Colorcoat Renew® User Guide

IES Virtual Environment

Contents

1 Introduction

IES-VE is capable of modelling the Colorcoat Renew® solar collector, which is a form of flat plate Transpired Solar Collector (TSC). TSCs are special building façades that comprise of a painted and perforated steel plate, a plenum cavity and an Air-Handling Unit (AHU). As solar radiation is captured by the plate, it heats up and the AHU draws air through the perforations. Heat transfer occurs between the plate and the incoming air and the heated air is passed into the building through mechanical ventilation.

This document is a user guide for the IES-VE user that explains how to create a simple model, import the Colorcoat Renew® component, assign surfaces to a plenum, create or import a HVAC network and perform thermal simulations. The guide will also include general hints for tweaking and customising the system to be modelled.

This guide is aimed at users that have little to no experience using IES-VE. Therefore the guide will also include some basic modelling methods that form prerequisites of setting up a Colorcoat Renew® solar collector. A key part of setting up the system is the Colorcoat Renew® navigator, which is a workflow tool that itemises the steps that are described below and also includes short-cut links to specific menus of relevance. This document will explain how Colorcoat Renew® solar collectors can be implemented without the navigator (where possible), but many of these steps will be replicated in the navigator. Comments regarding the navigator can be found in section 3.

2 A quick look at modelling in IES-VE

2.1 Overview

IES-VE is a software tool for the thermal modelling of buildings and infrastructure and comes under the umbrella of Building Information Management (BIM) software. It is designed with a focus on compliance with regulations, energy and thermal diagnostics and user versatility. The underlying model is based on the laws of physics, with occasional use of empirical results from the literature where relevant. The philosophy behind this approach is that each model represents an experimental black-box that can be customised as much as possible to describe real buildings at a level of detail specified by the user. For example, a user may be happy to make a quick model made up of a few cuboid-shaped rooms with default wall constructions and a simple idealistic heating system. If more detail is required, a user may instead specify the exact geometries of each room including occupancy, lighting, insulation, central heating systems, ventilation, furniture, glazing, etc.

The tools that allow these detailed specifications are split up into mini applications. The applications that will be required for modelling solar collectors are outlined below.

- ModelIT – main modelling tool for specifying building geometry.
- Components – interface for importing external objects
- Apache – main thermal modelling tool.
- ApacheHVAC – specification of HVAC networks and control systems.
- VistaPro – tool for querying output data.

Other applications may be used; including TSCs in a model should not conflict with any other applications, such as Macroflo or Suncast. A user planning to model typical operation of a TSC must have access to the ApacheHVAC application.

The solar collector data is intended to be visualised with VistaPro and it is recommended that this tool be used be used to query thermal model results rather than Vista.

2.2 The user-interface

When IES-VE is started, the screen shown in Fig. 1 will be displayed. In Fig. 1, each part of the screen is split into coloured rectangles that indicate the different panels. These are outlined as follows:

- Applications and navigators panel (red) – the applications tab is used to select the current operating application and the navigators tab is used to browse and operate navigators, which are streamlined task-lists for particular aspects of BIM modelling. Clicking on the applications will change the contents of the viewport, the list browser and the application toolbar to display the functions relevant for that particular application. See section 3 below for details about the Colorcoat Renew® navigator.
- List browser (green) – this is a list of all current rooms or components in the model, which can be organised and displayed in different groupings. This is used to select

specific rooms, surfaces or components to view and can also be used to set some properties.

- Main toolbar (blue) – the toolbar containing the main modelling functions that are often used in multiple applications. This includes different viewing options and standard functions, such as those for opening and closing models.
- Application toolbar (orange) – the toolbar containing the functions specific for the currently selected application.
- Viewport (yellow) – main visual display.

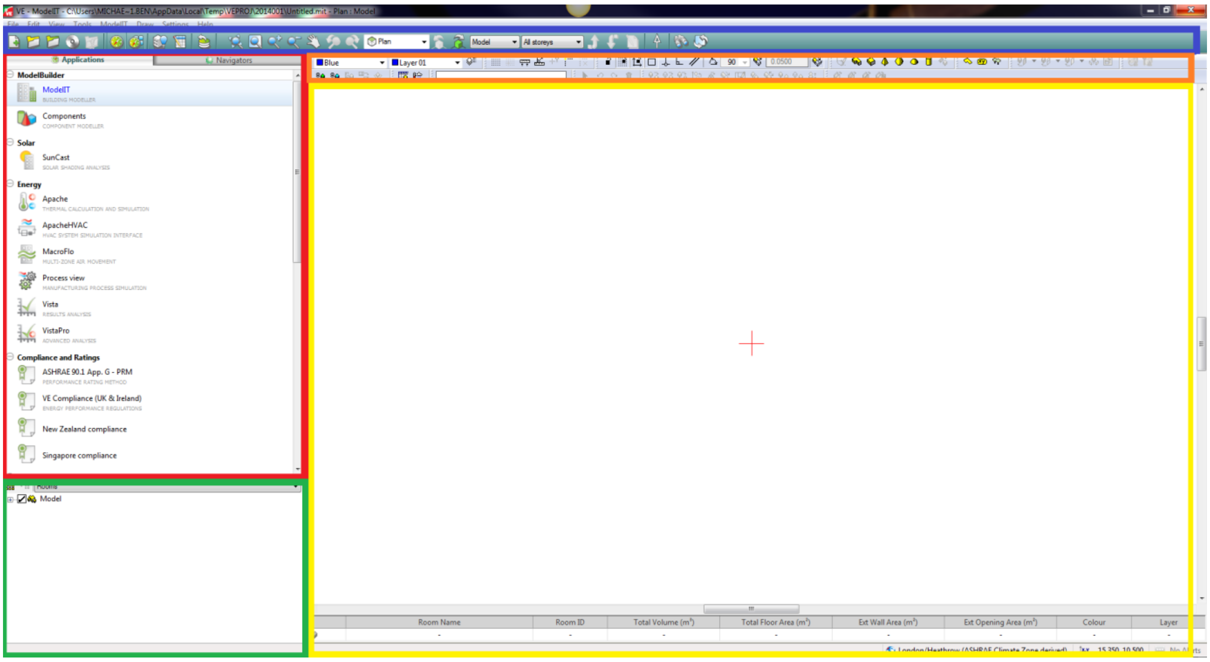


Fig. 1: Main IES-VE screen with coloured rectangles added to indicate the various parts of the user interface. These parts are the applications and navigators panel (red), list browser (green), main toolbar (blue), application toolbar (orange) and viewport (yellow).

2.3 Making a quick test model

The first task is to specify a building geometry. This is done using the ModelIT application, which is the default application open when IES-VE is started. It can be selected in the applications tab.

Rooms can be added using the draw functions on the application toolbar, which are shown in Fig. 2. Hovering over the icons with the mouse for a short time will give a tool-tip that specifies the icon.

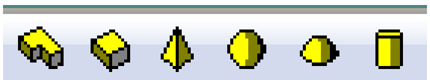


Fig. 2: Draw functions displayed on the ModelIT application toolbar. These are used to specify the building geometry. The draw functions are, from left-to-right: draw extruded shape, draw prism, draw pyramid, draw sphere, draw hemisphere and draw cylinder.

Rooms can be created using any of these tools, so feel free to experiment. However, in practise the most commonly used draw functions are the draw prism and draw extruded shape functions, since they can be used to create cuboid-shaped rooms, lobbies, porches, corridors, etc. which form the majority of room geometries in real buildings. For our test purposes, a single room drawn using the "draw prism" function (second icon from the left) will suffice.

The room can be drawn by clicking and dragging the surface area of the room. However, before this step is made, it is possible to change the name of the room, the plane and the height/depth of the room using the shape settings panel that pops up after clicking a drawing function item on the application toolbar. These settings can be modified after the room is created using geometrical tools.

The model can be visualised in a number of ways by using the views dropdown on the main toolbar, as shown in Fig. 3. Switching to axonometric view will make it easy to see all surfaces of the room.

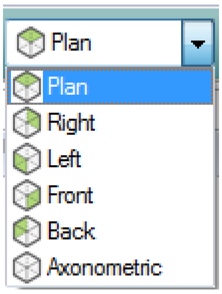


Fig. 3: The views dropdown on the main toolbar shows various possible views for the current model. The default is 'plan', but 'axonometric' is useful for visualising all surfaces of the model.

If you created a single room using the draw prism function, you should have a model that looks reminiscent of that shown in Fig. 4. The dimensions are important for the solar collector surface because the total surface area of the collector will dictate the flow rates needed by the fan in the solar collector system. For now we will not worry about obtaining an exact size, but we can probe the surface area of an individual surface by clicking on it in the viewport or by selecting it in the list browser.

An important feature is the idea of "room-level" and "surface-level" selections. These can be considered as different viewing modes allowing selection of rooms or individual surfaces. To traverse between different selection levels, click the arrows on the main toolbar (shown in Fig. 5). Double-clicking on a room will also automatically traverse to the surface level. These levels will also be traversed when clicking on rooms or surfaces in the list browser.

Another important feature is the site rotation feature. This icon is the third one from the right on the main toolbar (see Fig. 5). The default site rotation is set to North, but the entire model can be pointed in a different direction using this icon. This will be important since solar collector surfaces are typically installed on South-facing walls.

Once the room is created, click the “save project” icon on the main toolbar. You may also be prompted to save the project if you open a different application using the applications tab. We will now import the TSC component into our session.

