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1 What is the Thermal Applications Category?

The Thermal Applications Category of the Virtual Environment is set of software facilities for the thermal analysis of buildings, the capabilities of which are outlined in this document. Guidance on the views and applications contained within this Category and their calculation methods is set out in separate manuals.

Applications in the Thermal Applications category fall into three main groupings:

- **<Virtual Environment> compliance checks**
  - Analysis to test compliance with Section 6 of the Building Regulations (2004) - Scotland

- **Industry-standard thermal calculations**
  - CIBSE heat loss calculations (ApacheCalc, Vista)
  - CIBSE heat gain calculations (ApacheCalc, Vista)
  - ASHRAE heating loads calculations (ASHRAELoads, Vista)
  - ASHRAE cooling loads calculations (ASHRAELoads, Vista)

- **Dynamic simulation (ApacheSim & related programs)**
  - Building dynamic thermal simulation (ApacheSim)
  - Natural ventilation simulation (MacroFlo)
  - HVAC system simulation (ApacheHVAC)
  - Results viewing and analysis (Vista, OutView, PlotView)

These applications are accessed via Application Views as follows.

1.1 **<Virtual Environment> Compliance View**

- Preparation of input data for England & Wales Building Regulations compliance.
- Preparation of input data for Scottish Building Regulations compliance.
1.2 Apache Application View
- Preparation of input data for ApacheCalc ASHRAELoads and ApacheSim.
- Calculations and simulations using ApacheCalc, ApacheSim, ApacheHVAC and MacroFlo.

1.3 ApacheHVAC Application View
- Preparation of input data for ApacheHVAC.

1.4 MacroFlo Application View
- Preparation of input data for MacroFlo

1.5 Vista Application View
- Presentation and analysis of results from ApacheSim, ApacheHVAC and MacroFlo
2 Data Requirements for Thermal Applications

In common with other Virtual Environment applications, the Thermal applications derive their geometrical data from the ModelBuilder. This is supplemented with application-specific data provided within the Thermal Application Category.

The input data requirements of the thermal applications are summarised below. The data is managed by utility programs invoked from the Application Views. Where possible, applications access common data so that it is never necessary to re-enter values in order to carry out different types of analysis. The efficiency of data input is further enhanced by the use of objects called Templates.

Templates bring together groups of thermal input variables so that they can be assigned collectively to sets of rooms, building elements or other objects. Construction Templates store descriptions of constructions for the various categories of building element (walls, floors, windows and so on). Room Thermal Templates store sets of casual gains, air exchanges, plant operation parameters and zoning information associated with rooms of a given type. After a Room Thermal Template is assigned to a room it may be overridden by subsequent ad hoc changes. Templates can be transferred between projects. They offer a powerful means for imposing structure on the input data, maintaining data quality and saving the user time.

The following is a summary of the data required by the thermal applications and the utility programs that manage this data.

2.1 Site Location and Weather Data

Data on the global location of the building and the climate to which it is exposed are specified using the program APlocate.

The location data includes the latitude and longitude of the site, together with information about the local time zone and any summertime clock adjustment. The weather data covers the requirements of both the heat loss and heat gains calculations and the thermal simulation program.

For the heat loss calculation the weather data takes the form of a single outside winter design temperature.

For the heat gains calculation the data provides hourly dry-bulb temperatures, wet-bulb temperatures and solar data for one design day per month.

For thermal simulation the weather data is more extensive and is stored on a simulation weather file. This file contains the values of the following weather variables measured at hourly intervals over a year:

- Dry-bulb temperature
- Wet-bulb temperature
- Direct beam solar radiation
- Diffuse solar radiation
- Wind speed
- Wind direction
- Cloud cover

Weather data in these formats is available for a large number of sites worldwide.

### 2.2 Constructions

The material composition of the walls, windows and other elements of the building fabric are described using the program APcdb (Apache constructions database manager). APcdb provides databases of materials and constructions which may be imported into the building and edited as necessary. Constructions are built up from layers with specified thermophysical properties and widths. In the case of glazing constructions the layer properties include solar transmittance, absorptance and reflectance characteristics.

Construction details may be passed between projects using a Construction Template.

The following utilities are also provided:

- Calculation of U-values and admittance parameters
- Calculation of glazing angular solar transmission properties
- Condensation analysis

### 2.3 Profiles

Profiles provide the means for describing the time variation of input variables. They are used to specify how quantities such as casual gains, ventilation rates and set-points vary over the hours of the day, the days of the week and the months of the year. ‘Formula profiles’ allow inputs to vary in response to room or external conditions arising during simulations.

