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Controls options in building energy simulation programs

A survey carried out by the BEPAC Controls Task Group

Report compiled by E R Hitchin, British Gas plc

Building Environmental Performance Analysis Club

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BEPAC brings its work to its members and to industry and the professions generally, through publications, meetings and workshops, and has established a number of Task Groups for detailed study of particular issues. Publications will include both **Technical Notes**, written by members on subjects of topical interest, and **BEPAC Reports**, containing recommended data sets, guidance, procedures, etc, agreed by its Task Groups and the BEPAC Committee. BEPAC also aims to represent the interests of its members on other bodies concerned with research and standardisation in the field of environmental performance.

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HOW TO USE THIS REPORT

If you are interested in the topic as a whole, you will probably want to read the whole report.

However, if your interest is more specific, the following course is suggested:-

(i) read the Introduction (section 1).

(ii) refer to Table 2 for a general view of the range of options offered by each program.

(iii) if your interest is in a particular area of control, for example solar gain controls, refer to the relevant subsection of section 3 "Options variable by variable".

(iv) information on hardware requirements and program availability is given in section 4.

(v) if you need more detailed information, refer to the questionnaire responses summarised in Appendix II.

(vi) for information beyond this you will need to contact the program author or vendor - see Appendix III.

CONTROLS OPTIONS IN BUILDING ENERGY SIMULATION PROGRAMS

1. INTRODUCTION

This note reports the results of a survey, carried out during 1989/90, on behalf of the Controls Task Group of BEPAC, with the aim of helping users to identify building energy simulation programs which offer particular combinations of controls options. The report focusses on the range of options offered, but appendices contain tables which enable the interested reader to establish which programs offer which options. The controls considered are, in some instances, open loop controls such as a ventilation rate reset by external temperature; in others closed loop, for example ventilation rate controlled by the degree of overheating. At a later date it is intended to compare the results of this survey with a survey of controls on the market, and to identify any controls which are used in practice but not included in these programs.

Control systems may be modelled at different levels of idealisation, between the extremes of simulating each individual component of the control loop, to the treatment of the entire control system as a single "black box" which obeys defined control laws. This survey considers only the latter extreme, even where individual programs are capable of more detailed simulation. This approach is taken because many building energy simulation programs treat control systems at this level. No judgement is made as to whether this is appropriate; this must be a matter for the user to consider in the light of the problem he or she is addressing.

The survey does not, therefore, address such questions as the simulation of plant components, or within-room air movement and heat flow. It considers only dynamic building simulation programs - not steady-state or pseudo steady-state models. Neither does it include models of control systems which are separate from building simulation.

The survey was carried out by questionnaire, which was sent to a number of organisations, usually program authors, but sometimes informed users. Programs produced overseas were included, but there was a deliberate bias towards those which were known to be in use in the United Kingdom. Eighteen responses which were within the scope of the survey were received, of which eight were of UK origin.

The questionnaire asked whether each program offered any control options in each of nine general areas. If the answer for a particular area was "yes", respondents were asked to respond to further questions. These asked what options were offered for: the quantity which was varied (for example, convective heat input), the sensed variable (for example, dry resultant temperature) and the control mode (proportional control).

Some, primarily research-oriented, programs offer relatively few standard options, but are structured to encourage the user to define his own control systems. Other programs allow the user to specify his own control system, in addition to offering a range of standard options. In either case this is noted in the responses.

A survey of this nature inevitably becomes dated as new programs and new versions of existing programs appear. Readers should remember that the situation described is a "snapshot" at a particular time, and only covers

those programs of which the author was aware, and for which he was able to obtain information. It is intended only as a guide to potential users in identifying programs which claim particular features: no opinion is offered on the value or performance of any option.

2. OVERVIEW

Table 1 shows the total number of options identified for each of these for each area. On average, about one third of these were offered by any particular program but, as might be expected, there were wide differences between programs. The widest range of options is for control of heat input, as might be anticipated.

Table 1. TOTAL NUMBER OF OPTIONS IDENTIFIED

	Numbers of Options		
	Quantity Varied	Control Mode	Sensed Variable
Heat input	6	11	12
Temperature control	6	7	5
Surface temperature	3	10	11
Humidity	6	6	9
Ventilation	3	3	7
Art. lighting	2	5	3
Daylighting	1	2	3
Solar gain	1	3	4
U-value	2	2	5

Only six features were present in more than half the responses:-

1. Timed control of convective heat input, perfectly matched to load.
2. Timed variation of room air temperature setpoint.
3. Timed variation of fresh air ventilation rate.
4. Ventilation rate may vary as a function of room air temperature.
5. Timed heat input from artificial lighting.
6. Timed variation of window solar transmission.

Even these features are not universal and potential users need to examine the options offered by each program to find those which best meet their needs.

Table 2 is a summary of the range of options offered by each program. Each heading is discussed in more detail in subsections 3.1 to 3.9.

Table 2 RANGE OF OPTIONS FOR EACH TYPE OF CONTROL
(more * = more options, but not directly proportional)

Program	1 heat	2 setpt	3 surf	4 rh	5 vent	6 artlt	7 dayl	8 solar	9 fabrc
APACHE($)	*******	****	****	*****	*****	**	-	**	**
BLAST	*	*	-	-	**	*	*	*	*
CYPROS	-	**	-	-	-	-	-	-	-
DOE-2	****	**	-	*	***	**	**	**	***
EMGP2	***	*	-	-	-	-	-	-	-
ESP($)	*******	***	****	**	**	**	*	*	**
EXCALIBUR	*	-	-	-	*	**	-	-	-
HTB-2	*****	**	***	-	**	*	-	*	-
HVACSIM+(@)	**	**	-	*	*	-	-	-	-
K2($)	***	*	-	*	*	**	*	*	*
OASIS	**	-	-	**	-	-	-	-	-
PETER	***	**	-	-	*	-	-	-	-
RIGEL($)	****	*	-	-	-	-	-	-	-
SERI-RES	*	*	-	-	*	**	*	*	-
SIMULA	**	**	-	-	**	-	-	*	-
TAS($)	*****	***	*	****	***	-	-	*	*
TRNSYS(@)	-	*	-	*	*	*	-	-	-
THERM	***	**	**	-	*	**	-	*	*

Notes: (@) user encouraged to define own control modules - these programs were designed to have user-defined controls.

($) user permitted to define own control modules

3. OPTIONS VARIABLE BY VARIABLE

In the detailed part of the questionnaire, repondents were asked to identify the options available for the quantity varied (denoted "quantity controlled" in the questionnaire), the variables sensed and the modes of control. The questions and a summary of the responses, program by program, form appendixes 1 and 2 of this report.

The questions were divided into nine sections, each referring to a particular type of controlled variable: heat input, temperature setpoint, surface temperature, relative humidity (or other psychrometric variables), ventilation, artificial lighting, daylighting, solar control, fabric. The following sections summarise the replies for each of these.

A few programs are deliberately structured to encourage the user to define his own control laws and thus offer relatively few standard options (denoted @ in table 2). Others provide a wider range of options but also allow the user to add control systems of his own specification, though it may be complex to do this (denoted $ in table 2). Defining one's own control modules requires both time and expertise of the user, and is probably of more value to researchers than to building services design practitioners.

In the following sub-sections, programs have usually only been identified by name in the text if three or fewer offer a particular feature. In other cases, program names can be identified from the tables in appendix II. Each sub-section starts with a summary of the number of options offered by each program for: the quantity varied, the mode of control and the sensed variable. These numbers can only be a rough ranking: they give each option equal status, and do not reflect the versatility of those programs which are designed to allow the user to define his or her own control modules.

3.1 Control of Space Temperature by Variation of Heat Input

The space temperature is commonly thought of as the controlled variable, but in this section it is considered to be the "sensed variable". The "quantity varied" is the heat input to a space (which may be positive or negative). "Perfect control" of heat input results in the sensed temperature always having its desired value. Controls which reset this value are considered in section 3.2.

The questionnaire did not enquire about the implementation of limits imposed by predefined plant capacities: whether, for example, these are applied at each timestep, or only to the average heat requirment over some longer period.