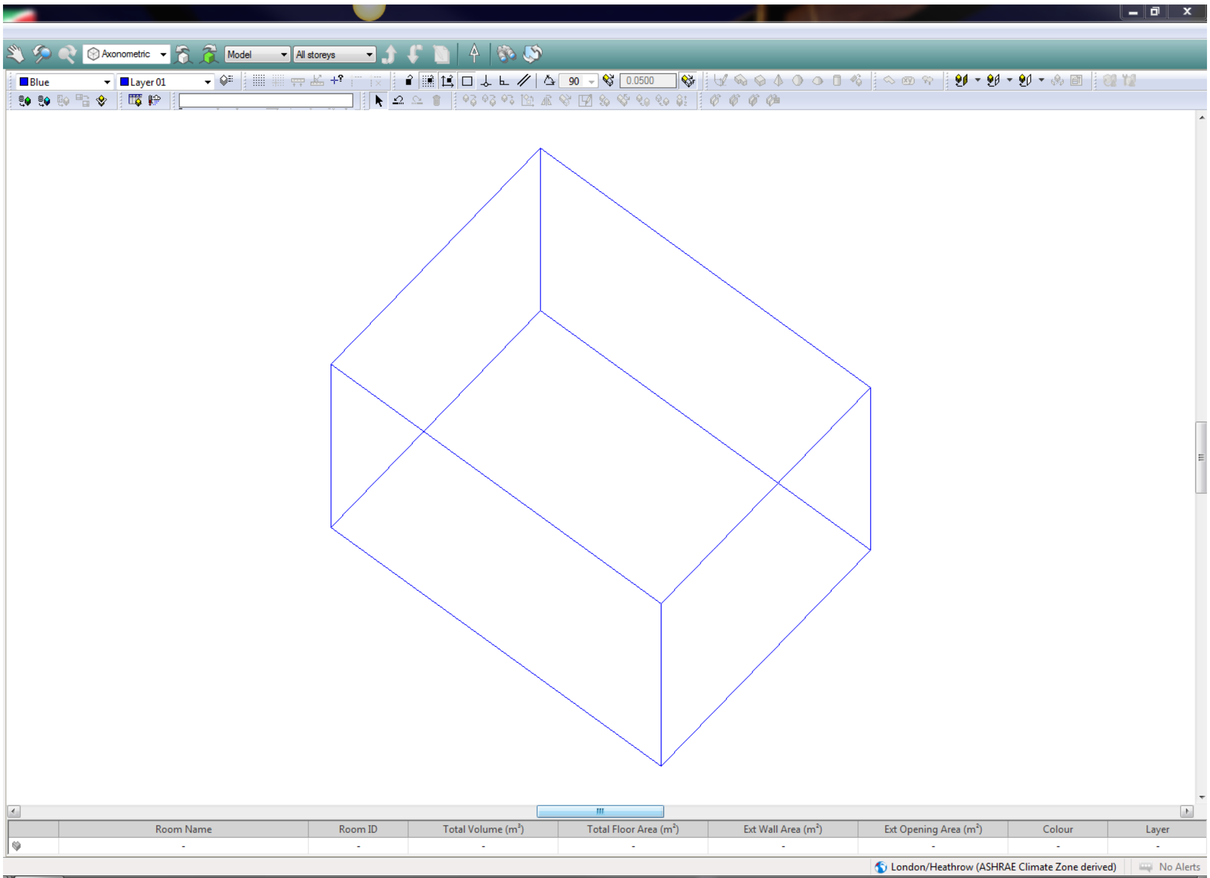


Fig. 4: A typical one-room model created using the draw prism function in ModelIT and displayed in axonometric view.

Fig. 5: Icons at the far right of the main toolbar. These functions are, from left to right: move up one level, move down one level, object list, site rotation, model viewer and refresh display.

3 The Colorcoat Renew® solar collectors navigator

Navigators are a feature in the IES-VE to allow guidance on particular workflows for setting up particular systems. They also include shortcuts to features that are unique to those systems.

A Colorcoat Renew® solar collectors navigator can be found by accessing the Navigators panel and selecting "Partners-> Colorcoat Renew® solar collectors" from the dropdown at the top of the panel. Fig. 6 shows the Colorcoat Renew® solar collectors panel.

By selecting different options in the Navigator, shortcuts to particular parts of the IES-VE can be accessed. For example, clicking on "Import the required systems from library" will open up the Import dialogue for Colorcoat Renew® solar collectors in the components module. Using these shortcuts is a good way of making sure that all of the required steps for implementing Colorcoat Renew® solar collector systems are made and in the correct order. Furthermore, this panel is used exclusively to assign additional surfaces to belong to a particular TSC plenum (see section 5.3) and to import the Colorcoat Renew® HVAC systems from the library for use in Apache simulations (see section 7.4.3).

Note that some of the options will be greyed out until check marks are made on the boxes on the right-hand side. This is to help ensure that necessary previous steps are made before certain shortcuts are available. In addition, notes can be added regarding each step by clicking the page icon by each entry.

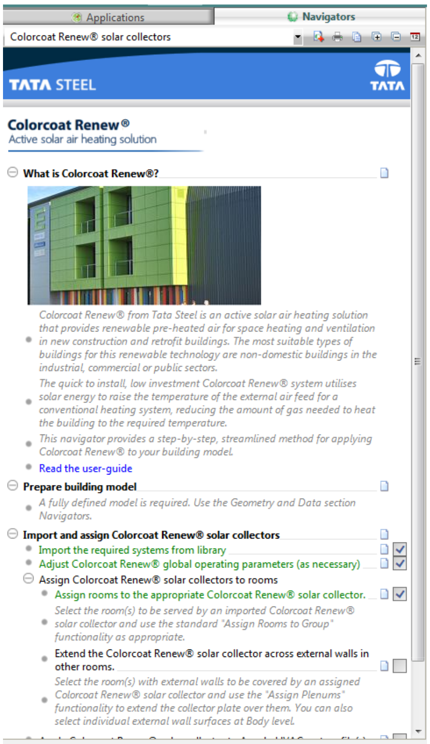


Fig 6: The Colorcoat Renew® solar collectors navigator. The navigator contains information related to the TSC systems and features a step-by-step workflow to implement Colorcoat Renew® solar collector systems in the VE.

4 Importing the Colorcoat Renew® component

Click on the application "Components" in the applications tab. An existing component "Radiator" will already be displayed. To import a new component, either select "Add from library" under the menu labelled "Components" at the top-left corner of the screen or click the right-most icon in the list browser. These buttons are shown in Fig. 7.

Fig. 7: List-browser icons for common component operations. These operations are, from left to right, create new component, copy current component, remove component and add component(s) from library.

Alternatively, select the option "Import the required systems from library" option in the Colorcoat Renew® solar collectors navigator.

Once this is clicked a new window will pop-up with the currently available components to add. This is shown in Fig. 8. If it is not already selected, the Colorcoat Renew® solar collectors can be selected from the dropdown menu. The four entries correspond to four different kinds of system (or variants).

The four variants are described in detail in the "Information" tab. Each variant can be summarised as follows:

- Variant A: TSC system with variable flow rate fan and controller
- Variant B: TSC system with constant flow rate controller and recirculation
- Variant C: client BMS driven TSC system with multiple operating modes
- Variant D: TSC system with constant flow rate controller, recirculation and additional boost heating

A schematic representation of the TSC component is shown in the "preview" tab, but the model geometry will not be updated to contain this schematic, so it is mainly for visual display purposes only.

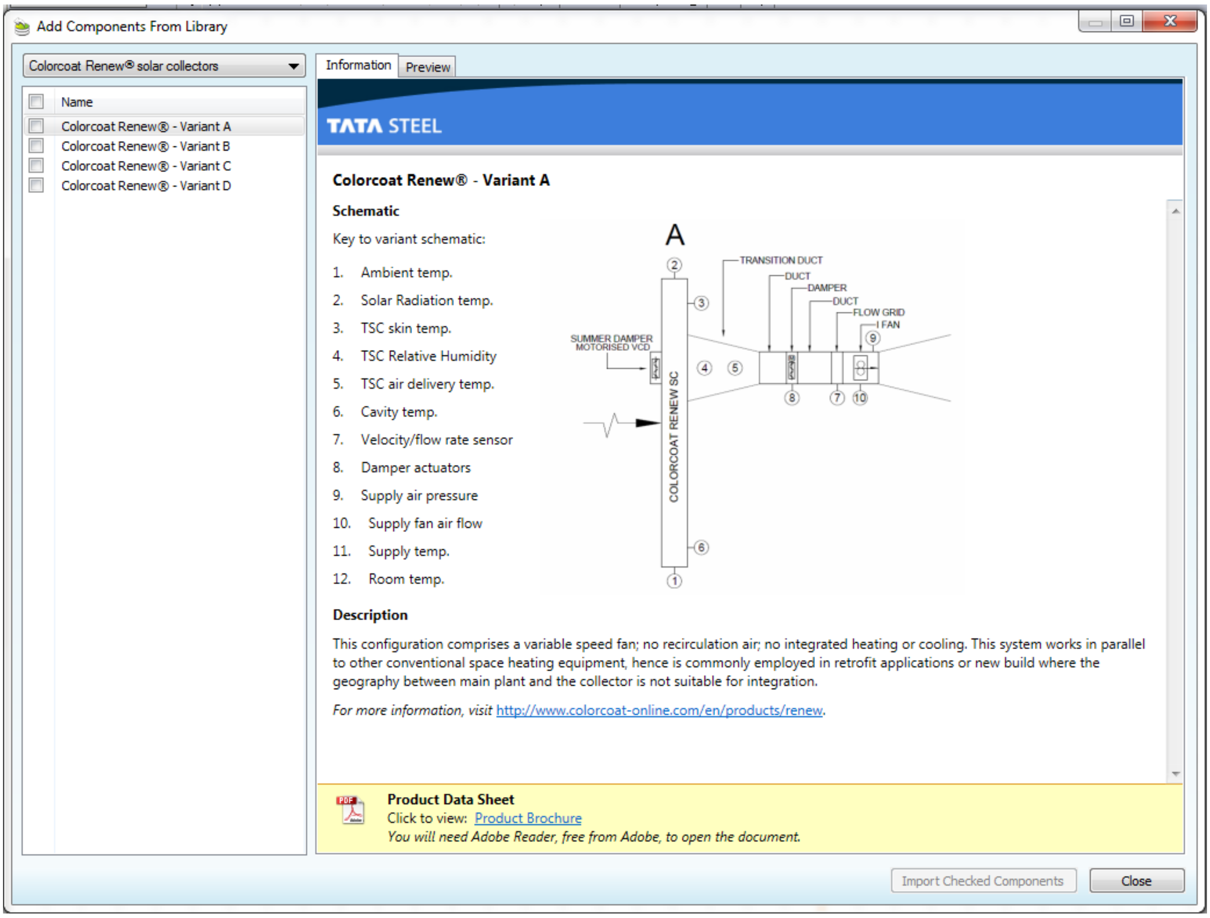


Fig. 8: Add component(s) from library window. The drop down in the top-left hand corner can be used to select the component to add. Various information is then displayed for that particular component. The component is then imported by clicking the tick-box on the left-hand list and clicking “Import Checked Components”. Updates to the build may include additional options in this dialogue, associated with control network variants or more up-to-date information in the right-hand panel.