Profiles are managed by the program APpro.
2.4 Internal Gains

Information on heat gains from occupants, lights and equipment is required as input to heat gain calculations and thermal simulation. Heat gains may be sensible or latent, and sensible gains are characterised by a radiant fraction. The magnitude and types of these casual gains, together with profiles to indicate their time variation, may be specified individually for each room or incorporated within a Room Thermal Template.

2.5 Infiltration and Ventilation

Infiltration and ventilation rates for rooms are specified by assigning them a maximum value and a profile. Ventilation rates can represent either mechanical or natural ventilation. The source of the ventilation may be outside air, air from another room or air at a specified (possibly time-varying) temperature. Like casual gains, air exchanges may be incorporated within a Room Thermal Template.

These pre-specified air exchanges may be supplemented by natural and mechanical ventilation air flows calculated dynamically at simulation time by the programs MacroFlo and ApacheHVAC.

2.6 Plant and Controls

Where rooms are conditioned by heating, cooling, humidification or dehumidification systems the characteristics of these systems must be specified. The specifications for room control include set-points, heating and cooling capacities and radiant fractions, together with profiles defining periods of plant operation. These parameters form part of the Room Thermal Template data.

In the case of thermal simulation, these idealised room control parameters may be overridden by detailed HVAC system models constructed in ApacheHVAC.

2.7 Heating and Cooling Zones

In the Thermal view, rooms may be grouped together into Heating Zones and Cooling Zones for the purpose of aggregating results from a calculation or simulation.
3 <Virtual Environment> Compliance Checks

The <Virtual Environment> compliance programs assess regulatory compliance for four building regulation methodologies:

- Analysis to test compliance with Part L1 (Dwellings) of the UK Building Regulations (2006) – England & Wales
- Analysis to test compliance with Part L (Dwellings & Non-domestic buildings) of the UK Building Regulations (2002) – England & Wales
- Analysis to test compliance with Section 6 of the Building Regulations (2004) – Scotland
- Analysis to test compliance with Part L (Dwellings & Non-domestic buildings) of the Building Regulations (2008) – Eire

Information required for these compliance checks is explained in the following documents that can all be found in the manuals directory of the IES <Virtual Environment> installation:

- <Virtual Environment> Compliance View User Guide
4 Industry-standard Thermal Calculations (ApacheCalc)


4.1 Heat Loss

Heat Loss provides for the calculation of room heating requirements and the sizing of heating plant.

Steady-state room heat losses are calculated in the absence of casual and solar heat gains. The calculation optionally includes conduction heat gains from adjacent rooms and the effects of mechanical and natural ventilation air exchanges.

Results are presented (in the program Vista) as tables or histograms of room or zone heat loss, broken down by heat loss mechanism. Losses can be expressed on a floor area or room volume basis. Room temperatures are also displayed. The data may be exported to other applications such as spreadsheets and word processors.

Post-processing options include the following:

- Inclusion of a factor for intermittent plant operation
- Radiator selection

4.2 Heat Gain

Heat Gain calculates room cooling requirements and summertime temperatures.

Room cooling loads and free-floating temperatures are calculated using the CIBSE admittance procedure. The calculation is carried out for a user-selected range of months using weather data provided in APlocate. The calculation takes into account the timing and nature of each gain, applying the appropriate radiant fraction to all sources of heat and cooling. Inter-room dynamic conduction and ventilation heat transfer is accounted for. Glazing solar transmission properties are treated using an analysis based on the Fresnel equations. At the user’s option the effects of ventilation air exchanges and external solar shading, as calculated by SunCast, may be incorporated.
The program Vista presents the results in tabular or graphical form in a variety of formats. Gains are broken down by heat transfer mechanism and by type (sensible or latent). Results may be displayed by room, by zone or totalled over the building and peak loads are identified. Various measures of room temperature are displayed, together with room relative humidity. Data may be exported to other applications.

Post-processing facilities are provided as follows:

- Calculation of ventilation supply conditions that will meet the calculated cooling loads
- User-definable tables of loads
5 Industry-standard Thermal Calculations (ASHRAE Loads)

The program ASHRAE Heating and Cooling Loads (ASHRAELoads) performs heating and cooling load calculations according using the ASHRAE Heat Balance Method.