3.1.1 Range of Options:-

Quantity Varied	Mode of Control	Sensed Variable
5 APACHE	10 ESP	10 APACHE
4 ESP	9 DOE2	8 ESP
4 TAS	8 TAS	8 HTB-2
3 BLAST	7 APACHE	4 PETER
3 DOE2	7 HTB-2	4 TAS
3 HTB-2	6 EMPG2	3 DOE2
3 PETER	6 PETER	3 K2
2 EMGP2	6 RIGEL	3 RIGEL
2 K2	5 K2	3 SIMULA
2 RIGEL	4 HVACSIM+	3 THERM
2 THERM	3 EXCALIBUR	2 EMGP2
1 EXCALIBUR	3 OASIS	2 HVACSIM+
1 HVACSIM+	3 THERM	1 BLAST
1 OASIS	2 SERI-RES	1 EXCALIBUR
1 SERI-RES	1 BLAST	1 OASIS
1 SIMULA	1 SIMULA	1 SERI-RES

The control of heat input is fundamental to building thermal modelling, so it is hardly surprising that all programs provide it. There is a wide variety of options available between programs but hardly any offer exactly the same range of options.

3.1.2 Sensed variables (temperatures).

Almost all programs offer a choice of sensed variables, the most common option by far being room air temperature. Five programs allow the user to define any mix of air and radiant temperatures. Environmental temperature control is explicitly available on five programs, and dry resultant temperature on two, and both these can, of course, also be generated by the programs with user-defined mixes. Globe temperature is offered by two programs (Apache and HTB-2). Four programs allow the averaging of temperatures from several sensors, four allow sensing of mean surface temperature, although in three cases this is simply one extreme of the range of possible user-defined sensed temperatures. Four programs allow the sensing of room relative humidity. Around half the programs offer sensing of external air temperature, but only three (Apache, ESP, Simula) can accept a solar control and two (ESP, Simula) a link to wind speed.

3.1.3 Quantity Varied.

The most common variable (controlled) quantity was convective heat input, offered by fourteen programs. Programs which did not offer this, offered instead heat input to an "environmental temperature" node: one (TAS) offered both options. Five programs allowed the supply air temperature to be varied. Variation of long-wave radiant heating was offered by six programs; of short-wave, directional radiation by four; and of heat input to some form of storage by four.

3.1.4 Control modes.

Timed, on/off control with heat input "perfectly" matched to load, was almost universally available. Modelling of more complex controls was much rarer.

For example, optimisers (which bring heating plant into operation at different times according to sensed internal or external conditions) with fixed parameters are available only in three programs, and adaptive optimisers in three (ESP, DOE2 and Excalibur). Eight programs offer proportional control, three P+I and none PID control (except to the extent that ideal control might be an approximation to it). Floating control is available in five programs. Five programs can control heat output pro-rata to that in a remote zone, but only one of these (HTB-2) offers a thermostat with an accelerator.

3.2 Variation of Temperature Setpoint

This section of the survey deals with controls which alter the temperature setpoint, for example, at different times of day. This is in contrast to the previous section, which dealt with control of heat input, typically in response to changes of room temperature: temperature was the sensed variable in section 3.1, while we are now considering it as the quantity which is controlled.

3.2.1 Range of Options:-

Quantity Varied	Mode of Control	Sensed Variable
4 HTB-2	4 APACHE	5 SIMULA
4 PETER	4 DOE2	4 APACHE
3 TAS	4 ESP	4 ESP
3 THERM	4 TAS	3 CYPROS
2 APACHE	3 CYPROS	3 HVACSIM+
2 CYPROS	3 HVACSIM+	3 TAS
2 DOE2	3 K2	2 DOE2
2 EMGP2	3 SIMULA	2 K2
2 ESP	2 HTB-2	2 RIGEL
2 HVACSIM+	2 THERM	1 BLAST
1 BLAST	1 BLAST	1 EMGP2
1 K2	1 EMGP2	1 HTB-2
1 RIGEL	1 PETER	1 PETER
1 SERI-RES	1 RIGEL	1 SERI-RES
1 SIMULA	1 SERI-RES	1 THERM
1 TRNSYS	1 TRNSYS	1 TRNSYS

3.2.2 Sensed Variables.

Six programs do not offer any ability to reset the setpoint in response to any sensed variables, apart from time. Four allow resetting according to occupancy. The most common meteorological variable offered was external air temperature (eight programs). Four also offered resetting in response to solar radiation and two (ESP and Simula) to wind.

3.2.3 Quantity Varied.

Variation of room air temperature setpoint is offered by virtually all programs, the only exceptions being SERI-RES and RIGEL. SERI-RES uses only environmental temperature, and four other programs offer this as an option. The same four also offer the option of controlling a dry resultant temperature setpoint. Although these two temperatures are not directly measurable and are, in a sense, fictitious, they are the recommended basis for heat loss calculations, and it is surprising that they are not more widely offered by programs which are primarily used by designers (although they are available in other programs as the sensed variables used to control heat input - see section 3.1). One program (HTB-2) allows variation of globe temperature setpoint and two (APACHE and PETER) an arbitrarily defined mixture of room and surface temperature.

Seven programs allow supply air temperature to be varied, which might equally be construed as control of heat input - see section 3.1.

3.2.4 Control Modes

Most programs offered two or three control modes. The basic and almost universal option is timed on/off control (this was not reported to be provided by CYPROS, but this may be an oversight). Seven programs allowed the setpoint value to be varied with time, and seven allowed proportional control (four offered both). Proportional plus integral control is available in three programs and PID in one (CYPROS). Four programs offer floating control - that is, a constant rate of change. The most common grouping of options: timed, multistep, floating, proportional was offered by four programs.

3.3 Control of Surface Temperature

Only four programs were identified which offer control of surface temperature - (Apache, ESP, HTB-2, THERM). All except THERM offers a wide range of options for sensed variables. In TAS (and possibly in some other programs), it is possible to approximate surface temperature control by defining a dummy zone.

3.3.1 Range of Options:-

Quantity Varied	Mode of Control	Sensed Variable
2 APACHE	8 ESP	9 APACHE
1 ESP	4 HTB-2	7 ESP
1 HTB-2	3 APACHE	7 HTB-2
1 THERM	3 THERM	3 THERM

3.3.2 Sensed Variables

At least seven options for the sensed variable were offered by all the programs except THERM, which only offers three. All offer control from room air temperature, and all except THERM mean surface temperature, an arbitrary air/radiant temperature mix, and averaging of more than one sensor. Control from a specified surface temperature is offered by one program (HTB-2).

Additional control from meteorological variables is available for air temperature and solar radiation (Apache, ESP), and wind (ESP).

3.3.3 Quantity Varied

In three of the four programs, the variable temperature is a that of a room surface, such as a floor. One program (THERM) only offers variation of radiator surface temperature, while one (Apache) offers both.

3.3.4 Control Modes

All four programs offer timed control, and each offers a different combination of alternative options, the largest range being provided by ESP (eight options). On/off control is offered by three (APACHE, ESP and HTB-2), in all cases with the possibility of a lag term. Other options, offered by, at most, two programs were:- pro-rata to demand in remote zone (ESP, THERM); equal to some other computed temperature (ESP, THERM); proportional (Apache, ESP); ideal (THERM); floating (ESP); thermostat with accelerator (HTB-2); multistep (FSP). Of course, here and elsewhere in this report, it may be possible for the user to generate unreported control modes within programs which offer the ability of user-definition.

3.4 Control of Room Air Humidity

Only seven programs offered any control of humidity. Of these, TRNSYS only offers idealised control of supply air humidity as standard, but is able to accept a wide range of user-defined procedures. Apache controls moisture content via models of plant action. (Programs which sense room humidity, but do not control it are not considered in this survey.)

3.4.1 Range of Options:-

Quantity Varied	Mode of Control	Sensed Variable
6 TAS	4 APACHE	7 APACHE
5 APACHE	4 ESP	3 TAS
3 ESP	4 TAS	2 DOE2
1 DOE2	3 DOE2	2 K2
1 K2	3 K2	1 ESP
1 OASIS	3 OASIS	1 OASIS
1 TRNSYS	1 TRNSYS	1 TRNSYS

3.4.2 Sensed Variables.

Room relative humidity was sensed by six programs. Only two offered any other option for indoor conditions - Apache offering room dewpoint temperature and DOE2 room moisture content control.

Three programs could sense outdoor relative humidity. The only other outdoor options were outdoor dewpoint (Apache) and outdoor wetbulb (K2).

3.4.3 Quantity Varied

Four programs offer variation of supply air humidity, and five of supply air moisture content. Three offer both options (Apache, ESP, TAS), while two (Apache, TAS) offer control of supply air dewpoint or wetbulb temperature. Four programs allow direct removal or production of moisture in the space.

3.4.4 Control Modes

Timed and on/off (that is, to a limiting value) control options were offered by six programs, with three offering proportional and four floating control. One (K2) offered proportional plus integral action, and two (Oasis and TRNSYS) ideal control.

