LinkageJS Requirements Specification

(Working Draft)

Oct 28, 2019

Contents

Chapter 1

Preamble and Conventions

This documentation specifies the requirements for LinkageJS software: a graphical user interface for editing Modelica models of HVAC and control systems.

It is intended to be mainly used as a discussion basis with the software development team.

Therefore the proposed design should not be considered finalized and will evolve as the development progresses.

Conventions

The words *must, must not, required, shall, shall not, should, should not, recommended, may, optional* in this document must be interpreted as described in RFC2119.

Chapter 2

Process Workflow

To be updated.

Chapter 3

Requirements

Todo: How to extract CDL part (to be translated) from whole system model?

- Specification with the configuration widget of "unbreakable" parts of the control sequence.
- Also need to 1) expand arrays into scalar instances and connections 2) suppress bus gateway variables `connect(v1, bus.v); connect(v2, bus.v)` into `connect(v1, v2)` unless supported by CDL spec. & translator?

Devise how return status signals can be generated for components that do not have built-in output status variables.

- Typically the pump model: difficult to implement without state event, otherwise short circuit the input control signal potentially with a `pre` operator.

Specify how modifying mo files so that diffs are minimal? The diff has to be done on JSON objects only?

3.1 General Description

3.1.1 Main Requirements

The software is primarily a graphical user interface for editing Modelica models in a diagrammatic form: see Section 3.2 and Section 3.3.

Built around this core functionality the following additional features are required:

1. A configuration widget supporting assisted modeling based on a simple HTML input form: see Section 3.4
2. A schematics export functionality: see Section 3.5
3. A set of functionalities to enable working with tagged variables: see Section 3.6

In terms of software design:

- The software must rely on client side JS code with minimal dependencies and must be built down to a single page HTML document (SPA).
- A widget structure is required that allows seamless embedding into:

- a desktop app – with standard access to the local file system,
- a standalone web app – with access to the local file system limited to Download & Upload functions of the web browser (potentially with an additional sandbox file system to secure backup in case the app enters an unknown state),
- any third party application with the suitable framework to serve a single page HTML document executing JS code – with access to the local file system through the API of the third party application:
  - the primary target is OpenStudio® (OS),
  - an example of a JS application embedded in OS is FloorspaceJS. The standalone SPA lives here: https://nrel.github.io/floorspace.js. FloorspaceJS may be considered as a reference for the development.

Note: Those three integration targets are actual deliverables.

- A Python or Ruby API is required to access the data model and leverage the main functionalities of the software in a programmatic way e.g. by OpenStudio measures.

3.1.2 Software Compatibility

The software requirements regarding platform and environment compatibility are presented in Table 3.1.

Table 3.1: Requirements for software compatibility

Feature	Support
Platform (minimum version)	Windows (10), Linux Ubuntu (18.04), OS X (10.10)
Mobile device	iOS, Android?
Web browser	Chrome, Firefox, Safari

3.1.3 UI Visual Structure

A responsive design is required.

A minimal mockup of the UI is presented Fig. 3.1.

The minimal requirements are:

- Left panel: library navigator
- Main panel: model editor with diagram, icon, documentation or code view
- Right panel:
  - Configuration tab, see Section 3.4
  - Connections tab, see Section 3.4.4.4
  - Parameters tab, see Section 3.4.5
- Menu bar
- Bottom panel: console

The placement of the different UI elements may be different than the one proposed here above but the user must have access to all those elements. Ideally a toggle feature should be implemented to show or hide each side panel, either by user click if the panel is pinned or automatically. Optionally a fully customizable workspace may be implemented.

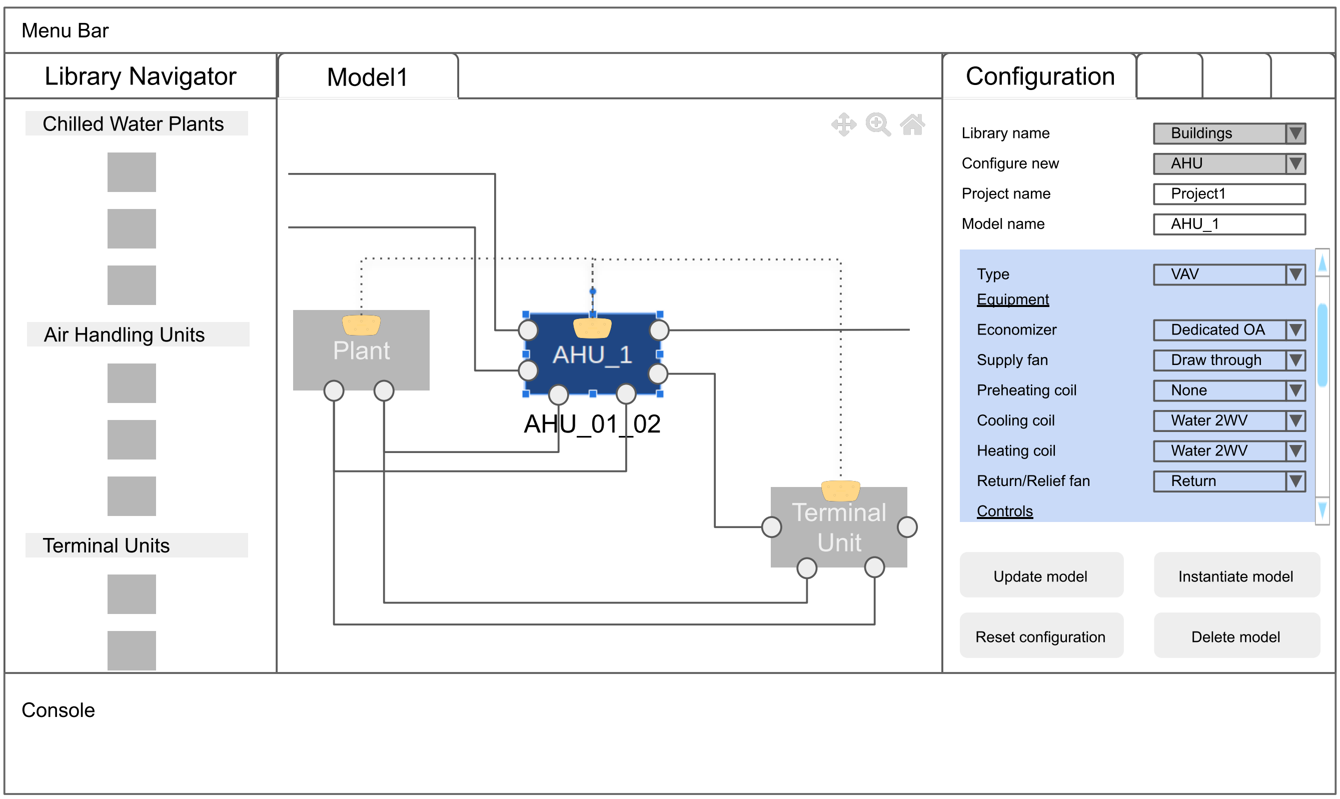

Fig. 3.1: UI Visual Structure

3.2 Detailed Functionalities

Table 3.2: Functionalities of the software – R: required, P: required partially, O: optional, N: not required

Feature	V0	V1	Comment
Main functionalities			(as per Section 3.1)
Diagram editor for Modelica models	R		See detailed requirements below.
Configuration widget	P	R	An alpha version of the widget is required in V0 for testing and refining the requirements.
Schematics export	N	R	
Working with tagged variables	N	R	
I/O			
Load `mo` file	P	R	To be updated cf. different integration targets Simple Modelica model or full package (V0). If the model contains annotations specific to the configuration widget (see Section 3.4), the corresponding data are loaded in memory for further configuration. If the model contains the Modelica annotation `uses` the corresponding library is loaded. If a package is loaded the structure of the package and sub packages is checked against *Chapter 13 Packages* (V1).
Export *mo* file	R		“Total model” export option?
Export simulation results	R		Export in the following format: `mat, csv`. All variables or selection based on variables browser (see below).
Variables browser	P	R	Query selection of model variables based on regular expression (V0) or Brick/Haystack tag [Bri] [Hay] (V1)
Plot simulation results	N	O	
Export control points summary	R		Relies on LBL module to generate the list of A/B I/O variables.
Export schematics	P	R	Only the equipment drawing in V0. Control points and SOO description in V1 see Fig. 3.16. Relies on LBL module CDL to Word translator.
Import/Export data sheet?	P	R	Additional module to 1) generate a file in CSV or JSON format from the configuration data (V0) 2) populate the configuration data based on a file input in CSV or JSON format (V1).
Modelica features			
Checking the compliance with Modelica standard	P	R	Real-time checking of syntax (V0) and connection (V1).

