not match the latest ASHRAE recommendations in Table 1, chapter 30, which are employed by the E-Book. For purposes of comparison, the table below compares the rates used by HAP and the values used by the E-Book.

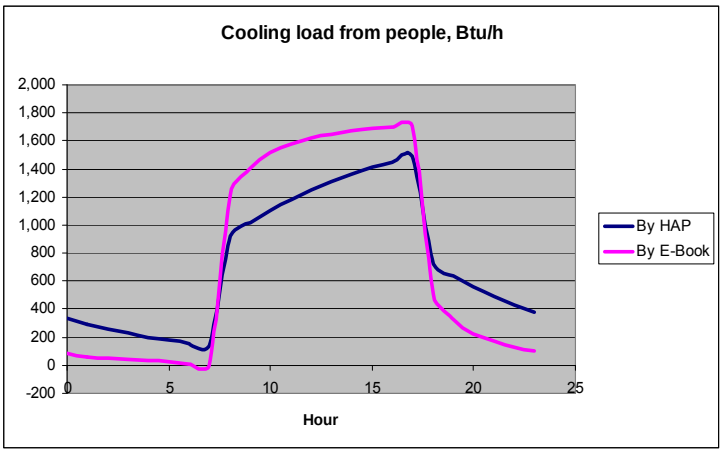
Occupancy	HAP sensible	E-Book sensible	HAP latent	E-Book latent	HAP % radiant heat	E-Book % radiant heat
Seated at rest	230	225-245	230	225-245	70	60
Office work	245	245-250	245	245-250	70	58
Sedentary work	280	275	280	275	70	58
Medium work	295	275	455	475	70	49
Heavy work	525	580-635	925	870-965	70	54
Dancing	305	305	545	545	70	49
Athletics	710	710	1090	1090	70	54

Judgment: The default heat gain rates used by the E-Book are taken from Table 4, *ASHRAE Fundamentals*, 2005. The source of the HAP heat gain values is not known. The heat gain rates are slightly different. The biggest difference is in the sensible heat for the category Heavy Works. The E-Book allows for wider variations in the occupancy.
HAP assumes the radiant portion of the sensible heat gain rates is constant and equal at 70%. The E-Book varies the radiant rate percentages from 49% to 60% depending on occupancy category.

Cooling load from people, Btu/h

HAP	E-Book
Applies obsolete TF method	Applies CTS/RTS methods recommended by ASHRAE

An example of the cooling loads simulated by each tool for room 120, with medium weighted structures, is shown below.

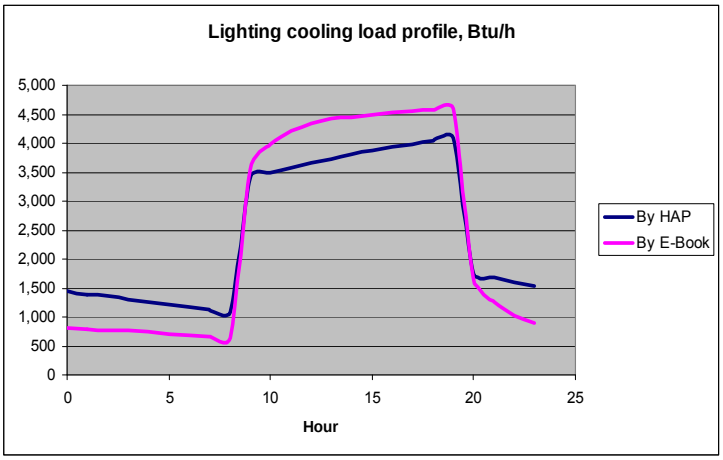


Judgment: In general, the profiles have a similar pattern. The E-Book seems to produce a higher peak load value.

Lighting cooling loads, Btu/h

HAP	E-Book
Applies obsolete TF method	Applies CTS/RTS methods recommended by ASHRAE

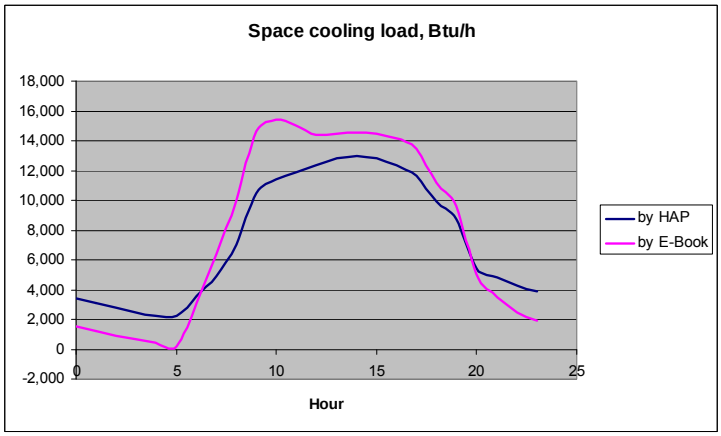
An example of the cooling load profiles calculated for room 120, with medium weighted structures, is shown below.