3.5 Control of Ventilation Rate

The questionnaire did not enquire into modelling methods, and so no distinction is made between, for example, programs which handle ventilation simply as a thermal resistance, and those which model it as a movement of air.

3.5.1 Range of Options:-

Quantity Varied	Mode of Control	Sensed Variable
3 APACHE	3 APACHE	7 APACHE
3 TAS	3 TAS	5 DOE2
2 BLAST	2 DOE2	3 ESP
2 DOE2	2 ESP	3 HVACSIM+
2 ESP	2 HTB-2	3 K2
2 EXCALIBUR	2 PETER	3 TAS
2 HTB-2	2 THERM	2 BLAST
2 SIMULA	1 BLAST	2 SIMULA
1 HVACSIM+	1 EXCALIBUR	2 THERM
1K2	1 K2	1 EXCALIBUR
1 PETER	1 SERI-RES	1 HTB-2
1 SERI-RES	1 SIMULA	1 PETER
1 THERM	1 TRNSYS	1 SERI-RES

Only one program (CYPROS) did not offer some control of ventilation rate.

3.5.2 Sensed Variable.

In addition to time, ten programs sense room air temperature. Two (Apache, SERI-RES) can sense environmental temperature - in the case of SERI-RES, this is the only possibility - and one (Apache) can sense dry resultant temperature. Occupancy can be sensed in two programs (DOE2, Excalibur).

Eight programs can sense external temperature and five internal to external temperature difference. One (ESP) can sense windspeed and three (Apache, DOE2 and TAS) air enthalpy.

3.5.3 Quantity Varied

Fresh air ventilation rate was variable in all programs, with around half of them also being able to control air movement from other zones.

3.5.4 Control Modes

Apart from two (K2, SERI-RES), all the programs offered time control of ventilation. Seven allowed ventilation rates to vary in response to at least one sensed variable. Three (Apache, HVACSIM+, TAS) allowed proportional control, and one (HVACSIM+) proportional plus integral. One (SERI-RES) allows ideal control.

3.6 Control of Artificial Lighting

Ten programs provide some means of controlling artificial lighting, but the primary aim seems to be to provide a realistic schedule of incidental heat gains for thermal calculations.

3.6.1 Programs offering the widest range of standard options:-

Quantity Varied	Mode of Control	Sensed Variable
1 APACHE	5 DOE2	3 DOE2
1 BLAST	4 K2	2 APACHE
1 DOE2	4 SERI-RES	2 ESP
1 ESP	3 APACHE	2 EXCALIBUR
1 EXCALIBUR	3 ESP	2 HTB-2
1 HTB-2	3 HTB-2	2 THERM
1 K2	2 BLAST	1 BLAST
1 SERI-RES	2 EXCALIBUR	1 K2
1 THERM	2 THERM	1 SERI-RES
1 TRNSYS	1 TRNSYS	1 TRNSYS

3.6.2 Sensed Variables

Five programs can sense external illumination and two (Apache, HTB-2) can use horizontal solar radiation, while Apache can sense radiation on any surface. Five use occupancy as a sensed variable, while two (DOE2 and SERI-RES) sense internal illuminance.

3.6.3 Quantity Varied

All the programs vary the energy input from lighting, either directly (six models) or via the illumination level (four models).

3.6.4 Control Modes

All the programs provide timed on/off control, and six allow several levels to be scheduled. Four offer proportional control, but only two allow lighting to be related to the times of dawn and dusk (DOE2 and THERM).

3.7 Control of Daylight

3.7.1 Range of Options:-

Quantity Varied	Mode of Control	Sensed Variable
1 DOE2	2 DOE2	3 DOE2
1 ESP	2 SERI-RES	2 ESP
1 K2	1 ESP	2 K2
1 SERI-RES	1 K2	1 SERI-RES

Only four programs (ESP, DOE2, K2, SERI-RES) offered daylight control.

3.7.2 Sensed Variables

Three programs (DOE2, ESP, K2) sensed internal daylight level. Two (DOE2 and ESP) sensed occupancy, one (K2) sun angle and one (SERI-RES) transmitted direct insolation. DOE2 can also sense glare level and external environmental variables.

3.7.3 Quantity Varied

In every case this was window transmission.

3.7.4 Control Modes

All four programs provide timed control, with DOE2 offering multistaged control. SERI-RES links daylight control to solar gain control using automatic blinds.

3.8. Control of Solar Gain

In practice, this means variation of the solar radiation transmission characteristics of window systems. This may be accompanied by variation of other properties (eg U-values): these are addressed in section 3.9.

3.8.1 Range of Options:-

Quantity Varied	Mode of Control	Sensed Variable
1 APACHE	3 APACHE	4 DOE2
1 BLAST	3 DOE2	3 APACHE
1 DOE2	1 BLAST	2 ESP
1 ESP	1 ESP	1 BLAST
1 HTB-2	1 HTB-2	1 HTB-2
1 K2	1 K2	1 K2
1 SERI-RES	1 SERI-RES	1 SERI-RES
1 SIMULA	1 SIMULA	1 SIMULA
1 TAS	1 TAS	1 TAS
1 THERM	1 THERM	1 THERM

Ten programs provided some control of solar gain, in most cases with few options, and little sophistication.

3.8.2 Sensed Variables

The most common sensed variable, even though it appeared in only five programs, was solar radiation level. Two programs (DOE2 and ESP) offered the option of room air temperature sensing, two (Apache and DOE2) occupancy and two (DOE2 and SERI-RES) transmitted direct solar radiation. DOE2 also allows solar gain control to be linked to external temperature and windspeed, and Apache links it to sun angle.

3.8.3 Quantity Varied

In every case, window solar transmission was variable.

3.8.4 Control Modes

All except one (SERI-RES) provided timed control. In SERI-RES control is ideal. Two programs (Apache and DOE2) also provided the option of proportional control. DOE2 also offers multistage control.

3.9 Control of Fabric Properties

The previous section reported on control of solar gain which, in practice, means variation of the short-wave radiation transmission properties of windows and blinds. This section deals with variation of other properties of the building fabric, including the thermal properties of window systems which were not covered in 3.8.

3.9.1 Range of Options:-

Quantity Varied	Mode of Control	Sensed Variable
2 BLAST	3 DOE2	4 DOE2
2 DOE2	2 APACHE	3 ESP
2 ESP	1 BLAST	2 APACHE
2 TAS	1 ESP	2 THERM
1 APACHE	1 K2	1 BLAST
1 K2	1 TAS	1 K2
1 THERM	1 THERM	1 TAS

Seven programs offered this type of control, of which the most obvious example is the use of curtains or shutters at night, or blinds during the day.

3.9.2 Sensed Variables

Five programs could sense either external illumination (DOE2, K2, THERM) or solar radiation (Apache, DOE2, ESP). In addition three could respond to occupancy (Apache, DOE2, THERM), two to external air temperature (DOE2 and ESP) and one to room air temperature (ESP). DOE2 can also sense other external environmental variables.

3.9.3 Quantity Varied

All seven programs could vary the U-value or the thermophysical properties of windows, and four could also change the properties of walls or roofs.

3.9.4 Control Modes

All seven programs provided timed control. Two (Apache and DOE2) could provide multistage control, and one (DOE2) proportional control.

4. AVAILABILITY OF PROGRAMS AND HARDWARE REQUIREMENTS

Table 3 summarises the conditions under which the programs are available, and outlines the hardware requirements reported in the questionnaire. More information is contained in Appendix III. Readers are reminded that the support facilities may be related to the costs of the software, and that there may be restrictions on the use of programs provided at non-commercial costs.

Table 3. HARDWARE REQUIREMENTS AND AVAILABILITY

Program	Version available for		Availability
	PC	Workstation/Mainframe	
APACHE	*	*	Commercially
BLAST	*	*	Distribution Cost
CYPROS	*	*	Commercially
DOE-2	*	*	Commercially (PC version) Distribution Cost (Mainframe)
EMGP-2	*	-	Uncertain
ESP	-	*	Commercially (Distribution Cost for some R&D uses)
EXCALIBUR	*	-	Commercially
HTB-2	-	*	Distribution Cost
HVACSIM+	*	*	Distribution Cost
K2	*	-	Commercially
OASIS	*	-	Commercially
PETER	-	*	Limited Basis
RIGEL	*	*	Limited Basis
SERI-RES	*	*	Distribution Cost (PC version Commercially)
SIMULA	*	-	Commercially
TAS	-	*	Commercially
THERM	*	*	Limited Basis
TRNSYS	*	*	Distribution Cost

5. AVAILABILITY OF ALGORITHMS AND TEST RESULTS

Most respondents said that the algorithms on which the programs are based could be inspected in the program manual. It is not within the scope of this report to judge how complete or accessible this information is. Only rarely had the algorithms been published: occasionally they could only be inspected at the author's office.