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Table 3.2 – continued from previous page

Feature	V0	V1	Comment
Translate model	P		The software settings allow the user to specify a command for translating the model with a third party Modelica tool e.g. JModelica. The output of the translation routine is logged in LinkageJS console.
Simulate model	P		The software settings allow the user to specify a command for simulating the model with a third party Modelica tool e.g. JModelica. The output of the simulation routine is logged in LinkageJS console.
Automatic medium propagation between connected components	P	P	Partially supported because only the configuration widget integrates that feature. When generating `connect` equation manually a similar approach as the *fluid path* used by the configuration widget may be developed, see components with 4 ports and 2 medium.
Support of Modelica graphical annotations	R		
Modelica code editor	P	R	Raw text editor (V0) with linter and Modelica specification check upon save (V1) Note that this functionality requires translation and reverse translation of JSON to Modelica (those translators being developed by LBL).
Icon editor	O	R	Editing functionalities similar to diagram editor
Documentation view	R		
Library version management	O	R	If a loaded model contains the Modelica annotation `uses` e.g. `uses(Buildings(version="6.0.0")` the software checks the version number of the stored library, prompts the user for update if the version number does not match, executes the conversion script per user request.
Path discovery	R		A routine to reconstruct the path or URL of a referenced resource within the loaded Modelica libraries is required. Typically a resource can be referenced with the following syntax `modelica://Buildings.Air.Systems.SingleZone.VAV`.
Object manipulation			
Vectorized instances	R		An array dimension descriptor appending the name of an object is interpreted as an array declaration. Further connections to the connectors of that object must comply with the array structure.
Expandable connectors	R		

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Table 3.2 – continued from previous page

Feature	V0	V1	Comment
Navigation in object composition	R		Right clicking an icon in the diagram view offers the option to open the model in another tab
Multiple objects selection for input of common parameters	O	R	If several objects are selected only their common parameters are listed in the Parameters panel. If a parameter alue s modified, all the selected objects will have their parameter value change.
Avoiding duplicate names	R		When instantiating a component, if the default name is already used in the model the software automatically appends he name with the lowest integer value that would ensure uniqueness. When copying and pasting a set of objects connected together, the set of connect equations is updated to ensure consistency with the appended object names.
Graphical features			A user experience similar to modern web based diagramming applications is expected e.g. draw.io.
Tab view	R		The diagram view is organized in tabs that can be manipulated, created and deleted typically as navigation tabs n a eb browser.
Diagram split view	N	R	The diagram view can be split (horizontally and vertically) into several views. Each tab can be dragged and dropped from one view to another. The views are synchronized so that if the same model is open in different views and gets modified, all the views of the model are updated to reflect the modifications.
Copy/Paste objects	R		Copying and pasting a set of objects connected together copies the objects declarations and the corresponding connect equations.
Pan and zoom on mouse actions	R		
Undo/Redo	R		
Draw shape, text box	O	R	
Start connection line when hovering connectors	O	R	
Connection line jumps	O	R	Gap jump at crossing
Customize connection lines	O	R	Color, width and line can be specified in the annotations panel
Hover information	R		Class path when hovering an object in the diagram view and tooltip help for each GUI element
Color and style of connection lines	P	R	Allow the user to manually specify (right click menu) the style of the connections lines (V0). When generating a `connect` equation automatically select a line style based on some heuristic to be further specified (V1).

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Table 3.2 – continued from previous page

Feature	V0	V1	Comment
Drawing guides	P	R	Snap to grid (V0) and alignment lines with neighbor objects (V1) with the option to enable/disable those guides.
Miscellaneous			
Choice of units SI / IP	?	?	
User documentation	R		User manual of the GUI and the corresponding API. Both an HTML version and a PDF version are required (may rely on Sphinx).
Developer documentation	R		All classes, methods, free functions and modules must be documented with an exhaustive description of the functionalities, parameters and return values. UML diagrams should also be provided. At least an HTML version is required, PDF version is optional (may rely on Sphinx or VuePress).

3.3 Modelica Graphical User Interface

3.3.1 Modelica Language

The software must comply with the Modelica language specification [Mod17] for every aspect relating to (the chapter numbers refer to [Mod17]):

- validating the syntax of the user inputs: see *Chapter 2 Lexical Structure* and *Chapter 3 Operators and Expressions*,
- the connection between objects: see *Chapter 9 Connectors and Connections*,
- the structure of packages: see *Chapter 13 Packages*,
- the annotations: see *Chapter 18 Annotations*.

3.3.2 JSON Representation

LBL has already developed a Modelica to JSON translator Modelica to JSON translator. This development includes the definition of two JSON schemas:

1. Schema-modelica.json validates the JSON files parsed from Modelica.
2. Schema-CDL.json validates the JSON files parsed from CDL (subset of Modelica language used for control sequence implementation).

Those developments should be leveraged to define a JSON-based native format for LinkageJS.

3.3.3 Connection Lines

When drawing a connection line between two connector icons in the diagram view:

- a `connect` equation with the references to the two connectors must be created,
- with a graphical annotation defining the connection path as an array of points and providing an optional smoothing function e.g. Bezier.

- When no smoothing function is specified the connection path must be rendered graphically as a set of segments.
- The array of points must be either:
  - created fully automatically when the next user's click after having started a connection is made on a connector icon. The function call `create_new_path(connector1, connector2)` creates the minimum number of *vertical or horizontal* segments to link the two connector icons with the constraint of avoiding overlaying any instantiated object,
  - created semi automatically based on the input points corresponding to the user clicks outside any connector icon: the function call `create_new_path(point[i], point[i+1])` is called to generate the path linking each pair of points together.
- The first and last couple of points must be so that the connection line does not overlap the component icon but rather grows the distance to it, see Fig. 3.2.

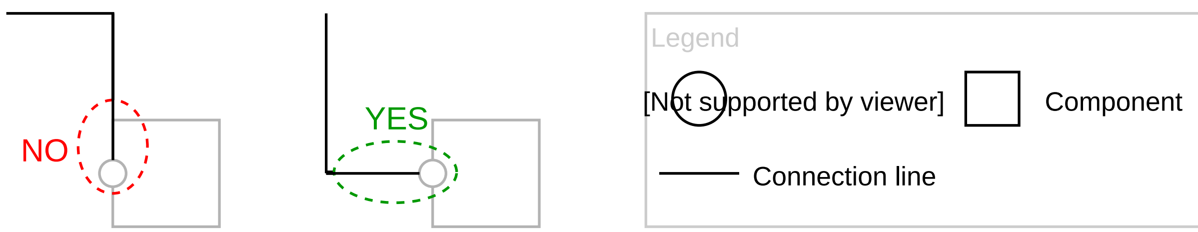


Fig. 3.2: Logic for generating a connection line in the neighborhood of a connector

3.4 Configuration Widget

3.4.1 Functionalities

The configuration widget allows the user to generate a Modelica model of an HVAC system and its controls by filling up a simple input form. It is mostly needed for integrating advanced control sequences that can have dozens of I/O variables. The intent is to reduce the complexity to the mere definition of the system's layout and the selection of standard control sequences already transcribed in Modelica [LBNL19].

Note: CtrlSpecBuilder is a tool widely used in the HVAC controls industry for specifying control sequences. It may be used as a reference for the development in terms of user experience minimal functionalities. Note that this software does not provide any Modelica modeling functionality.

There are fundamental requirements regarding the Modelica model generated by the configuration widget:

1. It must be "graphically readable" (both within LinkageJS and within any third-party Modelica GUI e.g. Dymola): this is a strong constraint regarding the placement of the composing objects and the connections that must be generated automatically.
2. It must be ready to simulate: no additional modeling work or parameters setting is needed outside the configuration widget.

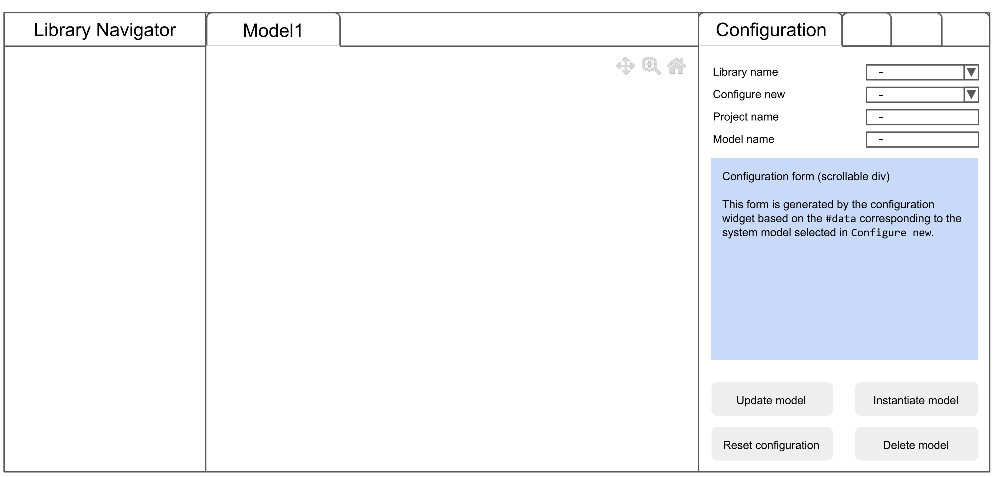
3. It must contain all annotations needed to regenerate the HTML input form when loaded, with all entries corresponding to the actual state of the model.
    - Manual modifications of the Modelica model made by the user are not supported by the configuration widget: an additional annotation should be included in the Modelica file to flag that the model has deviated from the template. In this case the configuration widget is disabled when loading that model.
4. The implementation of control sequences must comply with OpenBuildingControl requirements, see *§7 Control Description Language* and *§8 Code Generation* in [LBNL19]. Especially:
    - It is required that the CDL part of the model can be programmatically isolated from the rest of the model in order to be translated into vendor-specific code (by means of a third-party translator).
    - The expandable connectors (control bus) are not part of CDL specification: **how to represent communication between sub-systems?**

The input form is provided by the template developer (e.g. LBL) in a data model with a format that is to be further specified in collaboration with the software developer.