Judgment: The profiles have a similar pattern. The E-Book seems to produce a higher peak load value.

Space cooling loads, Btu/h

Comparison of the sensible cooling load profiles calculated by HAP and the E-Book for room 120, with medium weighted structures, is shown below. Each hourly value of the profiles is found as the sum of the coincident cooling loads from all of the room heat gain sources.



Judgment: The profiles have a similar pattern. The E-Book seems to produce a higher peak load value.

System ventilation air requirements, ft^3/min

Calculation method used by HAP	Calculation method used by E-Book
Uses recommendations of standard 62.1-2001	Uses recommendations of standard 62.1-2007
2974	2423

Judgment: The difference in the procedures introduced by each of the standards produces significant deviation in the ventilation airflow rates at the system level. Calculations performed by the E-Book comply with the latest ASHRAE requirements.

BUILDING LOAD REPORTS SUMMARY

The space-, zone-, and system-related load reports generated by the E-Book for the sample building are compared against the calculations performed by HAP for the same building. The comparison reveals cumulative deviations between the reported characteristics, caused by use of different methods, constants, and rates.

SPACE VENTILATION AIR REQUIREMENTS, CFM

Space ID	Space name	E-Book	HAP
101	Assembling room	195	195
102	Wash-down room	13	13
103	Dark room	23	23
104	Screen room	60	60
105	Office	10	10
106	Vestibule	175	175
107	Archives	92	92
108	Purchasing	32	32
109	Storage	24	24
110	Control centre	182	182
111	Storage	7	7
113	Corridor	155	155
114	Lettering room	112	112
115	Sign shop	13	13
116	Photocopy room	13	13
119	Lunch room	477	477
120	Decorating	112	112

SPACE SUPPLY AIR REQUIREMENTS, CFM

Space ID	Space name	E-Book	HAP
101	Assembling room	1,465	1,188
102	Wash-down room	253	170
103	Dark room	210	114
104	Screen room	833	562
105	Office	50	52
106	Vestibule	1,074	895
107	Archives	511	417
108	Purchasing	357	306
109	Storage	242	156
110	Control centre	2,256	1,727
111	Storage	25	20
113	Corridor	448	435
114	Lettering room	1,488	1,063
115	Sign shop	238	168
116	Photocopy room	102	102
119	Lunch room	1,439	1,462
120	Decorating	875	822

SPACE HEAT LOSSES, BTU/H

Space ID	Space name	E-Book	HAP
101	Assembling room	35,851	35,900
102	Wash-down room	4,141	4,100
103	Dark room	1,227	1,200
104	Screen room	12,810	12,400
105	Office	526	500
106	Vestibule	38,296	33,800
107	Archives	10,417	10,200
108	Purchasing	6,680	10,200
109	Storage	5,699	5,400
110	Control centre	36,184	33,600
111	Storage	2,983	2,600
113	Corridor	47,988	41,900
114	Lettering room	31,073	28,600
115	Sign shop	4,647	4,500
116	Photocopy room	750	700
119	Lunch room	25,849	23,900
120	Decorating	13,631	13,400

SPACE PEAK SENSIBLE COOLING LOADS, BTU/H

Space ID	Space name	E-Book	HAP
101	Assembling room	31,642	25,100
102	Wash-down room	5,460	3,600
103	Dark room	2,431	2,400
104	Screen room	17,991	11,900
105	Office	1,075	1,100
106	Vestibule	23,195	18,900
107	Archives	11,038	8,800
108	Purchasing	7,701	6,500
109	Storage	5,235	3,300
110	Control centre	48,715	36,600
111	Storage	538	400
113	Corridor	9,666	9,200
114	Lettering room	32,132	22,500
115	Sign shop	5,129	3,500
116	Photocopy room	2,203	2,100
119	Lunch room	31,069	30,900
120	Decorating	18,899	17,400

ZONE DESIGN COOLING LOADS, BTU/H

Zone ID	E-Book	HAP
Z-1	18,899	17,400
Z-2	31,069	30,900
Z-3	39,079	28,100
Z-4	31,642	25,100
Z-5	26,928	18,900
Z-6	23,195	18,900
Z-7	23,974	18,500
Z-8	9,666	9,200
Z-9	49,221	37,000