Most programs had been tested by code checking and around half claimed empirical validation, though the extent and rigor of this is unknown. In almost every case it is necessary to contact the program author to inspect test results.

6. DISCUSSION AND CONCLUSIONS

It is clear from this survey that there is in no sense a "best buy" program for controls modelling: each program offers a unique combination of options, and each will be more appropriate to some problems and less to others.

In any case, the range of controls options is very unlikely to be the only or even the dominant issue in choosing a program. Ease of use, familiarity, and all the issues raised in BEPAC Technical Note 89/2, "The Documentation and Evaluation of Building Simulation Models" are bound to be important (and are not addressed here).

This note aims to help the potential user construct a short-list of possible programs, based on this single criterion of the range of controls options offered. It should go without saying that he or she should carefully examine the programs being considered, and establish that they can meet their needs.

A few generalisations are possible; there are broadly four types of program:-

1. Very flexible programs which allow the user to define his own control systems (TRNSYS, HVACSIM+). These demand expertise on the part of the user, and time for development and testing. Users of these programs are likely to be research-based. They tend not to offer a very wide range of standard options. A number of other programs allow the user to insert his own control options, though this may not be easy. These are identified in Table 2.

2. Commercially available programs directed at designers, offering a relatively wide range of control options (APACHE, DOE-2, ESP, TAS)

3. Programs offering an intermediate level of options (BLAST, HTB-2, K2, SERI-RES, THERM). This is a somewhat heterogeneous group, with some programs being directed at designers and others at researchers, some sold commercially and others available at distribution cost.

4. Programs a with relatively limited number of control options (CYPROS, EMGP2, EXCALIBUR, OASIS, PETER, RIGEL, SIMULA). On the whole these are intended for a relatively limited range of applications, and only offer the control options which are relevant to them. Within their chosen ranges, they sometimes offer options which are not available elsewhere.

The rather wide variations between widely-used programs suggests that some of the options which are offered may be redundant, though it is not easy to see which these are - certainly there is no concensus amongst program authors. The rather limited number of options which are present in more than half the programs is presumably adequate for many users.

Some options which would seem, at first sight, to be needed fairly often were actually rather rare: control of one zone pro rata to another; daylighting related to dawn and dusk; solar resetting of heat input; detailed thermostat modelling; temperature control of blinds and curtains.

The questionnaire did not directly address the question of the range of applications to which each program is appropriate, nor did it probe at all deeply into the related issues of validation and testing. The information which was collected on these latter issues is not altogether reassuring, in that it suggests that, generally, the user has to take the performance of programs on trust. This is not to imply that program authors are untrustworthy, but rather to highlight the danger that users may unwittingly stray into inappropriate applications of programs, unless they are aware of their limitations. It seems that the user generally needs to invest some appreciable effort in order to see test results and, one suspects, even more to assess their relevance to particular applications.

APPENDIX I: The Questionnaire

BEPAC CONTROLS MODELLING SURVEY

NAME OF MODEL:
(and version number if appropriate)

NAME AND ADDRESS OF PERSON COMPLETING QUESTIONNAIRE:

WHAT IS THE EXTENT OF YOUR EXPERIENCE OF THE MODEL?
(For example are you its author, an experienced user, ----?)

AVAILABILITY: is the model available to other users
on a commercial basis?
at distribution cost only?
on a limited basis (eg authors premises, or only for academic use ---)?

WHAT HARDWARE HAS IT BEEN IMPLEMENTED ON?

INTRODUCTION

This questionnaire has a "layered" format:

* Section 1 - Controlled Variables, asks whether particular environmental variables can be controlled in a particular model - if the response is "yes", then further information is sought in Section 2. If the response is "no", no further action is needed with respect to that type of control.

* Sections 1 and 2 are in the form of checklists and so should be quick to answer.

* Section 3 asks for outline information on testing and algorithms, but only for those controls which have been identified in the earlier sections as being modelled.

Please continue on extra sheets if there is insufficient space. Please add explanatory comments if you feel they will help.

The questionnaire concentrates on controls which directly affect the indoor environment and excludes controls which are essentially internal to the HVAC system.

SECTION 1 - CONTROLLED VARIABLES

A word of explanation is needed before you fill in this section.

A control system, whether real or simulated, controls some quantities (eg heat input) on the basis of measurements made of others (eg room temperature). This questionnaire is structured so that Section 1 refers to quantities which are controlled whilst Section 2 deals, in several sub-sections, with the variables which are sensed in order for the model to exercise its control function.

So, question 1 asks whether it is possible to control the heat input to a room (or zone). If the answer is yes (as seems inevitable) section 2.1 will then ask, inter alia, about the temperature sensing for this control. Question 2 on this page refers to controls which act to reset the setpoint temperature.

****

Is it possible in this model to control the following quantities? Please circle either YES or NO. Please answer the questions in Section 2 for each quantity for which you have answered YES.

1.Heat Input to Room NO YES - please fill in section 2.1
(from HVAC system - includes cooling)

2.Setpoint Temperature NO YES - please fill in section 2.2
(any definition)

3.Surface Temperature NO YES - please fill in section 2.3
(including radiator)

4.Room Air Humidity NO YES - please fill in section 2.4
(dewpoint etc.)

5.Ventilation Rate NO YES - please fill in section 2.5

6.Lighting Level NO YES - please fill in section 2.6
(artificial)

7.Daylighting Level NO YES - please fill in section 2.7

8.Solar Gain NO YES - please fill in section 2.8

9.Fabric Properties NO YES - please fill in section 2.9
(eg blinds)

10.Is the model structured to allow the user to define his own control modules? NO YES - if appropriate, please append details in later sections

SECTION 2.1 - INFORMATION ON HEAT INPUT CONTROLS (includes cooling)
Please tick those items which apply to the model (if more than one option is possible please indicate all options)

1. What is the quantity which is controlled?

1.1 Convective heat input
1.2 Non-directional long-wave radiant heat input
1.3 Directional short-wave radiation
1.4 Heat input to environmental temperature node
1.5 Heat input to storage (eg electric storage heater)
1.6 Other - please specify

2. What modes of control are possible?

2.1 Ideal: input matched exactly to load
2.2 Timed
2.3 Optimiser: fixed parameters
2.4 Optimiser: adaptive
2.5 On/Off
2.6 On/Off with lag
2.7 On/Off with anticipation (eg thermostat with accelerator)
2.8 Multistep
2.9 Floating (ie constant rate of change)
2.10 Proportional
2.11 Proportional + integral
2.12 Proportional + differential
2.13 Proportional + integral + differential
2.14 Pro-rata to demand in a remote zone
2.15 Other: please specify

3. What sensed variables may be used?

3.1 Room air temperature
3.2 Mean surface temperature
3.3 Globe temperature
3.4 Environmental temperature
3.5 Dry resultant temperature
3.6 Arbitrary air/radiant temperature mix
3.7 Averaging of more than one sensor
3.8 External air temperature (eg open loop compensator,frost)
3.9 External air temperature and solar radiation (open loop)
3.10 External air temperature and wind (open loop)
3.11 Room relative humidity
3.12 Other: please specify

4. Other Questions

4.1 Are there modelling limitations on the combinations of sensed variable/control mode/controlled quantity?
Please summarise either the restrictions or the permitted combinations.

PLEASE REMEMBER TO FILL IN SECTION 3

SECTION 2.2 - INFORMATION ON TEMPERATURE SETPOINT CONTROL
Please tick those items which apply to the model (if more than one option is possible please indicate all options)

1. What is the quantity which is controlled?

1.1 Room air temperature
1.2 Globe temperature
1.3 Dry resultant temperature
1.4 Environmental temperature
1.5 Supply air temperature
1.6 Other: please specify

2. What modes of control are possible?

2.1 Timed
2.2 Multistep
2.3 Floating
2.4 Proportional
2.5 Proportional + integral
2.6 Proportional + integral + derivative
2.7 Other: please specify

3. What sensed variables may be used?

3.1 External air temperature (ie resetting compensator)
3.2 External air temperature and solar radiation
3.3 External air temperature and wind
3.4 Occupancy
3.5 Other: please specify

4. Other questions

4.1 Are there modelling limitations on the combinations of sensed variable/control mode/controlled quantity?
Please summarise either the restrictions or the permitted combinations.