The data model typically provides for each entry:

- the HTML widget and populating data to be used for requesting user input,
- the modeling data required to instantiate, position and set up the parameters of the different components,
- some tags to be used to automatically generate the connections between the different components connectors.

The user interface logic is illustrated in figures Fig. 3.3 and Fig. 3.4: the comments in those figures are part of the requirements.



`Update model`
Implement the configuration options specified by the user in the `Configuration form` by instantiating and connecting objects in the file `#library/User/#project/#model`.

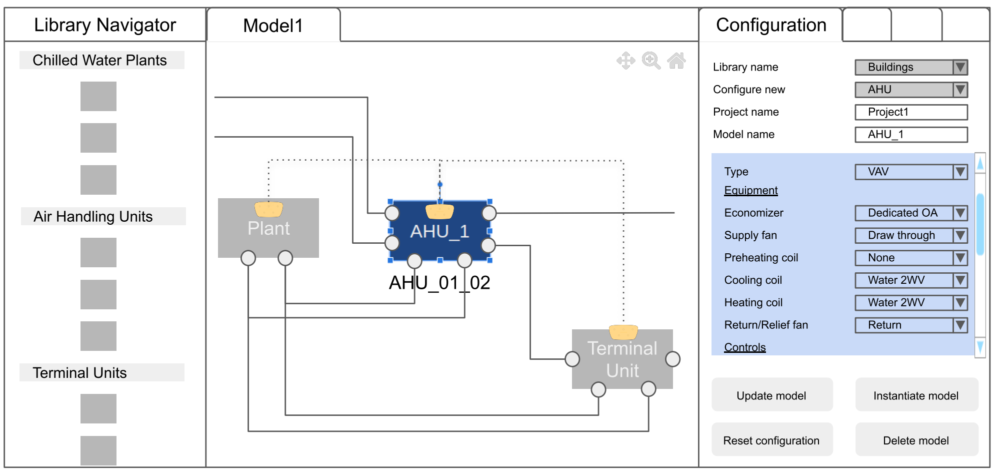
`Instantiate model`
Update and instantiate the class `#library/User/#project/#model` in the model loaded in the active tab of the main panel (here `Model1`).

`Reset configuration`
Reset the configuration options to the default values.

`Delete model`
Delete the class `#library/User/#project/#model` and all its instances in the model loaded in the active tab of the main panel (here `Model1`).

When no object is selected in the diagram view this is the default view for the `Configuration` panel.
The `Library name` is the last value selected (further referenced as `#library`). The drop down menu allows selecting between loaded libraries. The `Library name` is used to 1) load the configuration data stored in `#library/Configuration` directory, 2) define the root path of the directory where the built models will be saved i.e. `#library/User/*/`.
The `Configure new` drop down menu allows selecting the type of system model to configure. The menu is populated by `#data/#system.value` for all configuration data files in `#library/Configuration`.
The `Project name` is the last value entered (further referenced as `#project`). A real-time form test is required to validate the user input against syntax requirements and avoid duplicate in `#library/User`. The path of the directory where the built models will be saved is `#library/User/#project`.
The `Model name` is by default `#data/#name.value` (further referred to as `#model`). It can be modified by the user (call a `rename_class` function if the model has already been saved). A real-time form test is required to validate the user input against syntax requirements and avoid duplicate in `#library/User/#project`.

Fig. 3.3: Configuration widget – Configuring a new model



`Update model`
Implement the configuration options specified by the user in the `Configuration form` by instantiating and connecting objects in the file `#library/User/#project/#model.`

`Instantiate model`
Update and instantiate the class `#library/User/#project/#model` in the model loaded in the active tab of the main panel (here `Model1`).

`Reset configuration`
Reset the configuration options to the default values.

`Delete model`
Delete the class `#library/User/#project/#model` and all its instances in the model loaded in the active tab of the main panel (here `Model1`).

This is the view for the `Configuration` panel if:

- one object is selected in the main panel,
- and the corresponding class contains a model annotation `__Linkage_data(...)` providing the configuration data in a JSON-serialized format (further referred to as `#data`).

The `Configuration` panel is populated with the values from `#data`.
The `Library name` and `Configure new` fields are locked.
The `Project name` can be modified: when clicking `Update model` this will call a `move_class` function.
The `Model name` can be modified: when clicking `Update model` this will call a `rename_class` function.
All configuration options can be modified: when clicking `Update model` this will update the class `#library/User/#project/#model`.

Fig. 3.4: Configuration widget – Configuring an existing model

Equipment and controller models are connected together by means of a *control bus*, see Fig. 3.16: the upper-level Modelica model including the equipment and controls models is the ultimate output of the configuration widget, see Fig. 3.4 where the component named `AHU_1_01_02` represents an instance of the upper-level model `AHU_1` generated by the widget. That component exposes the outside fluid connectors as well as the top level control bus.

The logic for instantiating classes from the library is straightforward. Each field of the form specifies:

- the reference of the class (library path) to be instantiated depending on the user input;
- the position of the component in simplified grid coordinates to be converted in diagram view coordinates.

Section 3.4.3 and Section 3.4.4 address how the connections between the connectors of the different components are generated automatically based on this initial model structure.

3.4.2 Data Model

The envisioned data structure supporting the configuration process consists in:

- placement coordinates provided relatively to a simplified grid, see Fig. 3.5 – those must be mapped to Modelica diagram coordinates by the widget,
- an `equipment` section referencing the components that must be connected together with fluid connectors, see Section 3.4.3,
- a `controls` section referencing the components that must connected together with signal connectors, see Section 3.4.4,
- a `dependencies` section referencing additional components with the following characteristics:
  - they typically correspond to sensors and outside fluid connectors,
  - the model completeness depends on their presence,
  - the requirements for their presence can be deduced from the equipment and controls options,
  - they do not need additional fields in the user form of the configuration widget.

3.4.2.1 Format

A robust syntax is required for:

- auto-referencing the data structure e.g. `#type.value` refers to the value of the field `value` of the object which `$id` is `type`: must be interpreted by the configuration widget and replaced by the actual value when generating the model,
- conditional statements: potentially every field may require a conditional statement – either data fields (e.g. the model to be instantiated and its placement) or UI fields (e.g. the condition to enable a widget itself or the different options of a menu widget).

Ideally the syntax should also allow iteration `for` loops to instantiate a given number (as parameter) of objects with an offset applied to the placement coordinates e.g. chiller plant with `n` chillers. Backup strategy: define all (e.g. 10) possible instances and enable only the first `n` ones based on a condition.

Possible formats:

- JSON: preferred format but expensive syntax especially for boolean conditions or auto-referencing the data structure: is there any standard syntax?
- Specific format to be defined in collaboration with the UI developer and depending on the selected UI framework

3.4.2.2 Parameters Exposed by the Configuration Widget

The template developer is free to declare in the template any parameter of the composing components e.g. `V_flowSup_nominal` and reference them in any declaration e.g. `Buildings.Fluid.Movers.SpeedControlled_y(m_flow_nominal=(#air_supply.medium).rho_default / 3600 * #V_flowSup_nominal.value)`. The configuration widget must replace the referenced names by their actual values (literal or numerical). The user will be able to override those values in the parameters panel e.g. if he wants to specify a different nominal air flow rate for the heating or cooling coil. See additional requirements regarding the persistence of those references in Section 3.4.2.4.

Some parameters must be integrated in the template (examples below are provided in reference to `Buildings.Controls.OBC.ASHRAE.G36_PR1.AHUs.MultiZone.VAV.Controller`):

- when they impact the model structure e.g. `use_enthalpy` requires an additional enthalpy sensor: in that case the model declaration must use the `final` qualifier to prevent the user from overriding those values in the parameters panel,
- when no default value is provided e.g. `AFlo` cf. requirement that the model generated by the configuration widget must be ready to simulate.