5.1 Heating Loads

Heating Loads provides for the calculation of room heating requirements and the sizing of heating plant.

Steady-state room heat losses are calculated in the absence of casual and solar heat gains. The calculation optionally includes conduction heat gains from adjacent rooms and the effects of mechanical and natural ventilation air exchanges.

Results are presented (in the program Vista) as tables or histograms of room or zone heat loss, broken down by heat loss mechanism. Losses can be expressed on a floor area or room volume basis. Room temperatures are also displayed. The data may be exported to other applications such as spreadsheets and word processors.

Post-processing options include the following:

- Inclusion of a factor for intermittent plant operation
- Radiator selection

5.2 Cooling Loads

Cooling Loads calculates room cooling requirements and summertime temperatures.

Room cooling loads and free-floating temperatures are calculated using the ASHRAE Heat Balance Method. The calculation is carried out for a user-selected range of months using weather data provided in APlocate. The calculation takes into account the timing and nature of each gain, applying the appropriate radiant fraction to all sources of heat and cooling. Inter-room dynamic conduction and ventilation heat transfer is accounted for. Glazing solar transmission properties are treated using an analysis based on the Fresnel equations. At the user’s option the effects of ventilation air exchanges and external solar shading, as calculated by SunCast, may be incorporated.

The program Vista presents the results in tabular or graphical form in a variety of formats. Gains are broken down by heat transfer mechanism and by type.
(sensible or latent). Results may be displayed by room, by zone or totalled over the building and peak loads are identified. Various measures of room temperature are displayed, together with room relative humidity. Data may be exported to other applications.

Post-processing facilities are provided as follows:

- Calculation of ventilation supply conditions that will meet the calculated cooling loads
- User-definable tables of loads
6 Thermal Simulation (ApacheSim)

ApacheSim is a dynamic thermal simulation program based on first-principles mathematical modelling of the heat transfer processes occurring in and around a building. ApacheSim qualifies as a Dynamic Model in the CIBSE system of model classification, and exceeds the requirements of such a model in many areas.

The program provides an environment for the detailed evaluation of building and system designs, allowing them to be optimised with regard to comfort criteria and energy use.

Within ApacheSim, conduction, convection and radiation heat transfer processes for each element of the building fabric are individually modelled and integrated with models of room heat gains, air exchanges and plant. The simulation is driven by real weather data and may cover any period from a day to a year. The time-evolution of the building’s thermal conditions is traced at intervals as small as one minute.

Results output by the simulation include:

- Comfort statistics
- Energy consumption data
- CO₂ emission data
- Room load statistics
- Plant sizes
- Detailed performance measures including hourly room temperatures (air, mean radiant and dry resultant), humidities, plant loads, casual gains and air exchanges
- Surface temperatures for comfort studies or CFD boundary conditions

The simulation engine has the following features:

- Finite difference dynamic heat conduction modelling
- Dynamically calculated surface convection characteristics
- Air temperature, surface temperature and room humidity modelling
- Advanced solar and long-wave radiation exchange models
- External solar shading using data from SunCast
- Solar tracking through an arbitrary number of transparent internal partitions using data from SunCast
- Angle-dependent glazing transmission, reflection and absorption characteristics
- Accurate accounting for the radiant/convective characteristics of casual gains and plant heat inputs
- Room plant and control models allowing for limited heating or cooling capacity
- Simultaneous solution of sensible and latent heat balance equations for the whole building
- Optional integration with natural ventilation air flow simulation (MacroFlo) or HVAC system simulation (ApacheHVAC)
- Simultaneous integration with both MacroFlo and ApacheHVAC for the simulation of mixed-mode systems
7 HVAC System Simulation (ApacheHVAC)

ApacheHVAC simulates the performance of heating, ventilation and air conditioning systems. It links dynamically to the building simulation program ApacheSim, and optionally to MacroFlo.