PLEASE REMEMBER TO FILL IN SECTION 3

SECTION 2.3 - INFORMATION ON SURFACE TEMPERATURE CONTROL
Please tick those items which apply to the model (if more than one option is possible please indicate all options)

1. What is the quantity which is controlled?

1.1 Room surface temperature (eg floor temperature)
1.2 Radiator surface temperature
1.3 Other; please specify

2. What modes of control are possible?

2.1 Timed
2.2 Equal to some other computed temperature
2.3 Optimiser: fixed parameters
2.4 Optimiser: adaptive
2.5 On/Off
2.6 On/Off with lag
2.7 On/Off with anticipation (eg thermostat with accelerator)
2.8 Multistep
2.9 Floating (ie constant rate of change)
2.10 Proportional
2.11 Proportional + integral
2.12 Proportional + differential
2.13 Proportional + integral + differential
2.14 Pro-rata to demand in a remote zone
2.15 Other: please specify

3. What sensed variables may be used?

3.1 Room air temperature
3.2 Mean surface temperature
3.3 Globe temperature
3.4 Environmental temperature
3.5 Dry resultant temperature
3.6 Arbitrary air/radiant temperature mix
3.7 Averaging of more than one sensor
3.8 External air temperature (eg open loop compensator,frost)
3.9 External air temperature and solar radiation (open loop)
3.10 External air temperature and wind (open loop)
3.11 Other: please specify

4. Other questions

4.1 Are there modelling limitations on the combinations of sensed variable/control mode/controlled quantity?
Please summarise either the restrictions or the permitted combinations.

PLEASE REMEMBER TO FILL IN SECTION 3

SECTION 2.4 - INFORMATION ON ROOM AIR HUMIDITY CONTROL
Please tick those items which apply to the model (if more than one option is possible please indicate all options)

1. What is the quantity which is controlled?

1.1 Supply air relative humidity
1.2 Supply air moisture content
1.3 Supply air dewpoint
1.4 Supply air wetbulb temperature
1.5 Direct moisture production/removal from space
1.6 Other: please specify

2. What modes of control are possible?

2.1 Timed
2.2 On/Off (ie limit)
2.3 Proportional
2.4 Proportional + integral
2.5 Floating
2.6 Other: please specify

3. What sensed variables may be used?

3.1 Room relative humidity
3.2 Room moisture content
3.3 Room dewpoint
3.4 Room wetbulb
3.5 Outdoor relative humidity
3.6 Outdoor moisture content
3.7 Outdoor dewpoint
3.8 Outdoor wetbulb
3.9 Other: please specify

4. Other questions

4.1 Are there modelling limitations on the combinations of sensed variable/control mode/controlled quantity?
Please summarise either the restrictions or the permitted combinations.

PLEASE REMEMBER TO FILL IN SECTION 3

SECTION 2.5 - INFORMATION ON VENTILATION RATE CONTROL
Please tick those items which apply to the model (if more than one option is possible please indicate all options)

1. What is the quantity which is controlled?

1.1 Ventilation from outside (including mechanical)
1.2 Air movement from other zones
1.3 Other: please specify

2. What modes of control are possible?

2.1 Timed
2.2 Multistep (eg increased ventilation when temperature rises).
2.3 Other: please specify

3. What sensed variables may be used?

3.1 Room air temperature
3.2 Room dry resultant temperature
3.3 Room environmental temperature
3.4 Occupancy
3.5 Room carbon dioxide level
3.6 External temperature
3.7 Inside-outside temperature difference
3.8 Other: please specify

4. Other questions

4.1 Are there modelling limitations on the combinations of sensed variable/control mode/controlled quantity?
Please summarise either the restrictions or the permitted combinations.

PLEASE REMEMBER TO FILL IN SECTION 3

SECTION 2.6 - INFORMATION ON ARTIFICIAL LIGHTING CONTROL
Please tick those items which apply to the model (if more than one option is possible please indicate all options)

1. What is the quantity which is controlled?

1.1 Illumination level
1.2 Other: please specify

2. What modes of control are possible?

2.1 Timed
2.2 On/off
2.3 Multistage
2.4 Proportional
2.5 Dawn/dusk
2.6 Other: please specify

3. What sensed variables may be used?

3.1 External illumination
3.2 Occupancy
3.3 Other; please specify

4. Other questions

4.1 Are there modelling limitations on the combinations of sensed variable/control mode/controlled quantity?
Please summarise either the restrictions or the permitted combinations.

PLEASE REMEMBER TO FILL IN SECTION 3

SECTION 2.7 - INFORMATION ON DAYLIGHT CONTROL
Please tick those items which apply to the model (if more than one option is possible please indicate all options)

1. What is the quantity which is controlled?

1.1 Window transmission
1.2 Other: please specify

2. What modes of control are possible?

2.1 Timed
2.2 Multistage
2.3 Other: please specify

3. What sensed variables may be used?

3.1 Internal daylight level
3.2 Occupancy
3.3 Other: please specify

4. Other questions

4.1 Are there modelling limitations on the combinations of sensed variable/control mode/controlled quantity?
Please summarise either the restrictions or the permitted combinations.

PLEASE REMEMBER TO FILL IN SECTION 3

SECTION 2.8 - INFORMATION ON SOLAR GAIN CONTROL
Please tick those items which apply to the model (if more than one option is possible please indicate all options)

1. What is the quantity which is controlled?

1.1 Window solar transmission
1.2 Other: please specify

2. What modes of control are possible?

2.1 Timed
2.2 Multistage
2.3 Proportional
2.4 Other: please specify

3. What sensed variables may be used?

3.1 Room air temperature
3.2 Room dry resultant temperature
3.3 Room globe temperature
3.4 Room environmental temperature
3.5 Occupancy
3.6 Solar radiation level
3.7 Wind speed
3.8 Other: please specify

4. Other questions

4.1 Are there modelling limitations on the combinations of sensed variable/control mode/controlled quantity?
Please summarise either the restrictions or the permitted combinations.

PLEASE REMEMBER TO FILL IN SECTION 3

SECTION 2.9 - INFORMATION ON FABRIC PROPERTY CONTROL
(eg blinds, shutters)
Please tick those items which apply to the model (if more than one option is possible please indicate all options)

1. What is the quantity which is controlled?

1.1 Window U-value
1.2 Wall or Roof U-value
1.3 Other: please specify

2. What modes of control are possible?

2.1 Timed
2.2 Multistage
2.3 Proportional
2.4 Other: please specify

3. What sensed variables may be used?

3.1 External illumination
3.2 Occupancy
3.3 Room air temperature
3.4 Room dry resultant temperature
3.5 Room globe temperature
3.6 Room environmental temperature
3.7 External air temperature
3.8 Other: please specify

4. Other questions

4.1 Are there modelling limitations on the combinations of sensed variable/control mode/controlled quantity?
Please summarise either the restrictions or the permitted combinations.

PLEASE REMEMBER TO FILL IN SECTION 3

SECTION 3: TESTING AND ALGORITHMS

Please fill in as many copies of this as are necessary to cover all the controls which are modelled.

1. CONTROL TYPES COVERED BY THIS SHEET:

2. Where can the algorithms for the control models identified in sections 1 and 2 be inspected?
(eg published paper, program manual, authors office)

2. Please outline the tests which have been carried out on these control models.
(eg empirical validation in test rooms, code checking)

3. Where can the test results be inspected?

APPENDIX II: Tables of Responses

In this appendix, the responses to each section of the questionnaire are summarised in tables: one for each section. As space precludes the repitition of the questions themselves, these are referred to by their numbers. Thus the column headed 1.4 in the table for "Section 2.1 - Heat Input" relates to question 1.4 in that section of the questionnaire (can "Heat input to environmental temperature node" be controlled?). The questionnaire forms appendix I of this note.