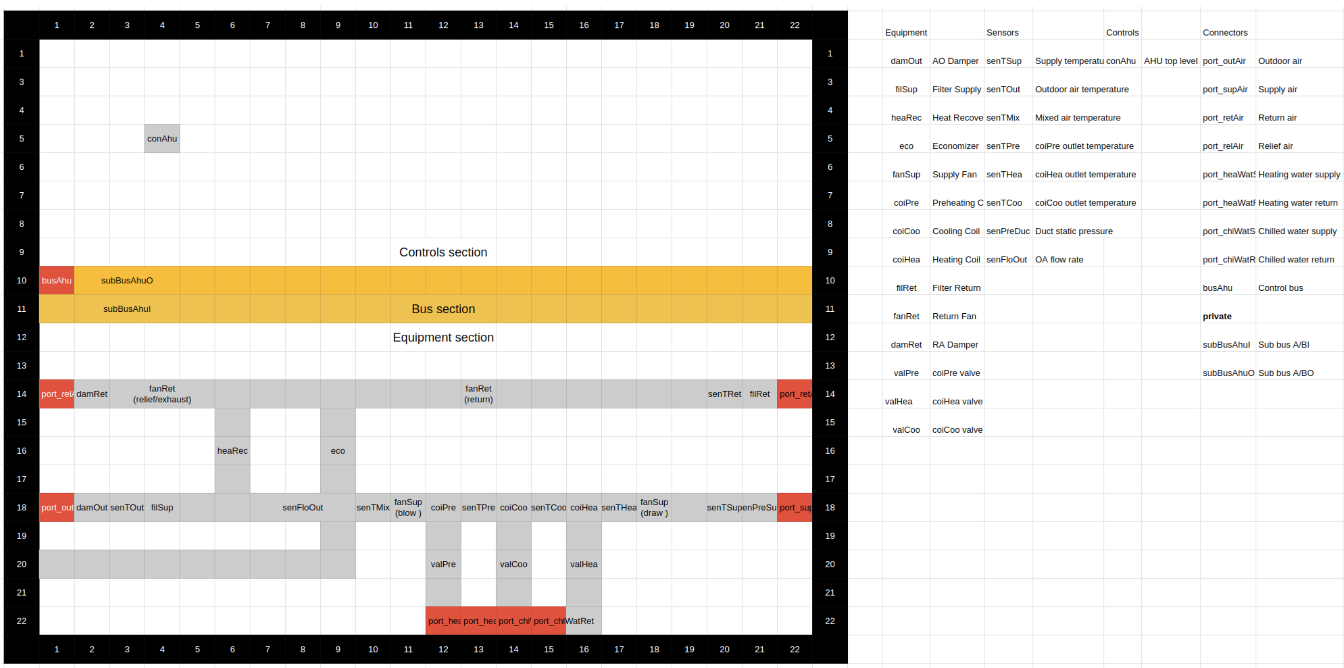


Fig. 3.5: Simplified grid providing placement coordinates for all objects to be instantiated when configuring an AHU model

3.4.2.3 API Description

For each object, the fields are defined as follows. When the type of a field is specified as a string marked with (C) it may correspond to:

- a conditional statement provided as a string that must be interpreted by the UI engine,

- a reference to another field value of type boolean (that may itself correspond to a conditional statement provided as a string).
- The syntax supporting this feature shall be specified in collaboration with the UI developer.

Note: The syntax must support e.g. `(#air_supply.medium).rho_default` where the first dot is used to access the property `medium` of the configuration object with `$id == #air_supply` (which must be replaced by its value) while the second dot is used to access Modelica property `rho_default` of the class `Medium` (which must be kept literal).

Configuration object definition

`type` : object : required

Type of system to configure e.g. air handling unit, chilled water plant.
Object defined as *elementary object*.

required : `[$id, description, value]`

`subtype` : object : required

Subtype of system e.g. for an air handling unit: variable air volume or dedicated outdoor air.
Object defined as *elementary object*.

required : `[$id, description, widget, value]`

`name` : object : required

Name of the component. Must be stored in the Modelica annotation `defaultComponentName`.
Object defined as *elementary object*.

required : `[$id, description, widget, value]`

`fluid_paths` : array : required

items : object

Definition of all parent fluid paths of the model.
Object defined as follows.

required : `[$id, direction, medium]`

`$id` : string : required

Unique string identifier starting with `#`.

`direction` : string : required

enum : `["north", "south", "east", "west"]`

Direction indicating the order in which the components must be connected along the path.

`medium` : string : required

Common medium for that fluid path and all derived paths e.g. `"Buildings.Media.Air"`

`icon` : string : required

Path to icon file.

`diagram` : object : required

Size of the diagram layout.

Object defined as follows.

`configuration` : array : required

items : integer

Array on length 2, providing the number of lines and columns of the simplified grid layout.

`model` : array : required

items : array

Array on length 2 providing the coordinates tuples of two opposite corners of the diagram rectangular layout.

items : integer

Array on length 2 providing the coordinates of one corner of the diagram rectangular layout.

`equipment` : array : optional

items : object

Object defined as *elementary object*.

`controls` : array : optional

items : object

Object defined as *elementary object*.

`dependencies` : array : optional

items : object

Object defined as *elementary object*.

Elementary Object Definition

`$id` : string : required

Unique string identifier.
Used for referencing the object properties in other configuration objects: references are prefixed with `#` in the examples e.g. `#id_value.property`.
If the object has a `declaration` field, the name of the declared component is the value of `$id`.
Must be suffixed with brackets e.g. `[2]` in case of array variables.

`description` : string : required

Descriptive string.

If the object has a `declaration` field, the descriptive string appends the component declaration in the Modelica source file (referred to as *comment* in *§4.4.1 Syntax and Examples of Component Declarations* of [Mod17]).

`enabled` : boolean, string (C) : optional, default `true`

Indicates if the object must be used or not. If not, the UI does not display the corresponding widget, no modification to the model is done and the object field `value` gets assigned its **default value or null?**.

`widget` : object : optional

Object defined as follows.

`type` : string : required

Type of UI widget.

`options` : array : optional

items : string

Options to be displayed by certain widgets e.g. dropdown menu.

`options.enabled` : array : optional

items : boolean, string (C)

Indicates which option can be selected by the user. Must be the same size as `widget.options`.

`value` : string (C), number, boolean, null : required

[*enum* : `widget.options` (if provided)]

Value of the object (default value prior to user input).

May be provided as a literal expression in which all literal references to object properties (prefixed with `#`) must be replaced by their numerical value.

`unit` : string : optional

Unit of the value. Must be displayed in the UI.

`declaration` : array, string (C), null : optional

[*items* : string (C)]

Any valid Modelica declaration(*) (component or parameter) or an array of those that has the same size as `widget.options` if the latter is provided (in which case the elements of `declaration` get mapped with the elements of `widget.options` based on their indices).

Note: (*) The name of the instance is not included in the declaration but provided with the `$id` entry: it must be inserted between the class reference and the optional parameters of the instance (specified within parenthesis).

If one option requires multiple declarations, the first one should typically be specified here and the other ones as dependencies.

`placement` : array, string (C) : optional

[*items* : array, integer]

[*items* : integer]

Placement of the component icon provided in simplified grid coordinates `[line, column]` to be mapped with the model diagram coordinates.

Can be an array of arrays where the main array must have the same size as `widget.options` if the latter is provided (in which case the elements of `placement` get mapped with the elements of `widget.options` based on their indices).

`connect` : object : optional

Data required to generate the connect equations involving the connectors of the component, see Section 3.4.3.

Object defined as follows.

`type` : string : optional, default `path`

enum : `["path", "tags", "explicit"]`

Type of connection logic.

`value` : string (C), object : required

If `type == "path"`: fluid path (string) that must be used to generate the tags in case of two connectors only. It must not be used if the component has more than two connectors or a non standard connectors scheme (different from one instance of `Modelica.Fluid.Interfaces.FluidPort_a` and one instance of `Modelica.Fluid.Interfaces.FluidPort_b`).

If `type == "tags"`: object providing for each connector (referenced by its instance name) the tag to be applied.

If `type == "explicit"`: object providing for each connector (referenced by instance name) the connector to be connected to, using explicit names e.g. `fanSup.port_a`.

`annotation` : array, string (C), null : optional

[*items* : string (C)]

Any valid Modelica annotation or an array of those which must have the same size as `widget.options` if the latter is provided (in which case the elements of `annotation` get mapped with the elements of `widget.options` based on their indices).

`protected` : boolean : optional, default `false`

Indicates if the declaration should be public or protected.

All protected declarations must be grouped together at the end of the declaration section in the Modelica model (to avoid multiple `protected` and `public` specifiers in the source file).

`symbol_path` : string (C) : optional

Path of the SVG file containing the engineering symbol of the component. This is needed for the schematics export functionality, see Section 3.5. That path path is specified by the template developer and not in the class definition because the same class can be used to represent different equipment parts e.g. a flow resistance model can be used to represent either an air filter (SVG symbol needed) or a duct section (no SVG symbol needed).

`icon_transformation` : string (C) : optional

Graphical transformation that must be applied to the component icon e.g. `"flipHorizontal"`.

An example of the resulting data structure is provided in annex, see Section 5.1.

3.4.2.4 Persisting Data

Path of the Configuration File

The path (relative to the library entry path, see *Path discovery* in Table 3.2) must be stored in a hierarchical vendor annotation at the model level e.g. `__Linkage(path="modelica://Buildings.Configuration.AHU")`.

Configuration Objects

The `value` of all objects must be stored with their `$id` in a serialized format within a hierarchical vendor annotation at the model level. (This is done at the model level since some configuration data may be linked to some model declarations indirectly using dependencies so annotations at the declaration level would not cover all use cases.)

This is especially needed so that the references to the configuration data in the object declarations persist when saving and loading a model.