If the component has been imported, the list browser will have an additional option “Tata Steel” which contains an item “Colorcoat Renew®”. Now we can move onto the next step, which is to assign surfaces of the model to belong to TSC plenums. The component library will need to be saved before traversing back to the ModelIT application (or can be saved at a prompt when switching applications).

5 Plenums

5.1 Colorcoat Renew® Mode

After importing the Colorcoat Renew® component, the list browser (in the application ModelIT) will now contain an extra option "Colorcoat Renew® solar collectors". Selecting this will put the model into a "Colorcoat Renew® mode" that allows assignment of Colorcoat Renew® systems to the model. For each system, a plenum is created.

A plenum is a unique entity in ModelIT that represents the cavity behind the collector plate and, together with the plenum cavity layer in the construction (see section 6.3), triggers the Apache thermal simulation to take into account the physics associated with heat exchange in the plenum cavity. Each Colorcoat Renew® system has a single plenum, which has one or more surfaces assigned to it; TSCs are typically installed on exterior surfaces, so it is common for plenum cavities to extend across the external walls of several rooms.

In Colorcoat Renew® mode TSCs will be displayed, but none have yet been assigned to the model. A list of rooms with assigned TSCs (and a list of rooms that haven't been assigned) can be found in the list browser.

5.2 Assigning a Colorcoat Renew® system to the model

To assign a room to contain a Colorcoat Renew® TSC system, click a room that you would like to contain the air inlet and then click the second icon from the left in the list-browser bar "Assign selected rooms to room groups". This list browser for Colorcoat Renew® mode is shown in Fig. 9. Any rooms that have not been assigned plenums will be listed under "Not served". The served room should have external walls so that some of its South-facing surfaces will automatically be assigned to be collector surfaces. The served room is used to identify any particular plenum and in most cases will represent the final destination of the incoming air stream. However, using HVAC networks, we can assign exactly where the air stream is going and this air stream may go to a different room if required.

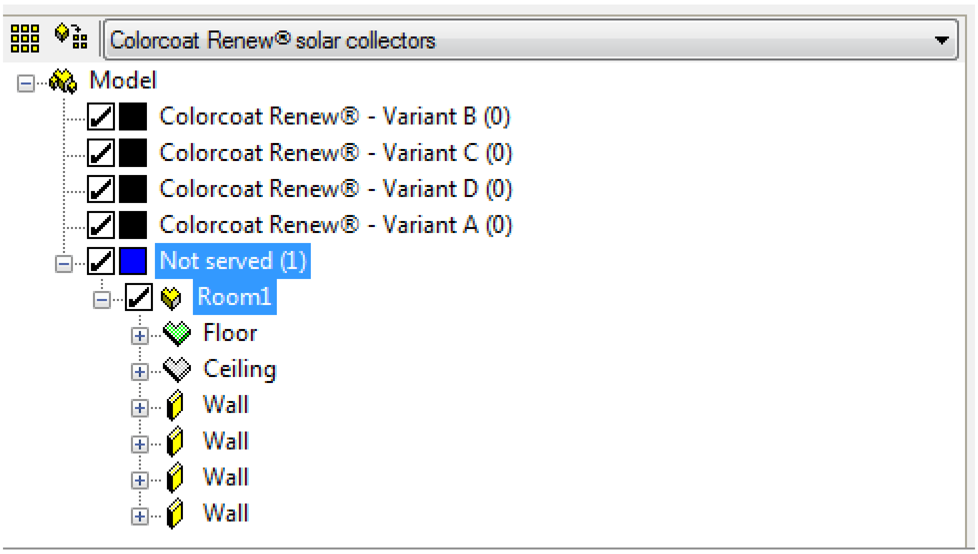


Fig. 9: List browser panel with Colorcoat Renew® mode enabled by selecting "Colorcoat Renew® solar collectors" option from the dropdown list. The two icons to the left of the dropdown list, from left to right, are "Edit room groups" and "Assign selected rooms to room groups".

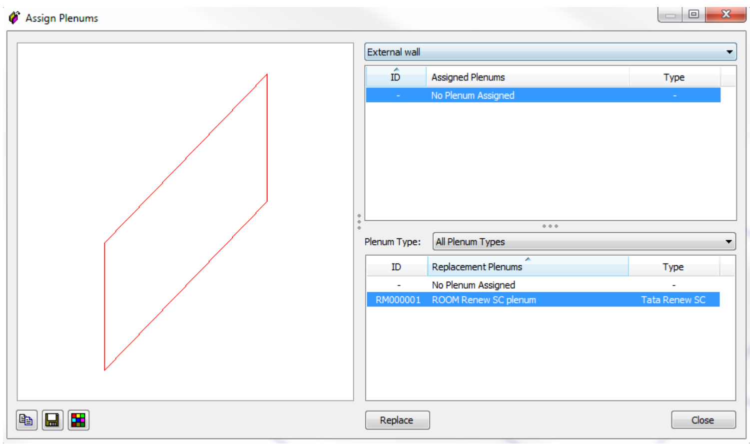
A small dialogue box will appear to ask which group to assign the room to. Assign it to a "Colorcoat Renew®" group and then close the box[1]. The room will now be set to be a 'served room' for the plenum and one or more surfaces will be assigned to be solar collector surfaces. These are automatically assigned to South-facing walls and are indicated by the shaded surfaces.

5.3 Assigning collector surfaces

There are two ways to assign further surfaces. The first method is to set the room group property of the room dialog box when rooms are being drawn. The new rooms which are created will then automatically be assigned to that room group and will have collector surfaces assigned automatically.

Using the method above, a new plenum instance will be created for each new room drawn. However, a single plenum can have multiple solar collector surfaces and these surfaces need not be those of the served room. The idea behind this is that the 'served room' is just the room containing the air inlet and the plenum cavity, which is determined by fitting a steel plate across an external area of the building and can overlap across the external walls of several rooms.

To assign existing surfaces to belong to a single plenum, select an existing surface you would like to assign (the list-browser is useful for this) and select the option "Extend the Colorcoat Renew® solar collector across external walls in other rooms" in the navigator. A new window will pop up, which is used to assign the surface to the plenum. This is shown in Fig. 10. The upper-right portion lists the surface and whether it is assigned to a plenum and the lower-right panel gives a list of available plenums to assign. To assign the plenum, click the plenum on the lower list and click replace.



[1] If a user wishes to use their own HVAC network, it doesn't matter which group is chosen as long as it is not "Not served". If a user wishes to import a preset HVAC network, the plenum should be assigned to the room group with the intended variant.

Fig. 10: Assign plenums window. The upper-right portion lists surfaces and their assigned plenums and the lower-right panel gives a list of available plenums to assign.

The window shown in Fig. 10 can also be opened up if a whole room is selected. This is useful if you wish to assign all surfaces that are currently assigned to a specific plenum to another one or to remove all assignments, but it is generally more convenient to assign individual surfaces to plenums one by one at the surface level.

Note that the panel can also be used to remove previous assignations. Therefore it is possible to choose any number of vertical, external surfaces to belong to the TSC system.

5.4 Considerations for solar collector surface assignments

A plenum is a cavity that belongs to a single TSC system and each TSC system in ModelIT is identified by its served room. By assigning surfaces to belong to a particular TSC system, those surfaces will be used to identify the dimensions of the underlying plenum cavity. However, in order to give realistic and meaningful results, one should consider some factors that will affect the reliability of the underlying thermal model.

Collector surfaces will automatically have their assignments removed if any modifications are made to the assigned surface. This is to ensure that any transformations that split, merge or otherwise modify the surface geometry do not create unusual plenum assignments. Therefore, for convenience, assigning collector surfaces to plenums should be performed after the model geometry is complete.

Only external walls can be assigned to be part of a plenum. Roofs cannot be directly assigned but external walls that are sloped can still be assigned. Since the underlying thermal physics model assumes that the collector is vertical, any results for output air conditions will not be representative of a roof collector and it is recommended that surfaces be made as close to vertical as possible.

It is possible for a user to add surfaces to a single plenum that are separated from each other. This is implemented to ensure that a user has the freedom to model slightly non-uniform plenum geometries, but a degree of common sense must be employed to ensure that each plenum forms a single body. In addition, the underlying thermal model assumes that the plenum has a cuboid structure and will subsequently approximate a non-uniform geometry as such. That is, the thermal model assumes that the plenum has a rectangular plan area and that the plenum depth does not vary much with height. Large deviations from this geometry may give unrealistic results.

Any windows or doors on a surface assigned to form part of a plenum will not contribute to the internal plenum volume or the solar collector area. Air flow through a plenum cavity does not take into account obstructions of this kind and the plenum will instead be treated as a regular plenum with a smaller plan area, internal volume and collector surface area.

5.5 Editing solar collector properties

The ability for a solar collector to operate depends on many factors, such as air flow rate, pitch, hole diameter, hole configuration, absorptivity, etc. Roughly, these factors can be split into two types: those that depend on the building fabric and those that depend on the HVAC network. Those that are related to the HVAC system (such as the flow rate control) are specified in section 7. For those that involve the building fabric, there are two types of properties: component properties and construction properties.

Component properties are properties related to the plenum, the perforations in the collector surface or other surface parameters. They can be edited by right-clicking on a group labelled "Colorcoat Renew®", for any variant in the list browser, and selecting "properties". Construction properties are discussed in section 6.

6 Constructions

6.1 Overview

The ability for a solar collector to operate depends on many factors, such as air flow rate, pitch, hole diameter, hole configuration, absorptivity, etc. Roughly, these factors can be split into those that depend on the building fabric and those that depend on the HVAC network. First we will configure the properties associated with the building fabric, which are collectively grouped as ‘constructions’. Constructions are stored in the Apache construction database (sometimes abbreviated to APcdb) and can be added, edited or removed using this tool.

6.2 Assigning constructions

Constructions can be assigned using the ModelIT or Apache applications, but there are icons in the Apache application to also query room properties and open the Apache construction database. Select a room and click on the “assign constructions” icon in the application toolbar (the left-most icon in Fig. 9; note the small arrow at the top of the icon, which distinguishes it from the icon that opens the Apache construction database). A new window will appear that works in exactly the same way as the assign plenums window, which can be used to assign different constructions to surfaces. Note that a default construction will be applied automatically to every surface in the model and this can be changed here.