KEY TO ENTRIES IN TABLES:
* yes
(*) yes with limitations
$ yes but see comments at end of section
- no
(+) under development;

SECTION 1 - SCOPE: (See also Table 2 of the main text)

Program	1 heat	2 setpt	3 surf	4 rh	5 vent	6 artlgt	7 dayl	8 solar	9 fabrc
APACHE	*	*	*	*	*	(*)	-	*	*
CYPROS	-	*	-	-	-	-	-	-	-
ESP	*	*	*	*	*	*	*	*	*
EXCALIBUR	*	-	-	-	*	*	-	-	-
HTB-2	*	*	*	-	*	*	-	*	-
HVACSIM+	*	*	-	*	*	(-)	(-)	(-)	(-)
K2	*	*	-	*	*	*	*	*	*
OASIS	*	-	-	*	-	-	-	-	-
PETER	*	*	-	-	*	-	-	-	-
RIGEL	*	*	-	-	-	-	-	-	-
SERI-RES	*	*	-	-	*	*	*	*	-
SIMULA	*	*	-	-	*	-	-	*	-
TAS	*	*	(*)	*	*	-	-	*	*
TRNSYS	-	*	-	*	*	*	-	-	-
THERM	*	*	*	-	*	*	-	*	*

Comments:

Section Program

6,7,8,9 HVACSIM+ Simple component models required

ESP Users with source code may define own modules

K2 User may define own control modules

RIGEL User may define own control modules

SERI-RES User may define own models via "user port" though this is not easy

TAS User may define own control modules

TRNSYS User may write own control modules in FORTRAN

SECTION 2.1 - HEAT INPUT

1. Quantity Controlled

Program	1.1	1.2	1.3	1.4	1.5	1.6
APACHE	*	*	-	*	*	$
BLAST	*	*	*	-	-	-
DOE2	*	-	*	-	*	-
EMGP2	*	-	-	-	*	-
ESP	*	*	*	-	*	-
EXCALIBUR	-	-	-	*	-	-
HTB-2	*	-	*	-	-	$
HVACSIM+	*	-	-	-	-	-
K2	*	*	-	-	-	-
OASIS	*	-	-	-	-	-
PETER	$	$	-	-	$	-
RIGEL	*	*	-	-	-	-
SERI-RES	-	-	-	*	-	-
SIMULA	*	-	-	-	-	-
TAS	*	*	-	*	-	$
THERM	*	-	-	-	-	$

2. Modes of Control

Program	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	2.14	2.15
APACHE	-	*	*	-	*	*	-	*	-	*	-	*	-
BLAST	*	-	-	-	-	-	-	-	-	-	-	-	-
DOE2	*	*	*	*	*	-	-	*	*	*	-	*	-
EMGP2	*	*	-	-	*	*	-	-	*	*	-	-	-
ESP	*	*	*	*	*	*	-	*	*	*	-	*	-
EXCALIBUR	*	*	-	*	-	-	-	-	-	-	-	-	-
HTB-2	$	*	-	-	$	*	*	-	-	$	-	*	-
HVACSIM+	-	*	-	-	*	-	-	-	-	*	*	-	-
K2	*	*	-	-	*	-	-	*	-	-	*	-	-
OASIS	*	*	-	-	*	-	-	-	-	-	-	-	-
PETER	*	*	-	-	*	-	-	-	*	*	*	-	-
RIGEL	*	*	-	-	*	*	*	-	-	*	-	-	(+)
SERI-RES	*	*	-	-	-	-	-	-	-	-	-	-	-
SIMULA	*	-	-	-	-	-	-	-	-	-	-	-	-
TAS	*	*	*	-	$	-	-	*	*	*	-	*	-
THERM	*	*	-	-	-	-	-	-	-	-	-	*	-

Note: no program offered options 2.12 or 2.13

3. Sensed variables

Program	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	3.10	3.11	3.12
APACHE	*	*	*	*	*	*	*	*	*	-	*	-
BLAST	*	-	-	-	-	-	-	-	-	-	-	-
DOE2	*	-	-	-	-	-	-	*	-	-	*	-
EMGP2	*	-	-	*	-	-	-	-	-	-	-	-
ESP	*	*	-	-	-	*	$	*	*	*	*	-
EXCALIBUR	*	-	-	-	-	-	-	-	-	-	-	-
HTB-2	*	*	*	*	-	*	*	*	-	-	-	$
HVACSIM+	*	-	-	-	-	-	-	*	-	-	-	-
K2	-	-	-	-	-	*	*	-	-	-	*	-
OASIS	*	-	-	-	-	-	-	-	-	-	-	-
PETER	*	*	-	-	-	-	-	(+)	-	-	-	*
RIGEL	*	-	-	-	-	*	-	*	-	-	-	-
SERI-RES	-	-	-	*	-	-	-	-	-	-	-	-
SIMULA	*	-	-	-	-	-	-	-	*	*	-	-
TAS	*	-	-	-	-	-	-	*	-	-	*	$
THERM	*	-	-	*	*	-	-	-	-	-	-	-

4. Comments

Question	Program	
1.1	PETER	1.1 and 1.2 simultaneously in fixed proportion
1.5	PETER	Input to storage controlled proportionately to time-averaged external temperature.
1.6	APACHE	Any radiant/convective mix
1.6	HTB-2	Directional and non-directional shortwave radiation. Heat input direct to structure.
1.6	TAS	Specified convective/radiative mix. Supply air temperature/volume
1.6	THERM	Convective plus longwave to represent radiator.
2.1	HTB-2	Convective heating only
2.1 2.2, 2.5	OASIS	Only one mode per zone. May have max and min setpoints.
2.5 2.10	APACHE	User may use Boolean logic to create any combination of on/off and proportional control
2.5	TAS	On/off control only with temperature sensor in same zone
2.15	RIGEL	Specific control systems under development
3.7	ESP	Averaging over more than one sensor
3.12	HTB-2	Specified surface temperature. Equivalent radiant temperature at surface.
3.12	TAS	Any air temperature or RH in building or air conditioning system.

SECTION 2.2 - TEMPERATURE SETPOINT

1. Quantity Controlled

Program	1.1	1.2	1.3	1.4	1.5	1.6
APACHE	-	-	-	-	*	*
BLAST	*	-	-	-	-	-
CYPROS	*	-	-	-	*	-
DOE2	*	-	-	-	*	-
EMGP2	*	-	-	-	*	-
ESP	*	-	-	-	*	-
HTB-2	*	*	*	*	-	-
HVACSIM+	*	-	-	-	*	-
K2	*	-	-	-	-	-
PETER	*	-	*	*	-	$
RIGEL	-	-	-	-	-	$
SERI-RES	-	-	-	*	-	-
SIMULA	*	-	-	-	-	-
TAS	*	-	-	-	*	$
THERM	*	-	*	*	-	-
TRNSYS	*	-	-	-	-	-

2. Modes of Control

Program	2.1	2.2	2.3	2.4	2.5	2.6	2.7
APACHE	*	*	*	*	-	-	-
BLAST	-	-	-	-	-	-	$
CYPROS	-	-	-	*	*	*	-
DOE2	*	$	*	$	-	-	-
EMGP2	*	-	-	-	-	-	-
ESP	*	*	*	*	-	-	-
HTB-2	*	-	-	-	-	-	$
HVACSIM+	*	-	-	*	*	-	-
K2	*	*	-	-	*	-	-
PETER	*	-	-	-	-	-	-
RIGEL	-	-	-	*	-	-	-
SERI-RES	*	-	-	-	-	-	-
SIMULA	*	*	*	-	-	-	-
TAS	*	*	*	*	-	-	-
THERM	*	*	-	-	-	-	-
TRNSYS	-	-	-	-	-	-	$

3. Sensed variables

Program	3.1	3.2	3.3	3.4	3.5
APACHE	*	*	-	*	-
BLAST	-	-	-	-	-
CYPROS	-	*	-	*	-
DOE2	*	-	-	-	-
EMGP2	-	-	-	-	-
ESP	*	*	*	-	-
HTB-2	-	-	-	-	-
HVACSIM+	*	-	-	*	-
K2	*	-	-	-	-
PETER	-	-	-	-	-
RIGEL	*	-	-	-	-
SERI-RES	-	-	-	-	-
SIMULA	*	*	*	*	-
TAS	*	-	-	-	$
THERM	-	-	-	-	-
TRNSYS	-	-	-	-	-

4. Comments

Question	Program	
1.6	PETER	Arbitrary mixture of room air and mean surface temperature.
1.6	RIGEL	Boiler water outlet temperature
1.6	TAS	Any temperature or RH in building or air conditioning system
2.2	DOE2	PTAC only
2.4	APACHE	User may use Boolean logic to combine on/off and proportional
2.7	BLAST	Ideal control
2.7	HTB-2	Intervention through external schedule.
2.7	TRNSYS	Ideal
3.5	TAS	Any temperature or RH in building or air conditioning system
	CYPROS	Only one sensed variable and one control mode at the same time

SECTION 2.3 - SURFACE TEMPERATURE

1. Quantity Controlled

Program	1.1	1.2	1.3
APACHE	$	*	-
ESP	*	-	-
HTB-2	*	-	-
TAS	-	-	$
THERM	-	*	-

2. Modes of Control

Program	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.14	2.15
APACHE	*	-	-	-	$	-	-	-	-	$	-	-
ESP	*	*	-	-	*	*	-	*	*	*	*	-
HTB-2	*	-	-	-	*	*	*	-	-	-	-	-
TAS	*	-	-	-	-	-	-	-	*	-	-	-
THERM	*	-	-	-	-	-	-	-	-	-	*	$

Note: no program offered options 2.11, 2.12 or 2.13

3. Sensed variables

Program	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	3.10	3.11
APACHE	*	*	*	*	*	*	*	*	*	-	-
ESP	*	*	-	-	-	*	*	*	*	*	-
HTB-2	*	*	*	*	-	*	*	-	-	-	$
TAS	*	-	-	-	-	-	-	-	-	-	-
THERM	*	-	-	*	*	-	-	-	-	-	-

4. Comments

Question	Program	
1.1	APACHE	Timed control only
1.3	TAS	Surface temperature may not be controlled directly, but this may be approximated using a dummy zone
2.5 2.10	APACHE	User may use Boolean logic to combine on/off and proportional
2.15	THERM	Ideal control.
3.11	HTB-2	Specific surface temperature.