There are two kind of references:

- LinkageJS references prefixed by `#` which must be interpreted by the configuration widget and replaced by their actual value e.g. `"declaration": "Modelica.Fluid.Interfaces.FluidPort_a (redeclare package Medium=#air_supply.medium)"` for the object `"$id": "id_value"` leads to `Modelica.Fluid.Interfaces.FluidPort_a id_value(redeclare package Medium=Buildings.Media.Air)` in the generated model.
- Modelica references provided as literal variables e.g. `"declaration": "Buildings.Fluid.Movers.SpeedControlled_y (m_flow_nominal=m_flowRet_nominal)"` for the object if `"$id": "id_value"` leads to `Buildings.Fluid.Movers.SpeedControlled_y id_value(m_flow_nominal=m_flowRet_nominal)` in the generated model.

Unless specified as `final` those references may be overwritten by the user. When loading a model the configuration widget must parse the `$id` and `value` of the stored configuration data and reconstruct the corresponding model declarations using the configuration file (and interpreting the references prefixed by `#`). Those declarations are compared to the ones present in the model: if they differ, the ones in the model take precedence.

Engineering Symbol SVG File path

The path (`symbol_path` in *Configuration API*) is stored in a vendor annotation at the declaration level e.g. `annotation(__Linkage(symbol_path="value of symbol_path"))`.

3.4.3 Fluid Connectors

The fluid connections (`connect` equations involving two fluid connectors) must be generated based on either:

- an explicit connection logic relying on one-to-one relationships between connectors (see Section 3.4.3.1) or,
- a heuristic connection logic (see Section 3.4.3.2) based on:
  - the coordinates of the components in the diagram layout i.e. after converting the coordinates provided relatively to the simplified grid,
  - a tag applied to the fluid connectors (or fluid ports) of the components.

3.4.3.1 Explicit Connection Logic

In certain cases it may be convenient to specify explicitly a one-to-one connection scheme between the connectors of the model e.g. a differential pressure sensor to be connected with the outlet port of a fan model and a port of a fluid source providing the reference pressure.

That logic is activated at the component level by the keyword `connect.type == "explicit"`.

The user provides for each connector the name of the component instance and connector instance to be connected to e.g. `"port_1": "component1.connector2`.

3.4.3.2 Heuristic Connection Logic

That logic relies on connectors tagging which supports two modes:

1. Default mode (`connect.type == "path"` or `null`)
   - By default an instance of `Modelica.Fluid.Interfaces.FluidPort_a` (resp. `Modelica.Fluid.Interfaces.FluidPort_b`) must be tagged with the suffix `inlet` (resp. `outlet`).
   - The tag prefix is provided at the component level to specify the fluid path e.g. `air_supply` or `air_return`.
   - The fluid connectors are then tagged by concatenating the previous strings e.g. `air_supply_inlet` or `air_return_outlet`.
2. Detailed mode (`connect.type == "tags"`)
   - An additional mechanism is required to allow tagging each fluid port individually. Typically for a three way valve, the bypass port should be on a different fluid path than the inlet and outlet ports see Fig. 3.6. Hence we need a mapping dictionary at the connector level which, if provided, takes precedence on the default logic specified above.
   - Furthermore a fluid connector may be connected to more than one other fluid connector (fork configuration). To support that feature the concept of *derived path* is introduced: if `fluid_path` is the name of a fluid path, each fluid path named `/^fluid_path_((?!_).)*$/gm` is considered a *derived path*. The original (derived from) path is the *parent path*. A path with no parent path is referred to as *main path*.
     For instance in case of a three way valve the mapping dictionary may be:
     `{"port_1": "hotwater_return_inlet", "port_2": "hotwater_return_outlet", "port_3": "hotwater_supply_bypass_inlet"}` where `hotwater_supply_bypass` is a derived path from `hotwater_supply`.

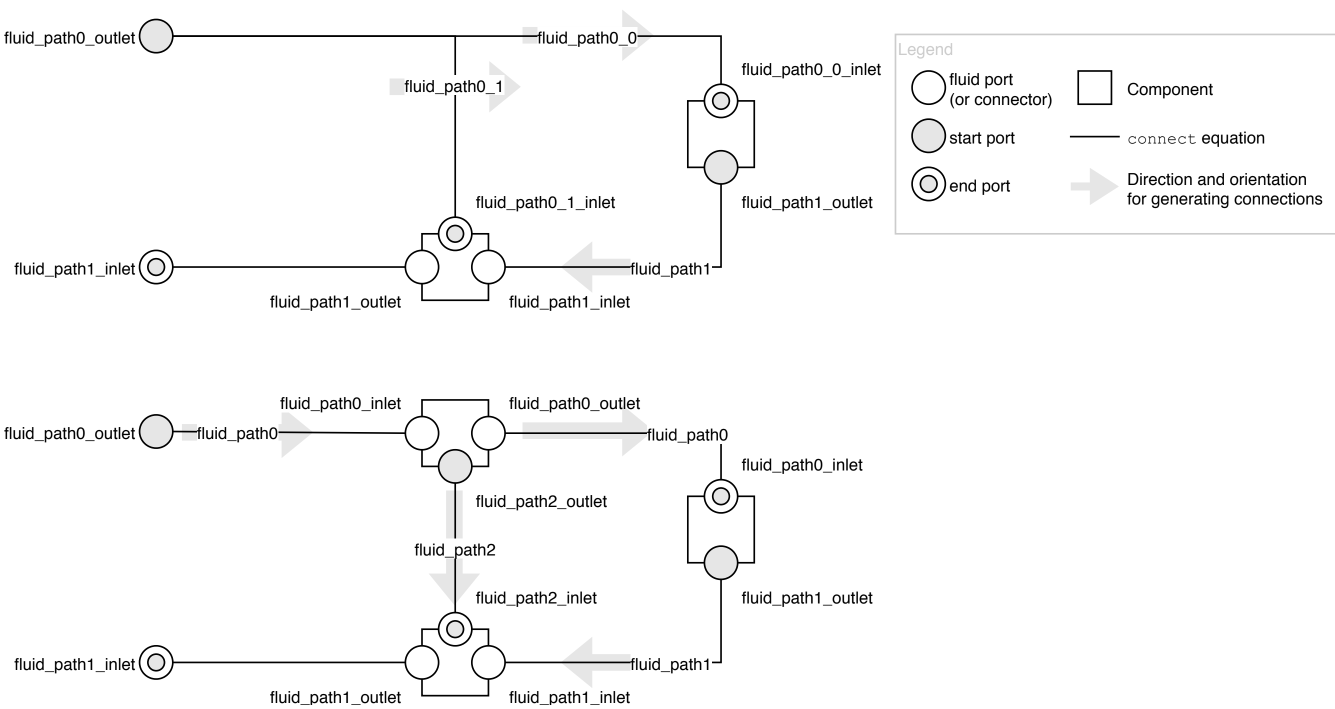


Fig. 3.6: *Example of the connection scheme for a three-way valve. The first diagram does not include an explicit model of the fluid junction whereas the second does (and represents the highly recommended modeling approach). This example illustrates how the fluid connection logic allows for both modeling approaches. In the first case the bypass and direct branches are derived paths from* `fluid_path0` *which consists only in one connector. In the second case they are different main paths, the bypass branch having a different direction than the direct branch (the user could also use an "explicit" connection logic to avoid the definition of an additional main fluid path).*

The conversion script throws an exception if an instantiated class has `connect.type != "explicit"` and some fluid ports that cannot be tagged nor connected with the previous logic e.g. non default names and no (or incomplete) mapping dictionary provided. Once the tagging is resolved for all fluid connectors of the instantiated objects with `connect.type != "explicit"`, the connector tags are stored in a list, furthered referred to as "tagged connectors list". All object names in that list thus reference instantiated objects with fluid ports that have to be connected to each other.

To build the full connection set, the direction (north, south, east, west) along which the objects must be connected needs to be provided for all main (not derived) fluid paths.

Note: The direction (as well as the fluid medium) of a derived path are inherited from the parent path.

Modelica `connect` construct is symmetric so at first glance only the vertical / horizontal direction of a fluid path seems enough. However the actual orientation along the fluid path is needed in order to identify the start and end connectors, see below.

The connection logic is then as follows:

- List all the different fluid paths in the tagged connectors list as obtained by truncating `_inlet` and `_outlet` from each connector name. Get the direction of the main fluid paths in the configuration data and finally reconstruct the tree structure of the fluid paths based on their names:

```
└── fluid_path0 (direction: east): [connectors list]
  ├── fluid_path0_0 (inherited direction: east): [connectors list]
  └── fluid_path0_1 (inherited direction: east): [connectors list]
    ├── fluid_path0_1_0 (inherited direction: east): [connectors list]
    └── fluid_path0_1_1 (inherited direction: east): [connectors list]
├── fluid_path1 (direction: west): [connectors list]
├── fluid_path3 (direction: north): [connectors list]
└── fluid_path4 (direction: south): [connectors list]
```

- For each fluid path:
  - Order all the connectors in the connectors list according to the direction of the fluid path and based on the position of the corresponding *objects* (not connectors) with the constraint that for each object `inlet` has to be listed first and `outlet` last.
  - For each derived path find the start and end connectors as described hereunder and prepend / append the connectors list.
    * If the first (resp. last) connector in the ordered list is an outlet (resp. inlet), it is the start (resp. end) connector. (Note that the reciprocal is not true: a start port can be either an inlet or an outlet see Fig. 3.7.)
    * Otherwise the start (resp. end) connector is the outlet (resp. inlet) connector of the object in the parent path placed immediately before (resp. after) the object corresponding to the first (resp. last) connector – where before and after are relative to the direction and orientation of the fluid path (which are the same for the parent path).
  - For each *parent path* split the path into several *sub paths* whenever a connector corresponds to the start or end port of a derived path.
  - Throw an exception if one of the following rules is not verified:
    * Derived paths must start *or* end with a connector from a parent path.
    * Each branch of a fork must be a derived path, it cannot belong to the parent path: so no object from the parent path can be positioned between the objects corresponding to the first and last connector of any derived path.