ApacheHVAC extends the capabilities of ApacheSim by providing a detailed representation of room heating and cooling units, air handling systems, central plant components and controls. These capabilities give the user a means of accurately assessing issues such as:

- Control operation and its impact on comfort performance
- Energy use
- Fresh air loads
- Free cooling
- Heat recovery
- Component sizing
- Sizing of mechanical air flows
- System psychrometrics
- Distribution efficiency
- Boiler and chiller performance
- Fan and pump energy
- Mixed-mode operation

Working through a graphical interface the user assembles a system schematic on screen and sets operational parameters for its components. Editing features facilitate operations such as copying and moving groups of components. The list of available component building blocks includes:

- Rooms
- Radiators
- Direct-acting heaters and coolers
- Chilled ceilings
- Heating and cooling coils
- Ducts
- Fans
- Humidifiers
- Heat recovery devices
- Controllers
- Boilers
- Chillers

Controllers may be configured for both on-off and proportional control, and may be cascaded to simulate complex control functions. Time variation of operational parameters is handled with profiles, and formula profiles offer additional flexibility in control specifications.

The component-based nature of the interface makes possible an almost unlimited range of system types, of which the following are examples:

- Variable air volume (VAV)
- Constant air volume (CAV)
- Fan-coil
- Displacement ventilation
- Chilled beams
- Radiators
- Underfloor heating

If the MacroFlo check box is ticked at run-time the simulation will include natural ventilation analysis. MacroFlo will then incorporate in its calculations any flow imbalances arising in the system simulation, providing a route for the simulation of mixed-mode systems.

ApacheHVAC generates an extensive range of outputs. At the detailed level it is possible to trace individual psychrometric and control processes occurring within a system. At the opposite extreme the program can supply aggregated monthly energy loads and consumption totals, optionally broken down by fuel or component type.
8 Natural Ventilation Simulation (MacroFlo)

MacroFlo is a simulation program for the design and appraisal of naturally ventilated and mixed-mode buildings. MacroFlo runs as an adjunct to ApacheSim, exchanging data at run-time to achieve a fully integrated simulation of air and thermal exchanges.

The following issues may be addressed with MacroFlo:

- Infiltration
- Single-sided ventilation
- Cross-ventilation
- Natural ventilation as a whole-building strategy
- Temperature-controlled window opening
- Mixed-mode solutions (used in conjunction with ApacheHVAC)

MacroFlo simulates the flow of air through openings in the building envelope. Openings are associated with windows, doors and ‘holes’ created in the geometry model and may take the form of cracks or larger apertures. Air flow is driven by pressures arising from wind and buoyancy forces (stack effect). It also takes account of mechanical air flows set up in ApacheHVAC.

Wind pressures on the building exterior are calculated at each simulation time step from data read from the weather file. Wind speed and direction data is combined with information on opening orientations and wind exposures to generate wind pressures on each external opening. The calculation involves wind pressure coefficients derived from wind tunnel experiments. Buoyancy pressures, varying with height in accordance with temperature-dependent air densities, are then superimposed.

The flow through each opening is calculated as a function of the imposed pressure difference and the characteristics of the opening. The height dependence of the buoyancy pressures means that two-way flow can occur through a single opening either side of a neutral pressure plane. Special situations such as the Rayleigh instability are detected and modelled appropriately. A network of pressure-flow relationships is solved to balance the flows in and out of each room.

MacroFlo exchanges data with ApacheSim and ApacheHVAC dynamically to achieve the simultaneous solution of the inter-dependent thermal and air flow balances.

Input data for MacroFlo is prepared in the MacroFlo application. Working from an editable database of Opening Types the user assigns opening properties to
windows and doors in the model. This process follows the same pattern as the assignment of construction types for the thermal analysis.

Opening Type properties allow for the specification of crack characteristics, the degree and timing of window opening and (as appropriate) its dependence on room temperature. Opening Types may be stored in a Template.
9 Viewing and Exporting Simulation Results (Vista, OutView, PlotView)

The Vista program provides facilities for the display, collation and export of data generated by the Virtual Environment’s thermal simulation applications.

Vista is itself a component of the Virtual Environment and as such has access to the geometry model stored in the ModelBuilder view. The geometry model provides a natural framework for browsing simulation output datasets.

By pointing to rooms on the model image you can instantly call up graphs or tables of room temperatures, plant loads, casual gains and other simulation variables. Results for different rooms can be displayed on the same axes or juxtaposed, and similar comparisons can be made between results datasets derived from alternative design options.

Results from MacroFlo may be displayed at either the room level or the opening level. To obtain a detailed picture of natural ventilation flows the user can point to an opening to view graphs of in-flows, out-flows and the degree of opening.

Energy and load totals from ApacheHVAC can be displayed as hourly time series or monthly totals.

All Vista outputs may be readily exported to external applications.

The programs OutView and PlotView provide additional facilities for viewing simulation results.