6.3 Creating new constructions

For solar collector surfaces the default construction is ‘TSC Wall’. If we want to edit the characteristics of any constructions such as this one, we need to use the Apache construction database. This can be opened either by clicking the APcdb button at the bottom of the assign constructions window or by clicking the Apache construction database manager icon on the Apache application toolbar. This is shown in Fig. 11.

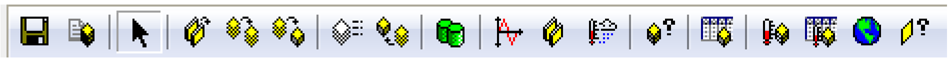


Fig. 11: Toolbar icons for the Apache application. These functions are, from left to right: save project files, export room data, select object (mode), assign constructions, edit group attributes, assign room thermal template to selection set, edit layer properties, edit selection set attributes, fuels data, Apache profile database manager, Apache construction database manager, Apache weather/location database manager, query, tabular room data, Apache systems, Apache tabular systems, renewables and edit multiple adjacencies.

The Apache construction database is used to add, edit or remove constructions from the database of materials. The list of defaults is rather sparse, so if the model is being generated to mimic an existing building, new constructions will need to be generated. Luckily there is a large array of materials to choose from to customise your own constructions. In this quick guide we will add one new construction that will represent the solar collector, the back wall and the plenum cavity.

The Apache construction database window shows a list of all constructions and defaults to the tab showing assigned thermal constructions. This is shown in Fig. 12. Various tabs that categorise each of these constructions are found at the bottom of the screen and are used as filters to display particular types of construction. TSC constructions are listed under their own category “TSC Walls”. To create a new construction, right-click the existing TSC Wall construction and select ‘duplicate construction’. The duplicated construction will then appear in the list. Right-click the new construction and choose “edit construction” or click the “edit construction” box at the bottom of the screen to edit it. Various properties of the construction can then be edited by replacing values in the relevant boxes in the new window that pops up. The majority of the functions and parameters that can be edited in the new window are self-explanatory.

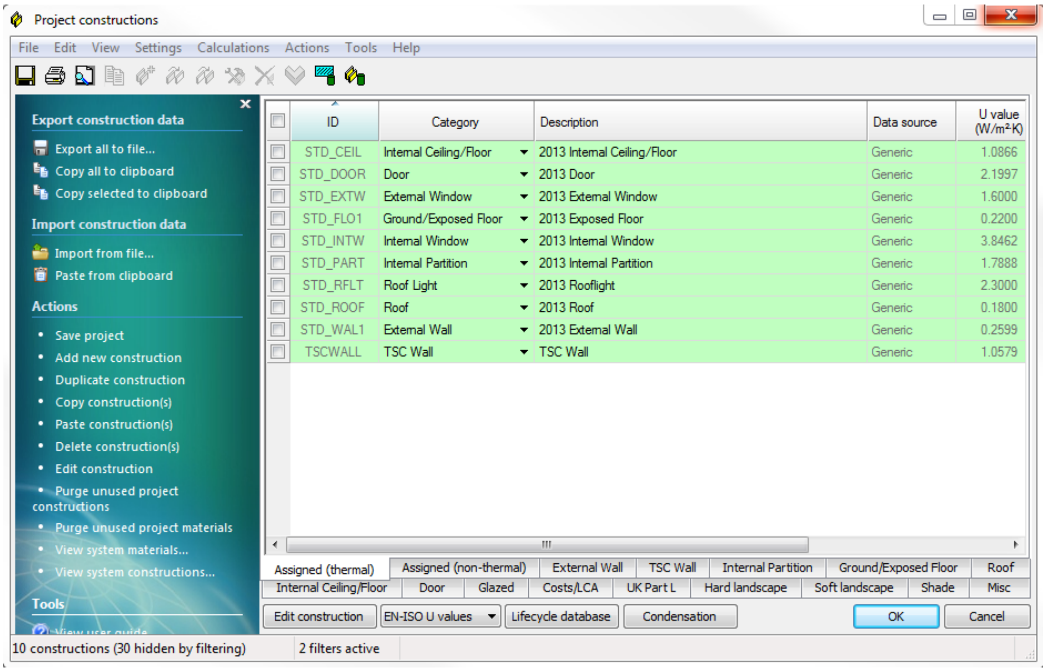


Fig. 12: Apache construction database window. The default tab lists assigned constructions in the model. Constructions are in general sorted into categories and can be viewed by looking at the tab for the category of interest, such as “TSC Wall”.

The only quirk that is specific for TSC constructions (as opposed to other types of construction) is the “plenum cavity” layer in the list of material layers. This layer is very important as the thermal model will use this layer as a trigger to split the wall into two separate ones, thereby correctly modelling the cavity space. The cavity depth can be changed by changing the thickness of this layer. Different constructions can be applied to different surfaces that belong to a particular plenum, which is useful, for example, for cases where the back wall materials differ for different room adjacencies.

7 The HVAC system and controls

7.1 Overview

A thermal model can be run straight away as it stands. However, the flow rate demand for the solar collector surface will be zero and the solar collector will operate permanently in a “passive” mode of operation, i.e. it will only undergo background heat transfer processes and not operate as an active system. To allow a normal “active” operation of the TSC, a HVAC system must be defined and the plenum, as defined in the building model by its served room, must be linked to the TSC system in the HVAC network. This is achieved either by importing one of the premade variants (accessible through the navigator) or by creating a new one from scratch. In this guide we will start by creating one from scratch in order to build a very simple system that will demonstrate the minimum criteria for ensuring an operational TSC and also introduce some of the basics of the HVAC functionality for more detailed control of air flow and temperature.

7.2 HVAC basics

The ApacheHVAC module is available in the applications tab and, when clicked, will load up a square grid for placing HVAC components. Sometimes the HVAC network may not be centred in the viewport, so the view can be centred by using the “fit to view” key. This is in the main toolbar and is shown in Fig. 13.

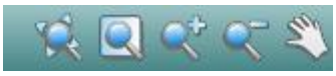


Fig. 13: Zoom functions on the main toolbar. The functions are, from left to right, fit view, zoom window, zoom in, zoom out and pan.

The module toolbar will now contain icons that can be used to add components and controllers to the HVAC network, which are connected together using the grey connector icons. These components can be added either by clicking the components in the module toolbar or by using the Components or Controllers menus at the top of the screen.

A simple HVAC network will typically contain an air inlet, an air outlet, a fan (left-intake), an air flow rate controller (independent time switch) and a room. An example network using this configuration is shown in Fig. 14 (left-hand panel). The time switch has been configured to set the volume flow rate to 50 litres per second, on continuously, and the room has been set to be the room in the model. This link ensures that the heat balance calculation in the room takes into account the HVAC network’s contribution to the loads. The components are configured by double-clicking them and changing parameters in the panel that appears (see Fig. 14, right-hand panel, for an example panel for configuring the flow rate controller).

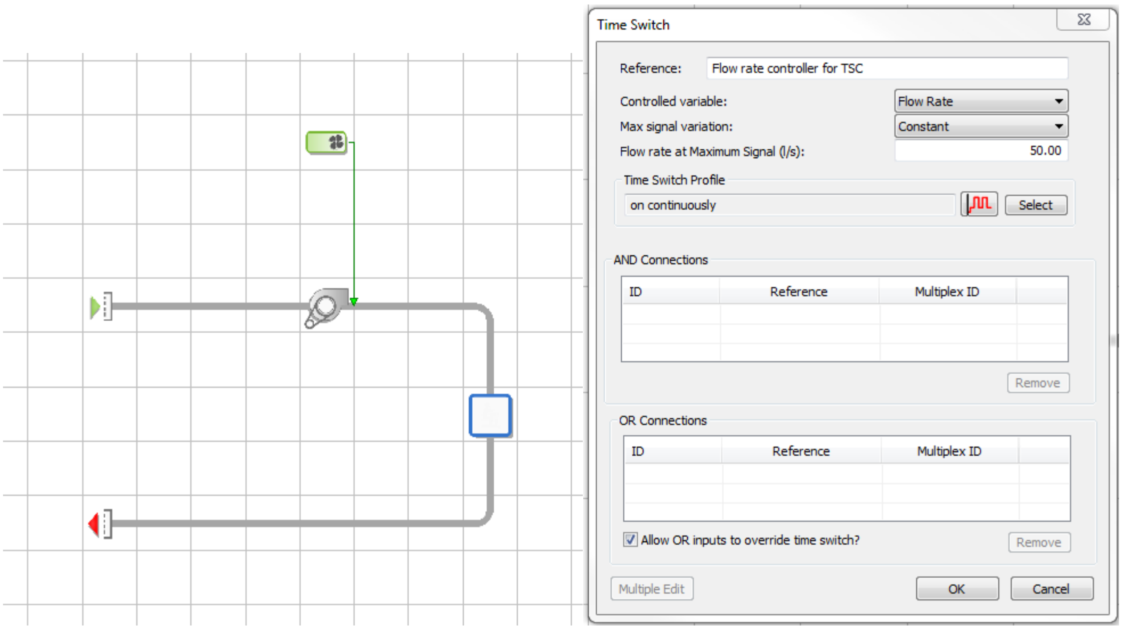


Fig. 14: A simple HVAC network for ventilation of a room (left) and an example configuration panel for the time switch controller (right). The HVAC system contains an air inlet (green arrow icon), air outlet (red arrow icon), supply fan (grey icon), a time switch controller (green icon with small fan symbol) and the room (white square with blue border).

When the thermal model is run, this HVAC network will bring air in from outside at the flow rate set by the controller, add some heat contribution from the fan to the air and dump it into the room. Air in the room will mix and the air movements for the room will be calculated, taking into account open windows, doors, cracks and other openings. The conservation of mass calculation will determine an air flow through the exhaust vent to the air outlet.

7.3 Linking a plenum with the TSC in HVAC

To implement the solar collector into the network, we just replace the air inlet icon with a solar collector icon (although the air leaves the TSC on the top side of the icon rather than the right-hand side). The icon for selecting the solar collector lies immediately to the left of the fans in the module toolbar. The icon and the final completed network are shown in Fig. 15. The air inlet icon is removed by selecting it and pressing the delete key.