  - Generate the `connect` equations by iterating on the ordered list of connectors and generate the connection path and the corresponding graphical annotation. The only valid connection along a fluid path is `outlet` with `inlet`.
  - Populate the `iconTransformation` annotation of each outside connector instantiated as a dependency so that, in the icon layer, they belong to the same border (top, left, bottom, right) as in the diagram layer and be evenly positioned considering the icon's dimensions. The bus connector is an exception and must always be positioned at the top center of the icon.

That logic implies that within the same fluid path, objects are connected in one given direction only: to represent a fluid loop (graphically) at least two fluid paths must be defined, typically `supply` and `return`.

Fig. 3.7 to Fig. 3.9 further illustrate the connection logic on different test cases.

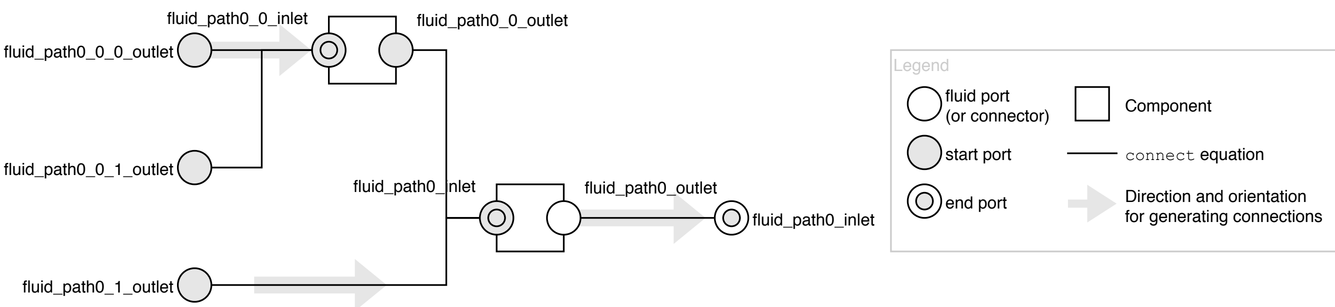


Fig. 3.7: Connection scheme with nested fluid junctions not modeled explicitly

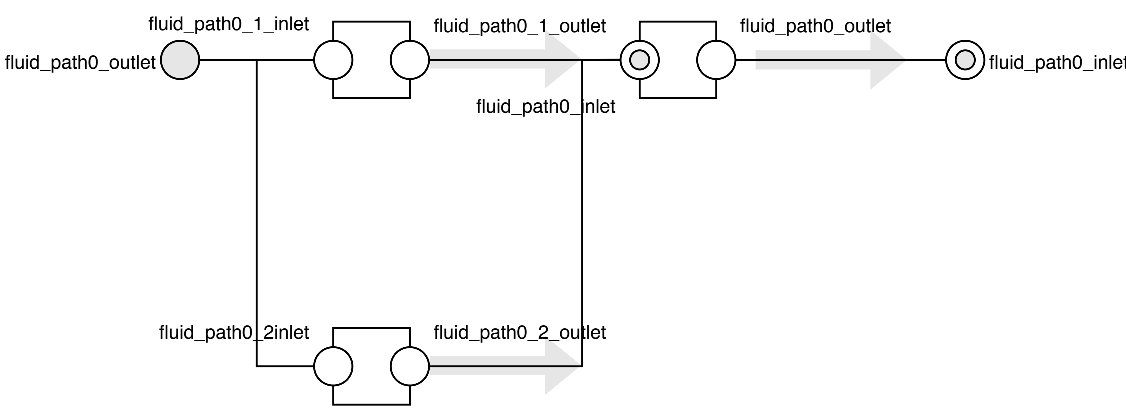


Fig. 3.8: Connection scheme with fluid branches with identical directions e.g. AHU with dedicated outdoor air damper for economizer

3.4.4 Signal Connectors

3.4.4.1 General Principles

Generating the `connect` equations for signal variables relies on:

- a (fuzzy) string matching principle applied to the names of the connector variables and their components e.g. `com.y` for the output connector `y` of the component `com`,

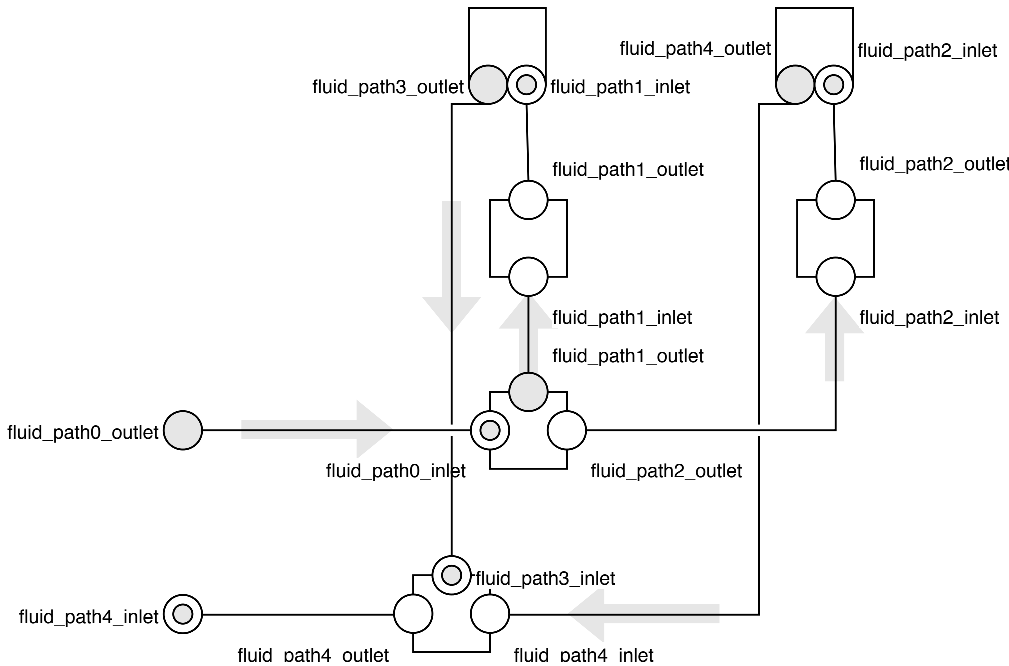


Fig. 3.9: Connection scheme with fluid branches with different directions e.g. VAV duct system. Here a flow splitter is used to start several main fluid paths with a vertical connection direction.

- a so-called *control bus* which has the type of an expandable connector, see *§9.1.3 Expandable Connectors* in [Mod17].
  (For clarity it may be useful to group control input variables in one sub-bus and control output variables in another sub-bus. The experience feedback on bus usage in Modelica shows that restricting the number of sub-buses and the use of bus variables to sensed and actuated signals only is a preferred option.)

The following features of the expandable connector are leveraged:

1. All components in an expandable connector are seen as connector instances even if they are not declared as such. In comparison to a non expandable connector, that means that each variable (even of type `Real`) can be connected i.e. be part of a `connect` equation.

   Note: Connecting a non connector variable to a connector variable with `connect(non_connector_var, connector_var)` yields a warning but not an error in Dymola. It is considered bad practice though and a standard equation should be used in place `non_connector_var = connector_var`.
   Using a `connect` equation allows to draw a connection line which makes the model structure explicit to the user. Furthermore it avoids mixing `connect` equations and standard equations within the same equation set, which has been adopted as a best practice in the Modelica Buildings library.

2. The causality (input or output) of each variable inside an expandable connector is not predefined but rather set by the `connect` equation where the variable is first being used. For instance when the variable of an expandable connector is first connected to an inside connector `Modelica.Blocks.Interfaces.RealOutput` it gets the same causality i.e. output. The same variable can then be connected to another inside connector `Modelica.Blocks.Interfaces.RealInput`.

3. Potentially present but not connected variables are eventually considered as undefined i.e. a tool may remove them or set them to the default value (Dymola treat them as not declared: they are not listed in `dsin.txt`): all variables need not be connected so the control bus does not have to be reconfigured depending on the model structure.
4. The variables set of a class of type expandable connector is augmented whenever a new variable gets connected to any *instance* of the class. Though that feature is not needed by the configuration widget (we will have a predefined control bus with declared variables), it is needed to allow the user further modifying the control sequence. Adding new control variables is simply done by connecting them to the control bus.