SECTION 2.4 - ROOM AIR HUMIDITY

1. Quantity Controlled

Program	1.1	1.2	1.3	1.4	1.5	1.6
APACHE	*	*	*	*	*	$
DOE2	-	*	-	-	-	-
ESP	*	*	-	-	*	-
K2	-	*	-	-	-	-
OASIS	-	-	-	-	*	-
TAS	*	*	*	*	*	$
THERM	-	-	-	-	-	-
TRNSYS	*	-	-	-	-	-

2. Modes of Control

Program	2.1	2.2	2.3	2.4	2.5	2.6
APACHE	*	$	$	-	*	-
DOE2	*	*	-	-	*	-
ESP	*	*	*	-	*	-
K2	*	*	-	*	-	-
OASIS	*	*	-	-	-	$
TAS	*	*	*	-	*	-
THERM	-	-	-	-	-	-
TRNSYS	-	-	-	-	-	$

3. Sensed variables

Program	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9
APACHE	*	-	*	*	*	-	*	*	$
DOE2	-	*	-	-	-	-	-	-	$
ESP	*	-	-	-	-	-	-	-	-
K2	*	-	-	-	-	-	-	*	-
OASIS	*	-	-	-	-	-	-	-	-
TAS	*	-	-	-	*	-	-	-	$
THERM	*	*	*	*	*	*	*	-	-
TRNSYS	-	-	-	-	-	-	-	-	-

4. Comments

Question Program

-	THERM	Moisture content computed but not controlled.
1.6	APACHE	Controlled via model of plant action
1.6	TAS	Any air temperature or RH in building or air conditioning system
2.2 2.3	APACHE	User may use Boolean logic to combine on/off and proportional
2.6	OASIS	Ideal control of r.h. May have max and min setpoint.
2.6	TRNSYS	Idealised
3.6	DOE2	Weighted average of all spaces
3.9	APACHE	Enthalpy
3.9	TAS	Any air temperature or RH in building or air conditioning system

SECTION 2.5 - VENTILATION RATE

1. Quantity Controlled

Program	1.1	1.2	1.3
APACHE	*	*	$
BLAST	*	*	-
DOE2	*	$	-
ESP	*	*	-
EXCALIBUR	*	$	-
HTB-2	*	*	-
HVACSIM+	*	-	-
K2	*	-	-
PETER	*	-	-
SERI-RES	*	-	-
SIMULA	*	*	-
TAS	*	*	$
THERM	*	(*)	-
TRNSYS	*	-	-

2. Modes of Control

Program	2.1	2.2	2.3
APACHE	*	*	$
BLAST	-	*	-
DOE2	*	*	-
ESP	*	*	-
EXCALIBUR	$	-	-
HTB-2	*	-	$
HVACSIM+	*	-	$
K2	-	?	-
PETER	*	*	-
SERI-RES	-	-	$
SIMULA	*	-	-
TAS	*	*	$
THERM	*	-	(*)
TRNSYS	*	-	-

3. Sensed variables

Program	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8
APACHE	*	*	*	*	-	*	*	$
BLAST	*	-	-	-	-	*	-	-
DOE2	*	-	-	*	-	*	*	$
ESP	*	-	-	-	-	*	-	$
EXCALIBUR	-	-	-	*	-	-	-	-
HTB-2	*	-	-	-	-	-	-	-
HVACSIM+	*	-	-	-	-	*	*	-
K2	*	-	-	-	-	*	*	-
PETER	-	-	-	-	-	-	-	-
SERI-RES	-	-	*	-	-	-	-	-
SIMULA	*	-	-	-	-	*	-	-
TAS	*	-	-	-	-	*	-	$
THERM	-	-	-	-	-	-	(*)	(*)
TRNSYS	*	-	-	-	-	-	-	-

4. Comments

Question	Program	
1.2	DOE2	From sunspaces only
1.2	EXCALIBUR	Values set up initially
1.3	APACHE	From defined temperature profile
1.3	TAS	Air flow from air conditionong system
2.1	EXCALIBUR	Day/night rates
2.3	APACHE	Proportional
2.3	HTB-2	Control through external schedule.
2.3	HVACSIM+	Proportional and proportional plus integral modes possible
2.3	SERI-RES	Ideal, subject to finite air change rate
2.3	TAS	Proportional
3.8	APACHE	Enthalpy difference
3.8	DOE2	Inside - outside enthalpy difference
3.8	ESP	Wind velocity
3.8	TAS	Enthalpy (only of air leaving enthalpy optimiser). Any air temperature or RH in building or air conditioning system.
-	THERM	Link to wind and temperature dependent ventilation model, experimentally only.

SECTION 2.6 - ARTIFICIAL LIGHTING

1. Quantity Controlled

Program	1.1	1.2
APACHE	-	$
BLAST	-	$
DOE2	*	-
ESP	*	-
EXCALIBUR	*	-
HTB-2	-	$
K2	*	-
SERI-RES	-	$
THERM	-	$
TRNSYS	-	$

2. Modes of Control

Program	2.1	2.2	2.3	2.4	2.5	2.6
APACHE	*	*	*	-	-	-
BLAST	*	-	-	*	-	-
DOE2	*	*	*	*	*	-
ESP	*	*	*	-	-	-
EXCALIBUR	*	*	-	-	-	-
HTB-2	*	*	*	-	-	-
K2	*	*	*	*	-	-
SERI-RES	*	*	*	$	-	-
THERM	*	-	-	-	*	-
TRNSYS	*	-	-	-	-	-

3. Sensed variables

Program	3.1	3.2	3.3
APACHE	*	*	-
BLAST	-	-	$
DOE2	*	*	*
ESP	*	*	-
EXCALIBUR	*	*	-
HTB-2	*	-	$
K2	*	-	-
SERI-RES	-	-	$
THERM	$	*	-
TRNSYS	-	-	-

4. Comments

Question Program

1.2 APACHE Lighting load

1.2 BLAST Electrical load

1.2 HTB-2 Lighting circuit load (heat gain)

1.2 SERI-RES Luminaire output

1.2 THERM Lighting load computed.

1.2 TRNSYS Energy gain

2.4 SERI-RES Ideal dimming

3.1 THERM Actually dawn/dusk.

3.3 BLAST Interior lighting level

3.3 HTB-2 External global horizontal solar.

3.3 SERI-RES Internal illuminance

- HTB-2 May have many separately controlled circuits within a zone

SECTION 2.7 - DAYLIGHT

1. Quantity Controlled

Program	1.1	1.2
DOE2	*	-
ESP	*	-
K2	*	-
SERI-RES	*	-

2. Modes of Control

Program	2.1	2.2	2.3
DOE2	*	*	-
ESP	*	-	-
K2	*	-	-
SERI-RES	-	-	$

3. Sensed variables

Program	3.1	3.2	3.3
DOE2	*	*	$
ESP	*	*	-
K2	*	-	$
SERI-RES	-	-	$

4. Comments

Question	Program	
2.3	SERI-RES	Linked to solar gain control using automatic blinds
3.3	DOE2	Discomfort glare level, external environmental variables
3.3	K2	Sun angle
3.3	SERI-RES	Transmitted direct insolation

SECTION 2.8 - SOLAR GAIN

1. Quantity Controlled

Program	1.1	1.2
APACHE	*	-
BLAST	*	-
DOE2	*	-
ESP	*	-
HTB-2	*	-
K2	*	-
SERI-RES	$	-
SIMULA	*	-
TAS	*	-
THERM	*	-

2. Modes of Control

Program	2.1	2.2	2.3	2.4
APACHE	*	-	*	$
BLAST	-	-	-	$
DOE2	*	*	*	-
ESP	*	-	-	-
HTB-2	*	-	-	-
K2	*	-	-	-
SERI-RES	-	-	-	$
SIMULA	*	-	-	-
TAS	*	-	-	-
THERM	*	-	-	-