The solar collector must be assigned to a particular plenum in the model. This is done by double-clicking on the component and identifying it by its served room ID. Note that although the served room is used to identify the solar collector, the room that actually receives the preheated air is determined purely by the HVAC network (i.e. the room assigned to the white square with the blue border around it in Fig. 14 and 15). Therefore, it is possible to experiment with different HVAC networks that divert flow to other rooms.

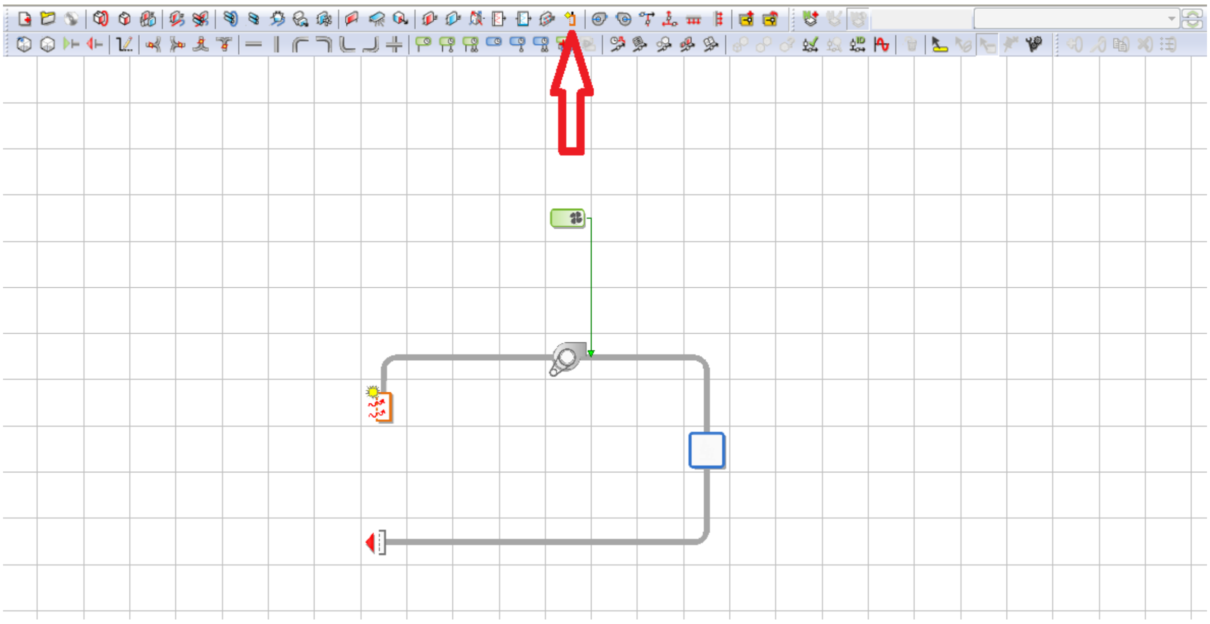


Fig. 15: A simple HVAC network that has a TSC instead of a standard air inlet. The red arrow indicates the icon on the module toolbar that is used to place a solar collector into the network. The HVAC system contains an air inlet (green arrow icon), air outlet (red arrow icon), supply fan (grey icon), a time switch controller (green icon with small fan symbol) and the room (white square with blue border).

When the thermal model runs the volume flow rate at the TSC (which in this case is directly set by the flow rate controller) is compared to the minimum flow rate, which is an intrinsic property of the TSC. If the flow rate is below the minimum flow rate the TSC operates in “passive mode”. In passive mode the TSC behaves much like a normal wall with a small amount of ventilation and its purpose is to correctly model how a TSC should behave when the supply fan is turned off or very low. In this mode, heat pickup from the solar collector is negligibly small and the ventilation in the space is calculated using natural convection laws based on pressure differences between outside air and the plenum cavity. Passive mode is also used if no solar collector is added to the HVAC network (the collector is only treated in the building fabric model) or if ASHRAE loads are being calculated (which do not consider TSCs). CIBSE loads do not implement any TSC or plenum physics and instead treat the collector surface as a standard construction with an additional unperforated steel plate with a U-value set by the TSC construction using the usual layer properties.

If the flow rate exceeds the minimum volume flow rate, the TSC is in active mode, which is the typical operating mode of the TSC. In this mode the heat pickup across the collector is calculated using Kutscher’s heat exchanger theory for vertical TSCs, including relevant convective heat transfer coefficient calculations for TSCs.

A rule of thumb to set a typical volume flow rate for a collector is to use the formula below:

$$\dot{V}_l = 1000\dot{V} = kA$$

where $\dot{V}_l$ is the volume flow rate in litres per second, $\dot{V}$ is the volume flow rate using SI units (i.e. m^3/s), A is the surface area of the solar collector (in m^2) and k is a velocity coefficient related to the suction velocity of the air entering the TSC. The applicable range of k is 10 – 40. For example, if k=25, which can be regarded as typical performance, the volume flow rate for a 100 m^2 collector would be 2.5 m^3/s (or 2500 litres per second). The air intake in this example calculation has a volumetric flux of 90 $m^3/hr/m^2$. Increasing the volumetric flux has the effect of increasing the collector efficiency. However, decreasing the volumetric flux increases the TSC air temperature lift over ambient temperature.

7.4 More realistic control systems

So far the HVAC system has been set up such that the flow rate through the TSC is a constant value of 50 litres per second. It will operate at this flow rate day and night. Typically, solar collectors are only operated during the day and involve controls that tweak the flow rate in order to achieve a desired output temperature. In this subsection, setting a time schedule and implementing recirculation.

7.4.1 Setting a time schedule (profile)

We can set an operating time schedule for the TSC by setting the flow controller to refer to a profile. We can create a profile by clicking the ApPro icon, which is a small sine wave icon in the Apache or ApacheHVAC module toolbar. The icon is shown in Fig. 16.

Fig. 16: The ApPro icon, which used to access a tool for managing time profiles.

ApPro will load into the VE with a list of existing profiles. Profiles in VE are split into five categories: daily profiles, weekly profiles, yearly profiles, free-form profiles and compact profiles. In our case we shall keep things simple and implement a daily profile and a weekly profile.

Ensure that the pattern dropdown has “daily” selected and click on “New” to open up a new panel for defining a new daily profile. The panel with an example of a new profile is shown in Fig. 17.

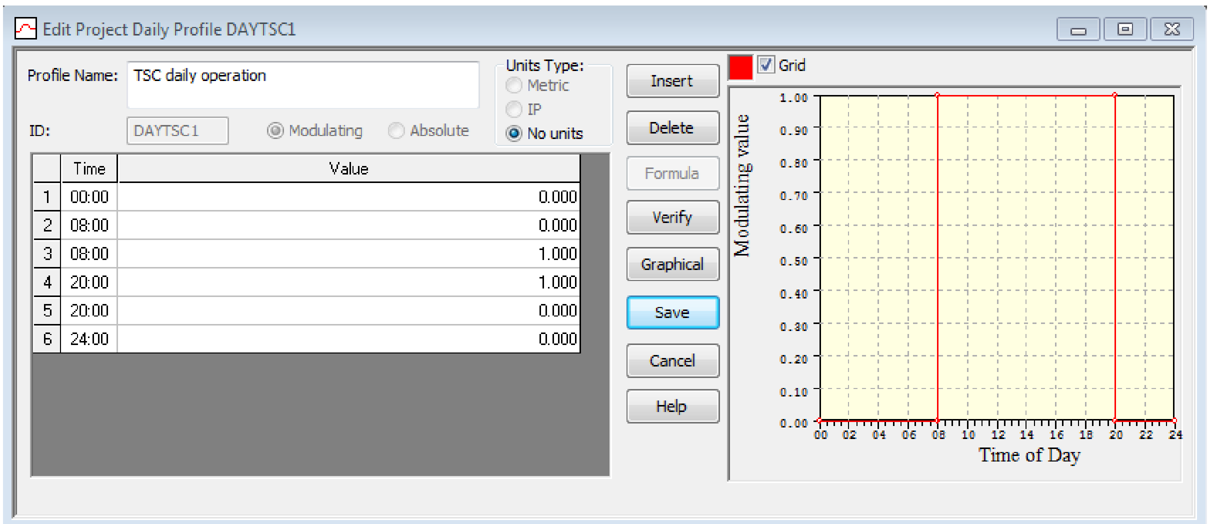


Fig. 17: Panel for defining new daily profiles. The profile is defined by adding new points using the insert button and manually changing each time and value accordingly. For a device that only turns on or off, such as a TSC, the only values we will need are 0 and 1 in a modulating profile. This figure shows a new profile that will signal the TSC to turn on at 8am and off at 8pm.

The profile is defined by adding points using the insert button and changing the values in the table to correspond the times when you want the TSC to turn on or off. In Fig. 17 the profile has been defined such that the TSC will operate (i.e. be in active mode) from 8am to 8pm and will be turned off (i.e. in passive mode) at all other times.

A weekly profile can be created, but this instead uses daily profiles as its input. This panel is shown in Fig. 18.

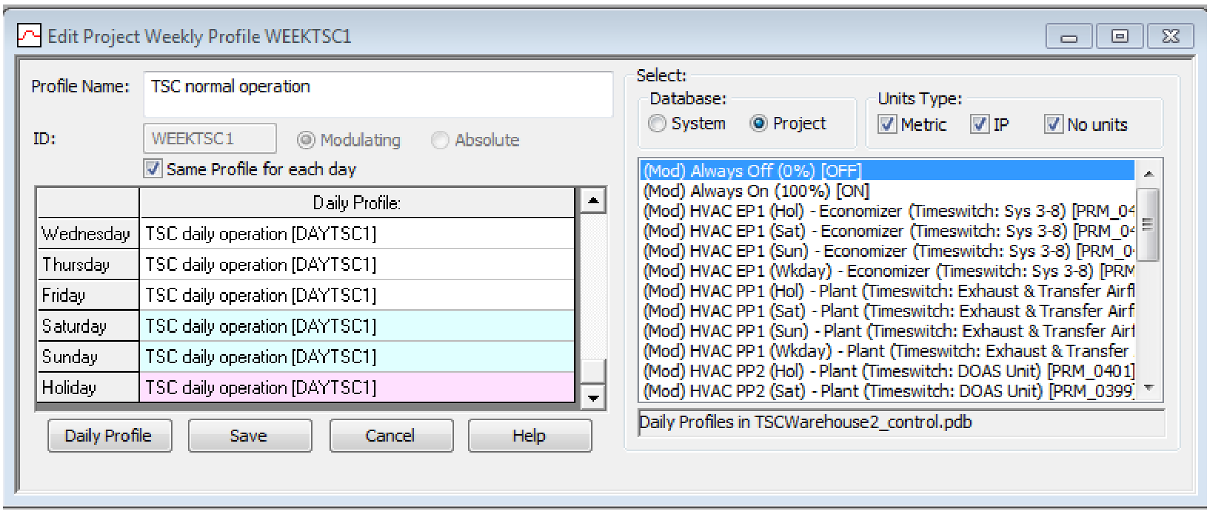


Fig. 18: Panel for defining new weekly profiles. The profile is defined by choosing daily profiles for each day of the week. It is also possible to set daily profiles for national holidays, such as bank holidays, Christmas Day and Boxing Day.