Those features are illustrated with a minimal example in annex, see Section 5.2.

3.4.4.2 Generating Connections by Approximate String Matching

To support automatic connections of signal variables a predefined control bus will be defined for each type of system (e.g. AHU, CHW plant) with a set of predeclared variables. The names of the variables must allow a one-to-one correspondence between:

- the control sequence input variables and the outputs of the equipment model e.g. sensed quantities and actuators returned positions,
- the control sequence output variables and the inputs of the equipment model e.g. actuators commanded positions.

Thus the control bus variables are used as “gateways” to stream values between the controlled system and the controller system.

However an exact string matching is not conceivable. An approximate (or fuzzy) string matching algorithm must be used instead.

Listing 3.1: Example of a Python function used for fuzzy string matching

```
from fuzzywuzzy import fuzz
from fuzzywuzzy import process
import itertools as it
import re


def return_best(string, choices, sys_type='Ahu'):
    # Constrain array to array and scalar (or array element) to scalar.
    # Need to specify a logic for tagging scalar variables that should be connected to array elements e.g. '*_zon*.y'.
    # But allow a single array element to be connected to a scalar variable: not bool(re.search('\[\d+\]', string))
    if bool(re.search('\[.+\]|_zon.*\.', string)) and not bool(re.search('\[\d+\]', string)):
        choices = [el for el in choices if re.search('\[.+\]', el)]
        # Replace [.*] by [:]
        string = re.sub('\[.*\]', '[:]', string, flags=re.I)
        string = re.sub('_zon.*\.', '[:].', string, flags=re.I)
    else:
        choices = [el for el in choices if not re.search('\[.+\]', el)]
```

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```
    # Replace pre by p and tem by t.
    string = re.sub('pre', 'P', string, flags=re.I)
    string = re.sub('tem', 'T', string, flags=re.I)

    # Do not consider controller and bus component names.
    # Remark: has only little impact.
    string = re.sub('^(con|bus){}\.'.format(sys_type), '', string)
    choices = [re.sub('^(con|bus){}\.'.format(sys_type), '', c) for c in choices]

    # Perform comparison.
    res = process.extract(string, choices, limit=2, scorer=fuzz.token_sort_ratio)

    return list(it.chain(*res))
```

Results in Fig. 3.10.

- Strict naming conventions solve most of the mismatch cases with a satisfying confidence (end score > 60).
- There is still a need to specify a convention to determine which array element should be connected to a scalar variable.
- There is one remaining mismatch (`busAhu.TZonHeaSet`) for which a logic consisting in using only the variable name if it is descriptive enough (test on length of suffix of standard variables names) and the initial matching score is low (below 50).

3.4.4.3 Validation and Additional Requirements

The use of expandable connectors (control bus) is validated in case of a complex controller, see Section 5.3.

Note: Connectors with conditional instances must be connected to the bus variables with the same conditional statement e.g.

```
if have_occSen then
    connect(ahuSubBusI.nOcc[1:numZon], nOcc[1:numZon])
end if;
```

With Dymola, bus variables cannot be connected to array connectors without explicitly specifying the indices range. Using the unspecified `[:]` syntax yields the following translation error.

```
Failed to expand conAHU.ahuSubBusI.nOcc[:] (since element does not exist) in connect(conAHU.
↪ahuSubBusI.nOcc[:], conAHU.nOcc[:]);
```

Providing an explicit indices range e.g. `[1:numZon]` like in the previous code snippet only causes a translation warning: Dymola seems to allocate a default dimension of **20** to the connector, the unused indices (from 3 to 20 in the example hereunder) are then removed from the simulation problem since they are not used in the model.

```
Warning: The bus-input conAHU.ahuSubBusI.VDis_flow[3] matches multiple top-level connectors␣
↪in the connection sets.
```

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Controller variable	Variable to connect to	Bus variable	IO	match	score	sec_score	match_to	score_to	sec_score_to
conAhu.VDis_flow[numZon]	V_flowDis_zonA.V_flow	busAhu.V_flowDis[:]	I	V_flowDis[:]	67	46	V_flowDis[:]	72	30
conAhu.TMix	TMix.T	busAhu.TMix	I	TMix	100	25	TMix	80	40
conAhu.ducStaPre	pStaDuc.p_rel	busAhu.pStaDuc	I	staFrePro	50	43	pStaDuc	70	70
conAhu.pStaDuc	pStaDuc.p_rel	busAhu.pStaDuc	I	pStaDuc	100	100	pStaDuc	70	70
conAhu.TOut	TOut.T	busAhu.TOut	I	TOut	100	75	TOut	80	62
conAhu.TOutCut	TOutCut.y	busAhu.TOutCut	I	TOutCut	100	86	TOutCut	88	75
conAhu.hOut	hOut.h	busAhu.hOut	I	hOut	100	75	hOut	80	62
conAhu.hOutCut	hOutCut.y	busAhu.hOutCut	I	hOutCut	100	86	hOutCut	88	75
conAhu.TSup	TSup.T	busAhu.TSup	I	TSup	100	73	TSup	80	62
conAhu.TZonHeaSet	modSetZon.TZonHeaSet[numZom]	busAhu.TZonHeaSet	I	TZonHeaSet	100	70	TZon[:]	33	33
conAhu.VOut_flow	V_flowOut.V_flow	busAhu.V_flowOut	I	V_flowOut	67	46	V_flowOut	72	35
conAhu.nOcc[numZon]	nOcc[numZom].y	busAhu.nOcc[:]	I	nOcc[:]	100	25	nOcc[:]	80	20
conAhu.TZon[numZon]	TZon_zonA.T	busAhu.TZon[:]	I	TZon[:]	100	57	TZon[:]	80	50
conAhu.TDis[numZon]	TDis_zonA.T	busAhu.TDis[:]	I	TDis[:]	100	46	TDis[:]	80	40
conAhu.TZonCooSet	modSetZon.TZonCooSet[1]	busAhu.TZonCooSet	I	TZonCooSet	100	70	TZonCooSet	62	44
conAhu.uZonTemResReq	reqResTZon.y	busAhu.reqResTZon	I	TZonHeaSet	57	48	reqResTZon	91	82
conAhu.uReqResT	reqResT.y	busAhu.reqResT	I	reqResT	93	80	reqResT	88	75
conAhu.uZonPreResReq	reqResPZon.y	busAhu.reqResPZon	I	TZonHeaSet	57	48	reqResPZon	91	82
conAhu.uReqResP	reqResP.y	busAhu.reqResP	I	reqResP	93	80	reqResP	88	75
conAhu.uOpeMod	modSetZon.yOpeMod	busAhu.modOpe	I	modOpe	46	43	modOpe	52	44
conAhu.uWin[numZon]	staWin_zonA.y	busAhu.staWin[:]	I	staWin[:]	60	31	staWin[:]	86	33
conAhu.uFreProSta	frePro.ySta	busAhu.staFrePro	I	staFrePro	63	59	staFrePro	60	56
conAhu.TZonResReq[nin].u	conVAVBox_zonA.yZonTemResReq	busAhu.reqResT[:]	I	TZon[:]	50	42	reqResT[:]	29	26
conAhu.reqResTZon[nin].u	conVAVBox_zonA.yReqResTZon	busAhu.reqResTZon[:]	I	reqResTZon[:]	91	74	reqResTZon[:]	65	50
conAhu.TSupSet	TSupSet.T	busAhu.TSupSet	O	TSupSet	100	73	TSupSet	88	62
conAhu.yHea	valHea.y	busAhu.yValHea	O	yValHea	73	43	yValHea	80	40
conAhu.yCoo	valCoo.y	busAhu.yValCoo	O	yValCoo	73	43	yValCoo	80	47
conAhu.ySupFanSpe	fanSup.y	busAhu.yFanSup	O	yFanSup	71	59	yFanSup	80	50
conAhu.yRetDamPos	eco.yRet	busAhu.yDamRet	O	yDamOut	59	59	reqResT	53	53
conAhu.yDamRetPos	eco.yDamRet	busAhu.yDamRet	O	yDamRet	82	82	yDamRet	78	78
conAhu.yOutDamPos	eco.yOut	busAhu.yDamOut	O	yDamOut	59	59	yDamOut	53	53
conAhu.yDamOutPos	eco.yDamOut	busAhu.yDamOut	O	yDamOut	82	82	yDamOut	78	78

Fig. 3.10: Fuzzy string matching test case – G36 VAV AHU Controller

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```
Bus-signal: ahuI.VDis_flow[3]

Connected bus variables:
ahuSubBusI.VDis_flow[3] (connect) "Connector of Real output signal"
conAHU.ahuBus.ahuI.VDis_flow[3] (connect) "Primary airflow rate to the ventilation zone from␣
↪the air handler, including   outdoor air and recirculated air"
ahuBus.ahuI.VDis_flow[3] (connect)
conAHU.ahuSubBusI.VDis_flow[3] (connect)
```

This is a strange behavior in Dymola. On the other hand JModelica 1) allows the unspecified `[:]` syntax and 2) does not generate any translation warning when explicitly specifying the indices range. JModelica's behavior seems more aligned with [Mod17] *§9.1.3 Expandable Connectors* that states: "A non-parameter array element may be declared with array dimensions ":" indicating that the size is unknown." The same logic as JModelica for array variables connections to expandable connectors is required for LinkageJS.