3. Sensed variables

Program	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8
APACHE	-	-	-	-	*	*	-	$
BLAST	-	-	-	-	-	-	-	$
DOE2	-	-	-	-	*	*	*	$
ESP	*	-	-	-	-	*	-	-
HTB-2	-	-	-	-	-	-	-	-
K2	-	-	-	-	-	*	-	-
SERI-RES	-	-	-	-	-	-	-	$
SIMULA	-	-	-	-	-	*	-	-
TAS	-	-	-	-	-	-	-	-
THERM	-	-	-	-	-	-	-	-

4. Comments

Question	Program	
1.1	SERI-RES	Blind
2.4	BLAST	Weather tape input
2.4	SERI-RES	Ideal
3.8	APACHE	Solar angle
3.8	BLAST	Weather tape input
3.8	DOE2	Outside temperature
3.8	SERI-RES	Transmitted direct insolation

SECTION 2.9 - FABRIC PROPERTIES

1. Quantity Controlled

Program	1.1	1.2	1.3
APACHE	*	-	-
BLAST	*	*	-
DOE2	*	*	-
ESP	$	$	-
K2	*	-	-
TAS	*	*	-
THERM	*	-	-

2. Modes of Control

Program	2.1	2.2	2.3	2.4
APACHE	*	*	-	-
BLAST	-	-	-	$
DOE2	*	*	*	-
ESP	*	-	-	-
K2	*	-	-	-
TAS	*	-	-	-
THERM	*	-	-	$

3. Sensed variables

Program	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8
APACHE	-	*	-	-	-	-	-	$
BLAST	-	-	-	-	-	-	-	-
DOE2	*	*	-	-	-	-	*	$
ESP	-	-	*	-	-	-	*	$
K2	*	-	-	-	-	-	-	-
THERM	*	$	-	-	-	-	-	-

4. Comments

Question	Program	
1.1&1.2	ESP	Thermophysical properties varied
2.4	BLAST	Library material specification
2.4&3.2	THERM	Occupancy via schedule.
3.8	APACHE	Solar radiation and wind speed
3.8	DOE2	External environmental variables
3.8	ESP	Incident solar radiation

TESTING AND ALGORITHMS

Program	Algorithm Inspection	Code Checking	Empirical Validation	Test Results Inspection
APACHE	Published papers and author	-	(*)	Author
CYPROS	Published papers		Published papers	
ESP	Author and manual (some)	*	(*)	Author - report on testing of controls modules to be issued to users
EXCALIBUR	Author and published papers	*	(*)	Author
HTB-2	Manual	*	(*)	Published reports
HVACSIM+	Manual	-	-	-
K2	Manual	*	-	Author
OASIS	Manual	*	(*)	Manual
PETER	Author	(*)	-	Author
RIGEL	Thesis and sourcecode	*	(*)	Author
SERI-RES	Manual, source code	*	(*)	-
SIMULA	-	-	-	-
TAS	Manual and author	*	-	Author
THERM	Manual	*	(*)	Author
TRNSYS	Manual	*	-	-

APPENDIX III: PROGRAM AVAILABILITY and QUESTIONNAIRE RESPONDENTS

*APACHE:

Implemented on 386PC, VAX, Prime
Available commercially

Questionnaire completed by program author:-
S Irving,
Facet Ltd.,
Marlborough House,
Upper Marlborough Road,
St. Albans,
Herts. AL1 3UT.

Tel. 0727 50830

*BLAST 3.0:

Implemented on IBM-PC 386,286, Apple Macintosh II, Apollo, Harris, VAX.
Available at distribution cost

Questionnaire completed by experienced user:-
Blast Support Office,
1206 W Green St.,
Urbana,
IL 61801,
USA.

*CYPROS HVAC 1.0:

Implemented on IBM-PC XT, AT and compatibles, VAX-VMS.
Available commercially

Questionnaire completed by program authors:-
V Novakovic,
SINTEF,
7034 Trondheim,
Norway.

S Schonkopf,
CAMO A/S,
Jarleveien 4,
7041 Trondheim,
Norway

*DOE-2.1D:

Implemented on DEC-VAX, IBM mainframe, IBM-PC compatible, Sun-4.
Available commercially (PC version), at distribution cost (mainframe)

Questionnare completed by program co-author:-
F Winkelman,
90-3147,
Lawrence Berkeley Laboratory,
Berkeley,
CA 94720,
USA.

*EMGP2:

Implemented on IBM-PC, AT,XT,PS/2
Availability uncertain

Questionnaire completed by program author:-
W L Dutre,
Mechanical Engineering Institute,
K U Leuven,
Celestijnenlaan, 300A,
B-3030 Heverlee,
Belgium

*ESP 7.2:

Implemented on Sun 3, Sun 4, Mistral Hitech, Silicon Graphics Iris LD,
Acorn R140, VAX VMS, Apollo version 500n.
Available commercially (in some cases at distribution cost for R&D)

Questionnaire completed by program co-author:-
D McLean
Abacus Simulations Ltd.,
1:06 Kelvin Campus,
West of Scotland Science Park,
Maryhill Road,
Glasgow, G20 0SP.

*EXCALIBUR/3

Implemented on IBM-PC compatibles
Available commercially from:-
Amazon Computers Ltd.,
Sunrise Parkway,
Linford Wood,
Milton Keynes, MK14 6LQ.

or on research basis

Questionnaire completed by program author:-
J M Penman
Energy Studies Unit,
The University,
Exeter EX3 4QL

*HTB-2

Implemented on Sun 3,
Available at distribution cost

Questionnaire completed by program author:-
D Alexander,
School of Architecture,
University of Wales College of Cardiff,
PO Box 25,
Cardiff, CF1 3XE.

*HVACSIM+

Implemented on IBM PC, VAX, Perkins-Elmer, Sun ----
Available at distribution cost

Questionnaire completed by experienced user:-
P Haves,
University of Oxford,
Dept of Engineering Science,
Parks Road,
Oxford, OX1 3PJ.

*K2

Implemented on IBM-PC and Compaq
Available commercially

Questionnaire completed by program author:-
A J Baxter,
Hevacomp,
212-218, West Street,
Sheffield, S1 4EU.

*OASIS 1.4

Implemented on IBM PC and compatibles with arithm. co-processor
Available commercially

Questionnaire completed by model author:-
Michel Raoust
Dialogic,
70, Boulevard de Magenta,
75010 Paris,
France.

*PETER

Implemented on mainframe
Available on limited basis

Questionnaire completed by program author:-
P Basnet,
ERDC
Capenhurst,
Chester, CH1 6ES.

*RIGEL

Implemented on PC and HP300 Workstation
PC version available on limited basis

Questionnaire completed by experienced user and author of control model:-
Alexandre Jeandel
Gaz de France - DETN - CERUG E3
361, Av du President Wilson
BP - 33, 93211 La Plaine St Denis
France

*SERI-RES 1.2 (ETSU)

Implemented on Sun-3, VAX, Perkin Elmer, Prime, ----- , IBM-PC (special version)
Available at distribution cost (PC version on limited commercial basis)

Questionnaire completed by enhancer of program:-
P Haves,
Department of Engineering Science,
Parks Road,
Oxford OX1 3PJ.

*SIMULA

Implemented on PC-compatable IBM-AT
Available commercially (through IPTIC)

Questionnaire completed by program authors:-

C Marenne,
Laboratoire CERMA,
Ecole d'Architecture de Nantes,
rue Massanet
44200 Nantes,
France.

*TAS 7.0:

Implemented on Apollo Domain.
Available commercially

Questionnaire completed by program author:-
M Gough,
EDSL,
14 Cofferidge Close,
Stony Stratford,
Milton Keynes, MK11 1BY

*THERM

Implemented on IBM mainframe, Harris (Simplified version - MicroTherm+ on IBM-PC)
Available on limited basis

Questionnaire completed by user:-
E R Hitchin,
British Gas plc.,
Watson House,
Peterborough Road,
London SW6 3HN.

*TRNSYS 12.2:

Implemented on IBM-PC compatibles and a wide variety of mainframes.
Available at distribution cost.

Questionnaire completed by person who currently maintains and improves TRNSYS:-
R Urban,
TRNSYS Engineer,
Solar Engineering Laboratory,
1500 Johnson Drive,
Madison,
WI 53706,
USA.

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