Once you have created the weekly profile, the profile can be assigned to the flow rate controller. This can be set by selecting the time switch profile in the configuration panel for the controller (see Fig. 14, right-hand panel).

7.4.2 Setting up recirculation and temperature control

We will outline here how to set up a system that includes recirculation and supply air temperature control. The first thing to do is to add a mixing damper set to form the recirculation channel. The connectors currently lying in the spot where the damper components will sit will need to be deleted and the damper set can then be placed using the two icons immediately to the right of the fan icons (see also Fig. 19, where the icons are indicated by the arrow). The damper set must be positioned so that each component of the set lies in a vertical line for it to operate correctly. The damper should be configured to have a minimum flow rate lower than the flow rate set by the flow rate controller.

Once the mixing damper set is placed and configured, an additional independent time switch controller should be placed after the damper to set a target temperature. This is done by double clicking the temperature control and setting the Dry-bulb temperature (^{o}C) to the target temperature. The damper set will then modulate automatically during the thermal simulation to mix recirculation air and TSC air to achieve the target temperature.

Once the components are added and configured, the final network should look something like the one in Fig. 19.

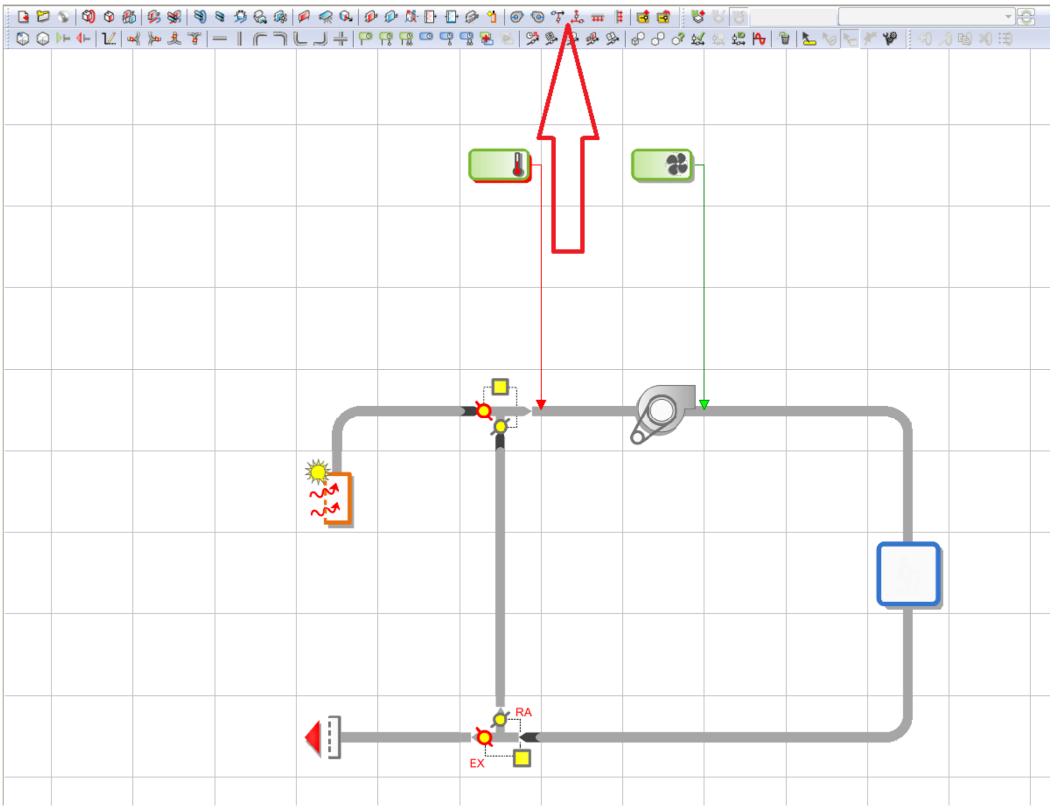


Fig. 19: A HVAC network with a recirculation duct and a mixing damper set. The red arrow indicates the icons on the module toolbar for adding the mixing damper set components.

The HVAC system contains an additional temperature controller which is used to tell the damper which set point to use. The damper will mix air from the TSC and the recirculation air in order to achieve as close as possible the set point of the temperature controller. It is possible to set a minimum flow rate for the mixing damper set by double clicking the top part of the set.

7.4.3 Importing a Colorcoat Renew® HVAC network

Variants A-D of the Colorcoat Renew® systems have been provided for use in Apache HVAC. These networks allow a user to model specific Colorcoat Renew® systems by use HVAC networks that follow as close as possible the control logic of those systems. The control logic for these systems maximises energy delivered into the served room by comparing the space temperature setpoint with the air temperature in the TSC plenum and the ambient air, rather than simply aim to achieve a pre-specified supply temperature. Furthermore, variant C can be used as a sub-network to implement TSCs as part of a large BMS system with 3 different operating modes.

To include one of these networks, go to the navigator and click on "Apply Colorcoat Renew®" to ApacheHVAC system file(s)". This will bring up a box to either apply the network to an existing file or save it as a new file. Create a new file or edit a current one and then go back to the ApacheHVAC application. Open the file to take a look at the imported network. The particular variant imported will depend on which room group the plenum was placed when the plenum was created. An example of this network is shown in Fig. 20 for the case of variant D.

The network components will be set default parameters, but more often than not these parameters will not be optimal to your model. A user can either set all of the parameters manually or use an import parameter panel that can be used to set parameters relevant to the variant. This panel is accessed by double-clicking the grey title bar of the network and selecting "Colorcoat Renew® Import Parameters" and is shown in Fig. 21. The panel lists the various parameters that are used and, once the parameters are set, the parameters are placed in all relevant components.

The import parameters panel is a convenience panel to help users get a feel for what parameters are important to each variant and to help a user perform settings adjustments without having to manually set each component. However, it is only designed to set parameters and any manual tweaks made to the components will not change the contents of the parameters in the panel. Furthermore, the parameters are set according to prefixes in the description of each component (such as TSC_MAX or TSC_FC1), so it is not recommended to delete these prefixes in the description unless you wish an existing component to ignore the import parameters panel. Generally the best course of action is to initially set the parameters using the import parameters panel shown in Fig. 21 and then manually tweak all of the various components in order to make corrections. Components can also be added or removed from the network as required.

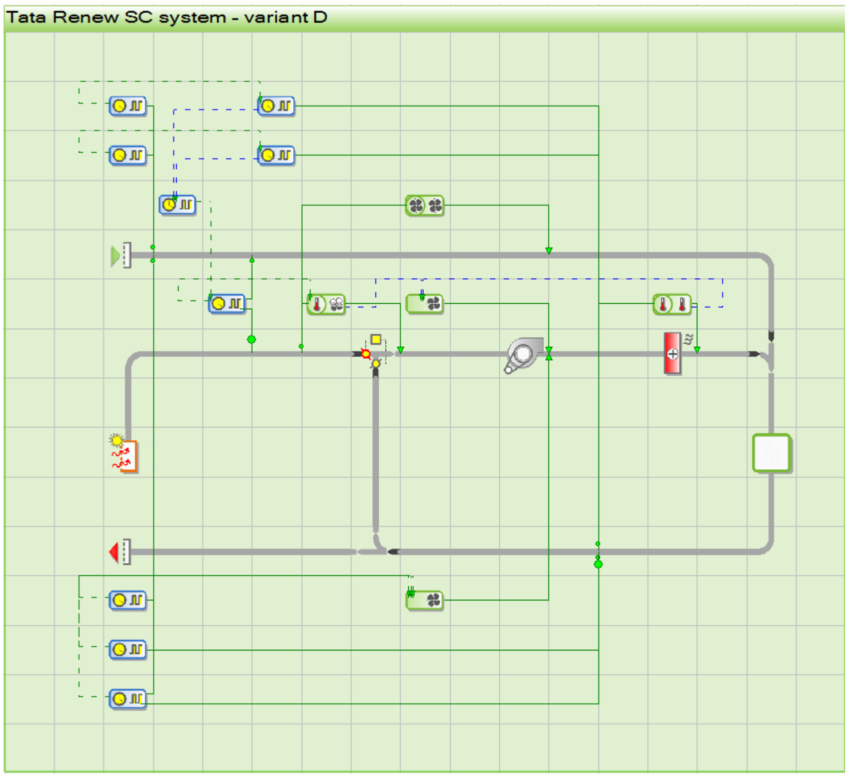


Fig. 20: Imported HVAC network from the navigator. The "Fit view" button may need to be pressed if the network isn't automatically centred in the view.