SYSTEM DESIGN LOAD SUMMARY

System name	Peak sensible loads, Btu/h	Supply airflow rate, ft^3/min	Outdoor airflow rate, ft^3/min
CAV by E-Book	225,377	11,866	2,423
CAV by HAP	196,344	9,658	2,974
VAV by E-Book	219,778	10,178	2,423
VAV by HAP	196,344	9,400	2,107

SIZING OF COOLING COIL, BTU/H

	CAV	CAV
CAV system	E-Book	HAP
Sensible cooling load	370,692	323,500
Latent cooling load	75,804	104,200
Total cooling load	446,497	427,700

VAV system	E-Book	HAP
Sensible cooling load	340,543	273,200
Latent cooling load	75,829	98,500
Total cooling load	416,372	371,900

SIZING OF PREHEAT COIL, BTU/H

System name	E-Book	HAP
Heating coil load, Btu/h	145,806	223,700

Note: HAP does not account for the supply and return fan heat gains at winter conditions

SIZING OF HUMIDIFIER, LB/H

E-Book	HAP
45	69

Note: E-Book does not account for loss of moisture with infiltration air

SPACE HEATING UNIT SUMMARY, BTU/H

Space	E-Book	HAP
Assembling room	35,851	35,900
Wash-down room	4,141	1,200
Dark room	1,227	1,200
Screen room	12,810	12,400
Office	526	500
Vestibule	38,296	33,800
Archives	10,417	10,200
Purchasing	6,680	10,200
Storage	5,699	5,400
Control centre	36,184	41,900
Storage	2,983	2,600
Corridor	47,988	41,900
Lettering room	31,073	28,600
Sign shop	4,647	4,500
Photocopy room	750	700
Lunch room	25,849	23,900
Decorating	13,631	13,400

CONCLUSION OF THE STUDY

The E-Book's accuracy and features make it sufficient for real design of HVAC systems. In contrast with HAP, the E-Book uses the latest methods recommended by ASHRAE, implying reliable outcomes. The deviations are caused by different methods.

Advantages of the current version of the E-Book against HAP are:

- Cooling load calculations using RTS/CTS methods are more reliable than the calculations by Transfer Function and Heat Extraction methods. This is because the former do not require hour-to-hour simulation of the system performance, which is dependent on the system's control settings and the transient heat transfer process in the served spaces. In particular, HAP simulates the cooling coil design load based on the peak space sensible load. If this load occurs at an evening hour, the coincident ventilation load of the coil at this hour will be simulated less than at noon, as the ambient temperature in evening hours drops. The simulated time lag between the space and ventilation peak loads may result in undue reduction of the coil size, as the actual conditions may reveal no time lag. To avoid possible coil size underestimate, the E-Book sizes the coil assuming coincidence of the space and ventilation peak cooling loads.
- The E-Book calculates the heat gain rates from windows using the new method introduced by *ASHRAE Fundamentals*, 2005, and updated values of the solar constants. In contrast, current version of HAP applies outdated methods and outdated solar constants.
- Interpretation of inputs and outputs is simpler, resulting in a lesser level of error margin.
- The Excel code accompanied by formula descriptions reveals each line of the interim calculations. This feature makes quality control of the calculations more efficient than when using HAP, which resembles "a black box" with inputs and outputs.
- Capability of the modules to be easily linked with any other spreadsheets, updated, and customized allows the creation of flexible "technology of HVAC project production."
- Excel format of the reports is more convenient for storage and use than HAP reports.
- HAP calculates ADP parameters while sizing the cooling coil on the assumption that the by-pass factors indicating thermal and dehumidifying capabilities of the coil, $BF_T=(T_{in}-T_{adp})/(T_{out}-T_{adp})$ and $BF_{HR}=(HR_{in}-HR_{adp})/(HR_{out}-HR_{adp})$, are equivalent, $BF_T= BF_{HR}$, which is not always correct. In contrast, the E-Book allows the selection of a desired indoor humidity level used to calculate the psychrometrics without this assumption.

Disadvantages of the current version of the E-Book against HAP are:

- The number of spaces, zones, and systems for one module are limited to 150 spaces, 50 comfort zones, and 3 systems.
- Absence of a user-friendly interface.
- Limited variety of envelope component arrangements
- Limited number of envelope elements for each space.
- Absence of the procedure calculating heat losses through partitions.
- Absence of the procedure for sizing the dehumidifier and heat recovery system.

- Duct heat gain rates and leakage are neglected.
- Infiltration air latent load is neglected.
- The space, zone, and system airflow rate calculation methods are limited by the constant and variable air volume concepts.
- Schedules for occupancy, lighting, and equipment are limited to two sets.
- Simulation of annual system energy performance is not possible.