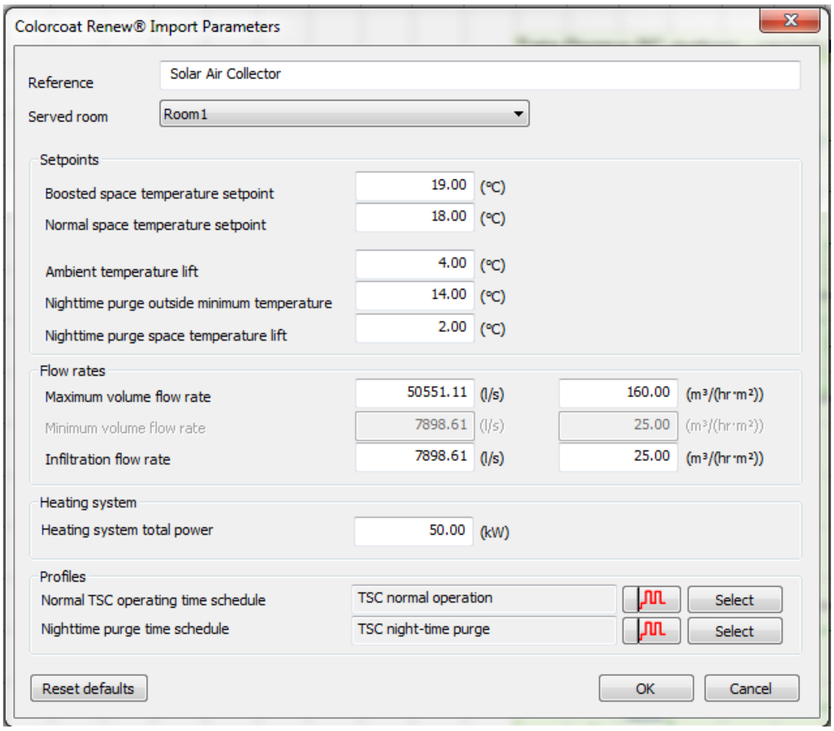


Fig. 21: Import parameters panel for setting component properties in the HVAC network. This panel is only used to set parameters as a whole and any manual changes to the HVAC network will not be replicated in this panel. The flow rates are converted into two sets of units automatically using the known collector surface area.

8 Initiating a thermal model calculation

To calculate the heat transport, open the Apache application in the applications tab. The viewport will shift to the building model. At the bottom of the screen click the button labelled "Apache Sim (Dynamic Simulation)". A panel will open detailing simulation parameters for the run, as shown in Fig. 22. The most important parameters to set specific for TSCs are outlined below:

i) Set the ApacheHVAC link to the HVAC network

In order for the HVAC network created earlier to be included in the thermal calculation, the checkbox "ApacheHVAC link?" must be checked and the network must be specified in the dropdown list.

ii) Include component output

Click on the "Output options" button and make sure the box "ApacheHVAC component results" is selected; the output variables for the TSC are accessed through the HVAC component results in VistaPro.

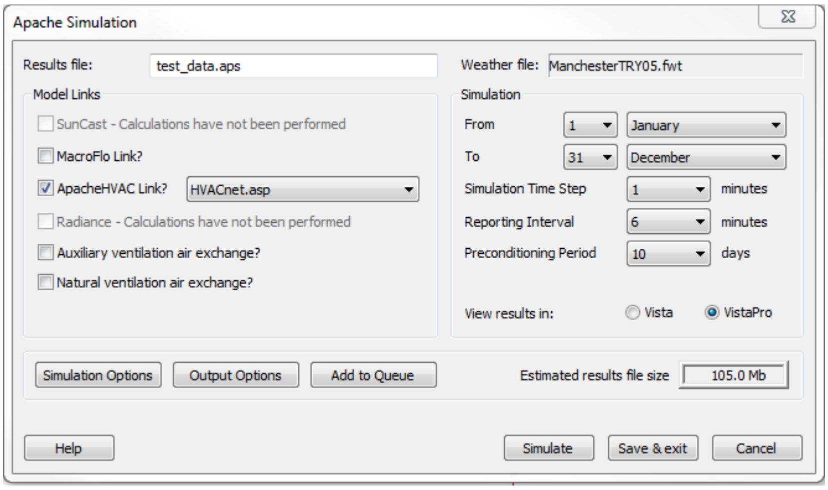


Fig. 22: Apache simulation dialogue for initiating a thermal calculation.

Once these settings are made, click the "Simulate" button to initiate the thermal model.

9 Possible error messages and solutions

- **Error: TSC component Solar Air Collector detected in .sdb file, but no matching plenums were detected. Please check to ensure that all TSC components in HVAC are assigned to served room and that these assignments are consistent with those in ModelIt.**

  In ApacheHVAC, open the HVAC network we created and double click on the TSC component. In the dropdown list, change the “Room:” from “Unset” to the served room ID in the model.

- **There are one or more unassigned Room component(s) and/or Active Duct location(s) in the ApacheHVAC network. These assignments are required for the simulation to run.**

  In ApacheHVAC, open the HVAC network we created and double click on the room (white square with blue border and blue question mark). In the dropdown list, change the “Room:” from “Unset” to the served room ID in the model or the room in the model you wish to receive the preheated air from the TSC.

- **Can’t run Apache. The HVAC network check has failed; please open the network and run the network check to see the details of the failure message below!**

  Controllers must be defined.

  The HVAC network needs controllers. Two independent time switches need to be added, with one set to be a temperature control and one set to be a flow rate control (see Fig. 19). The parameters are set by double clicking the controller after it is placed. Also ensure that the controller points to the correct point in the HVAC network. The point in the network where the controller set a value can be changed by single clicking a controller and then dragging the arrow to a different position in the network.

- **Can’t run Apache. The HVAC network check has failed; please open the network and run the network check to see the details of the failure message below!**

  Selected controller[ID: <controller ID>] is disconnected.

  The arrow indicating the position in a network where a controller is set is accidentally floating. This often occurs when a controller is moved. If you single-click the controller with the floating arrow to select it, the arrow can be dragged to place it back onto a network connection.

- **Error: Flow at node <node number> cannot be set – insufficient control definition.**
- **Error: Flow overspecified at HVAC damper set inlet or splitter outlet node <node number>.**

  There are too few, too many or incorrectly placed controllers in the HVAC network. The network in Fig. 19 only needs a single flow rate controller in the loop downstream of the mixing damper because the mixing damper sets the flow in the recirculation channel automatically based on the mix of air required to achieve the target temperature set by the temperature control. Ensure that you are using a mixing damper set (rather than standard branch connectors), that the mixing damper set components lay in a vertical line and that the controller positions set by the arrows are positioned correctly according to Fig. 19.

10 Querying results

10.1 Making plots

Thermal results are queried by using the VistaPro application. At the end of the Apache simulation focus will automatically be shifted to VistaPro, but the module can be selected at any time on the applications panel. The screen should look something like that of Fig. 23, except that the viewport will contain the building model instead of the HVAC network.

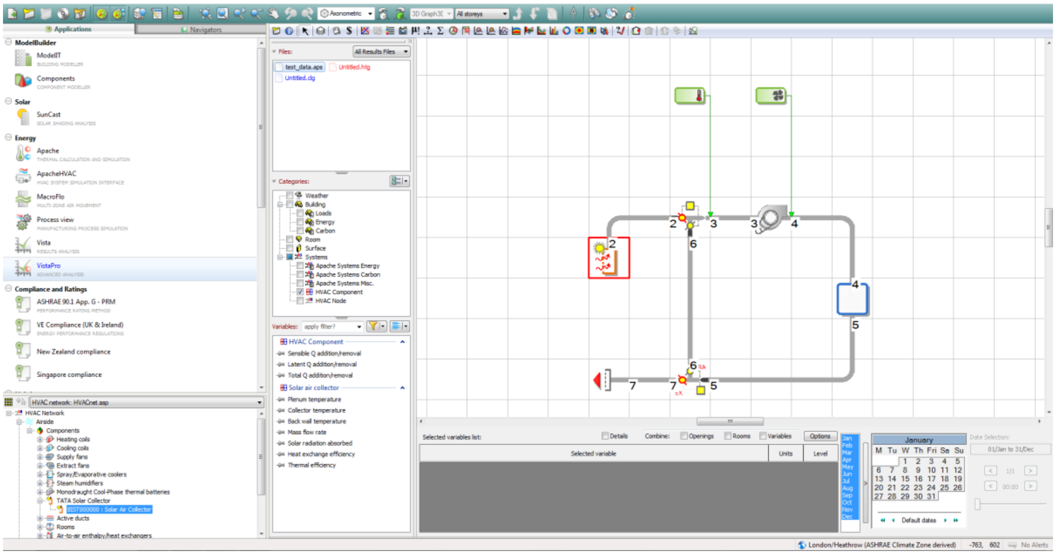


Fig. 23: The VistaPro display. The list browser dropdown in the bottom-left hand corner has the HVAC network selected, so the viewport displays the HVAC network instead of the building model. The bottom panel contains the variables currently selected and the time domain selector. The variables available for numerous visualisation functions are available are in the middle lower panel, which are categorised. The categories are in the panel above the variables and the data files are at the top-most panel. Various charts, tables and functions for data manipulation are found on the module toolbar.

To bring the HVAC network up in the viewport, select the HVAC network from the list browser in the bottom-left corner of the screen. Clicking on nodes (indicated by the numbers) or components will allow you to access the data regarding those objects.

One of the most useful functions is the graph function, which can be accessed from the menu titled “Analysis” at the top of the screen (or using the seventh icon from the left in the module toolbar). After selecting the solar collector and a variable (such as plenum air temperature), the graph function can be used to plot that variable over the whole year. A particular portion of data of data can be defined using the time domain selector in the bottom-right hand corner. Individual days or months can be plotted by clicking and a range can be plotted by holding shift whilst clicking. Similarly, multiple variables can also be selected by using control- or shift-clicking.

10.2 Typical results

The following graphs represent typical operating results for a TSC. A one-room model with a HVAC network of variant D was used to determine the following results. These results can be used to identify whether a TSC system is operating normally.

10.2.1 Temperature response

According to Kutscher's heat exchanger theory, the temperature of the plenum air should decrease with increasing flow rate. This behaviour is seen in Fig 24, where the plenum air temperature dips as the temperature increases. This is because the collector plate and the plenum air are strongly coupled in terms of heat transfer, so as heat exchange between the collector plate and the plenum air increases, the temperature of both the collector and the plenum air decreases relative to the case without a TSC.

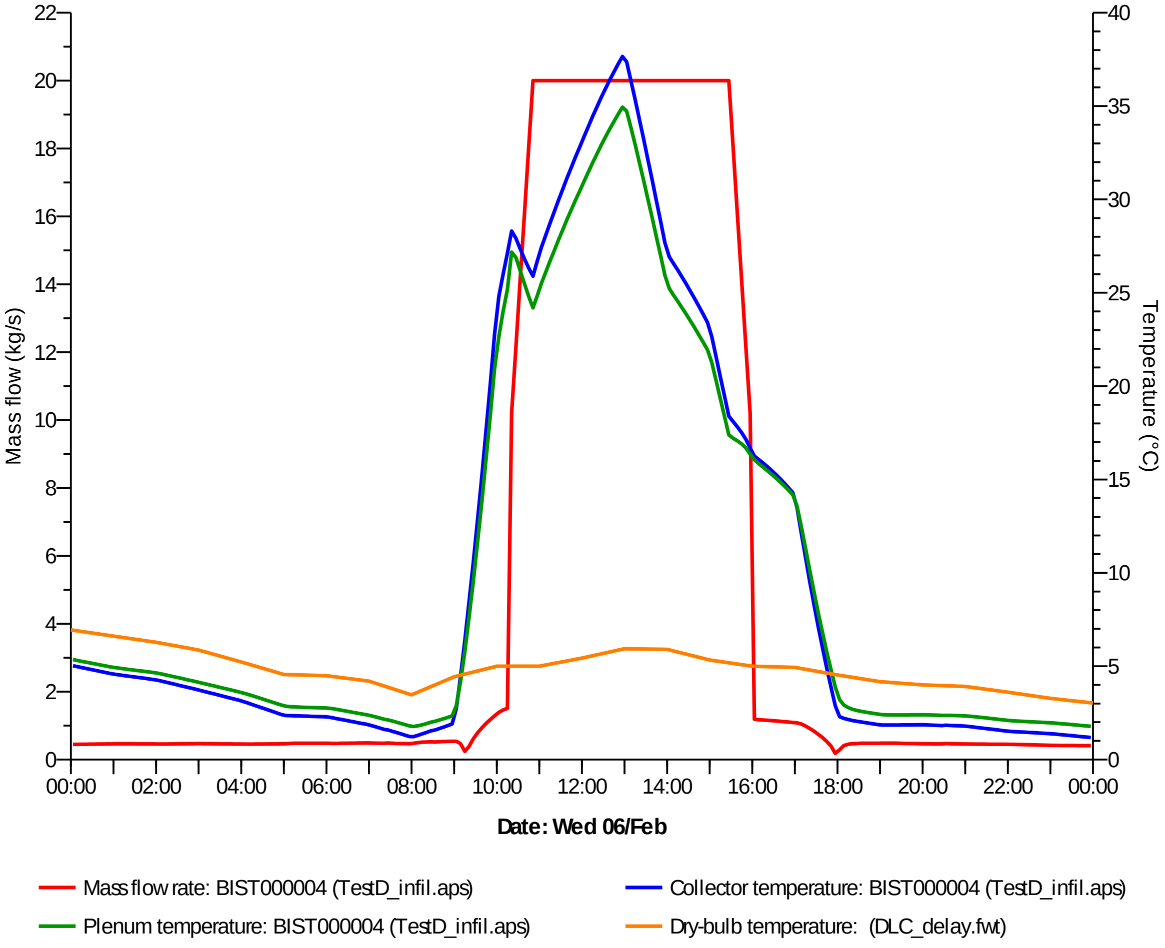


Fig. 24: Typical plenum temperature response for a TSC. When the flow rate demand increases, the plenum temperature decreases. The reason for this is that the plenum temperature depends heavily on the collector temperature. Note the dip in temperature of both the collector and the plenum air at 10:30 when the TSC fan turns on. Also note that during the night the temperature of the plenum air and the collector is lower than the ambient air. This is because during night-time the collector plate radiates to the external environment, causing heat to be lost.

10.2.2 Efficiency

There are two measures of efficiency of a TSC; the heat exchange efficiency and the thermal efficiency. The heat exchange efficiency, ε_{HX}, is defined as

$$\varepsilon_{\mathrm{HX}} \equiv \frac{(T_{\mathrm{ent}} - T_{\mathrm{o}})}{(T_{\mathrm{c}} - T_{\mathrm{o}})}$$

where T_{ent} is the plenum air temperature immediately following heat exchange with the collector, T_{o} is the ambient air temperature and T_{c} is the collector temperature. This efficiency is a direct measure of how effective heat transfer is at the collector plate as heat is picked up from the plate to the air stream. The heat exchange efficiency is inversely proportional to the flow rate, so heat transfer is more effective at low flow rates. However, this parameter does not take into account the ability of the system to actually transfer energy from the collector plate, which depends on the external irradiance, to the plenum air stream. Therefore, the heat exchange efficiency is a poor measure of the overall effectiveness of a TSC. A better diagnostic is the thermal efficiency, defined as the ratio of the heat transferred into the air stream and the absorbed solar irradiance

$$\eta \equiv \frac{\dot{m} c_P (T_{\mathrm{ent}} - T_{\mathrm{o}})}{I_{abs}}$$

where $\dot{m}$ is the mass flow rate (kg/s), c_{P} is the heat capacity of air (J/kg/K)and I_{abs} is the absorbed solar irradiance (W). This parameter is zero when no solar radiation is impinging on the collector plate, increases slightly for passive mode and increases significantly for active mode. Efficiencies during active mode will be approximately 50 – 70%, but higher instantaneous efficiencies can be attained depending on the weather conditions and the TSC controls. Both the heat exchange efficiency and thermal efficiency are plotted in Fig. 25.

Energy delivered is also plotted on Fig. 25. Energy delivered is only calculated if the TSC is operating in active mode. This explains the non-zero thermal efficiency at 09:30 in Fig. 25 whilst the energy delivered at that time is zero. The energy delivered is the only parameter with this constraint and is purposefully set in order to allow annual yields to be calculated for the TSC. Yields can be determined by clicking the “Sigma” icon in the VistaPro module toolbar when the energy delivered parameter is selected. Yields are an important indicator for the performance of a TSC because they directly quantify the amount of renewable heat brought into the building as preheated air through the TSC system. An example table of yields is given in Tab. 1 below.

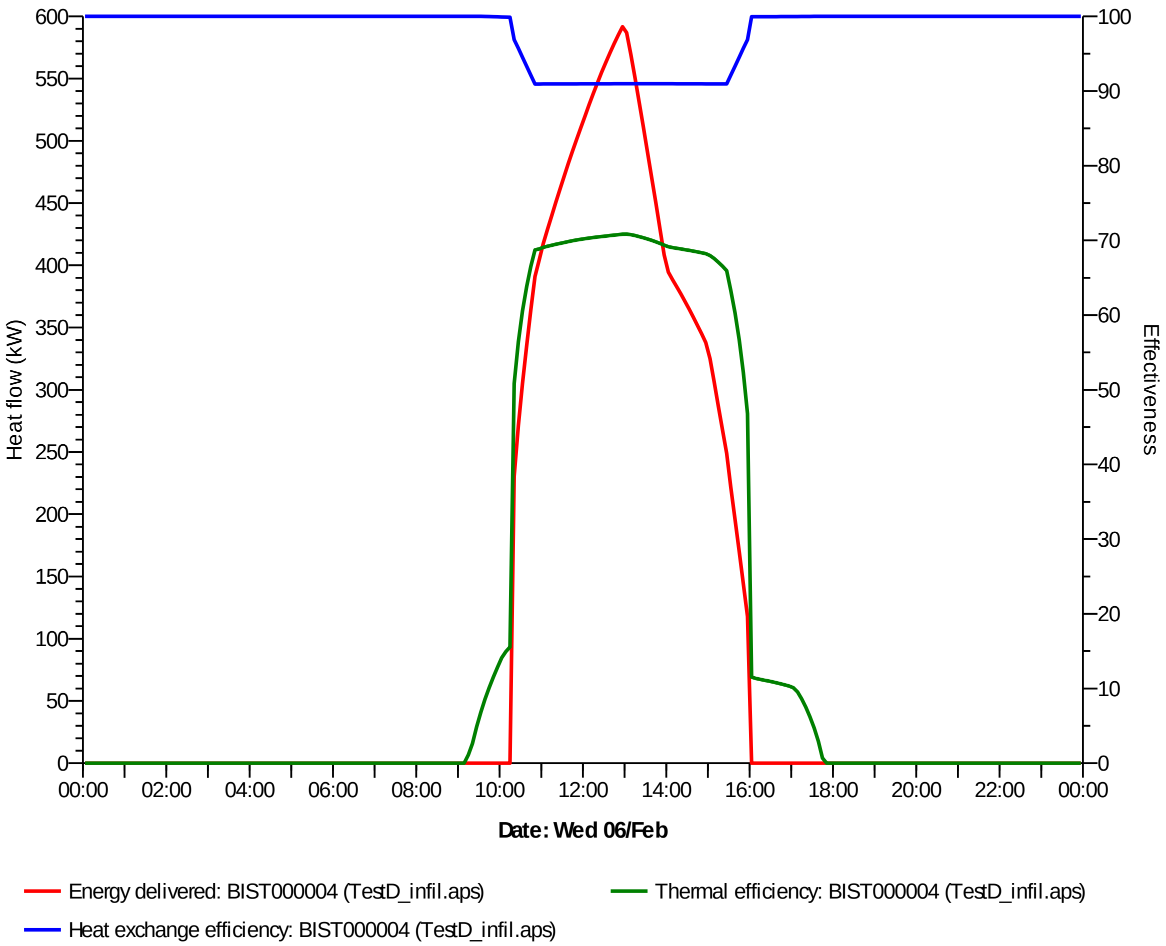


Fig. 25: Heat exchange efficiency, thermal efficiency and energy delivered as a function of time for the same data and day displayed in Fig. 24.

Date	**Energy delivered (MWh)**
Jan 01-31	13.5694
Feb 01-28	30.6018
Mar 01-31	33.7730
Apr 01-30	51.0475
May 01-31	50.0850
Jun 01-30	42.2745
Jul 01-31	5.2620
Aug 01-31	16.4549
Sep 01-30	26.1170
Oct 01-31	25.8060
Nov 01-30	27.3739
Dec 01-31	23.2001
Summed total	**345.5652**

Tab. 25: An example of annual yields for a TSC system. For this model, where variant D is used for the HVAC control system, the yields are greatest during the spring and autumn months where there is both heating demand and significant daytime solar irradiance on the collector plate.

10.3 Exporting data

Data from Vista can be exported as a table by selecting the variables you wish to export and selecting the table function from the VistaPro module toolbar. There is a limit to how much data can be exported in a single file, so it will be necessary to split the whole dataset into parts by variable or by time domain if the amount of data to export is large.

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