3.4.4.4 Additional Requirements for the UI

Based on the previous validation case, Fig. 3.11 presents the Dymola pop-up window displayed when connecting the sub-bus of input control variables to the main control bus. A similar view of the connections set must be implemented with the additional requirements listed below. That view is displayed in the connections tab of the right panel.

The variables listed immediately after the bus name are either:

- *declared variables* that are not connected e.g. `ahuBus.yTest` (declared as `Real` in the bus definition): those variables are only *potentially present* and eventually considered as *undefined* when translating the model (treated by Dymola as if they were never declared) or,
- *present variables* i.e. variables that appear in a connect equation e.g. `ahuSubBusI.TZonHeaSet`: the icon next to each variable then indicates the causality. Those variables can originally be either declared variables or variables elaborated by the augmentation process for *that instance* of the expandable connector i.e. variables that are declared in another component and connected to the connector's instance.

The variables listed under `Add variable` are the remaining *potentially present variables* (in addition to the declared but not connected variables). Those variables are elaborated by the augmentation process for *all instances* of the expandable connector, however they are not connected in that instance of the connector.

In addition to Dymola's features for handling the bus connections, LinkageJS requires the following:

- Color code to distinguish between:
  - Variables connected only once (within the entire augmentation set): those variables should be listed first and in red color. This is needed so that the user immediately identify which connections are still required for the model to be complete.

    > **Warning:** Dymola does not throw any exception when a *declared* bus variable is connected to an input (resp. output) variable but not connected to any other non input (resp. non output) variable. It then uses the default value (0 for `Real`) to feed the connected variable.
    > That is not the case if the variable is not declared i.e. elaborated by augmentation: in that case it has to be connected in a consistent way.

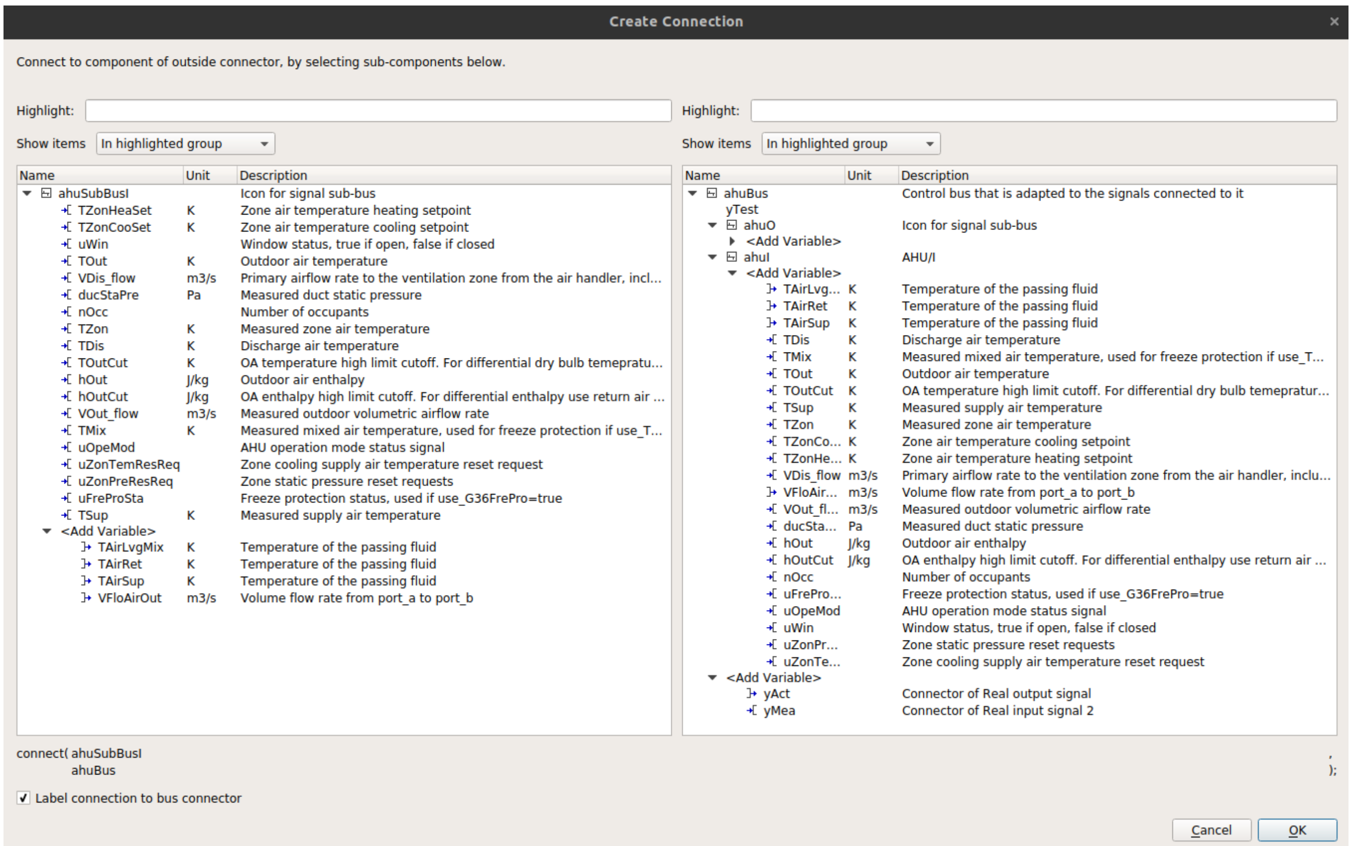

Fig. 3.11: Dymola pop-up window when connecting the sub-bus of input control variables (left) to the main control bus (right) – case of outside connectors

> JModelica throws an exception in any case with the message `The following variable(s) could not be matched to any equation`.

- Declared variables which are only potentially present (not connected): those variables should be listed last (not first as in Dymola) and in light grey color. That behavior is also closer to [Mod17] *§9.1.3 Expandable Connectors*: "variables and non-parameter array elements declared in expandable connectors are marked as only being potentially present. [...] elements that are only potentially present are not seen as declared."

- View the "expanded" connection set of an expandable connector in each level of composition – that covers several topics:
  - The user can view the connection set of a connector simply by selecting it and without having to make an actual connection (as in Dymola).
  - The user can view the name of component and connector variable to which the expandable connector's variables are connected: similar to Dymola's function `Find Connection` accessible by right-clicking on a connection line.
  - From [Mod17] *§9.1.3 Expandable Connectors*: "When two expandable connectors are connected, each is augmented with the variables that are only declared in the other expandable connector (the new variables are neither input nor output)."

    That feature is illustrated in the minimal example Fig. 3.12 where a sub-bus `subBus` with declared variables `yDeclaredPresent` and `yDeclaredNotPresent` is connected to the declared sub-bus `bus.ahuI` of a bus. `yDeclaredPresent` is connected to another variable so it is considered present. `yDeclaredNotPresent` is not connected so it is only considered potentially present. Finally `yNotDeclaredPresent` is connected but not declared which makes it a present variable. Fig. 3.13 to Fig. 3.15 then show which variables are exposed to the user. In consistency with [Mod17] the declared variables of `subBus` are considered declared variables in `bus.ahuI` due to the connect equation between those two instances and they are neither input nor output. Furthermore the present variable `yNotDeclaredPresent` appears in `bus.ahuI` under `Add variable` i.e. as a potentially present variable whereas it is a present variable in the connected sub-bus `subBus`.
    - This is an issue for the user who will not have the information at the bus level of the connections which are required by the sub-bus variables e.g. Dymola will allow connecting an output connector to `bus.ahuI.yDeclaredPresent` but the translation of the model will fail due to `Multiple sources for causal signal in the same connection set`.
    - Directly connecting variables to the bus (without intermediary sub-bus) can solve that issue for outside connectors but not for inside connectors, see below.
  - Another issue is illustrated Fig. 3.15 where the connection to the bus is now made from an outside component for which the bus is considered as an inside connector. Here Dymola only displays declared variables of the bus (but not of the sub-bus) but without the causality information and even if it is only potentially present (not connected). Present variables of the bus or sub-bus which are not declared are not displayed. Contrary to Dymola, LinkageJS requires that the "expanded" connection set of an expandable connector be exposed, independently from the level of composition. That means exposing all the variables of the *augmentation set* as defined in [Mod17] *9.1.3 Expandable Connectors*. In our example the same information displayed in Fig. 3.13 for the original sub-bus should be accessible when displaying the connection set of `bus.ahuI` whatever the current status (inside or outside) of the connector `bus`. A typical view of the connection set of expandable connectors for LinkageJS could be:

Table 3.3: Typical view of the connection set of expandable connectors – visible from outside component (connector is inside), "Present" and "I/O" columns display the connection status over the full augmentation set

Variable	Present	Declared	I/O	Description
bus				
`var1` (present variable connected only once: red color)	x	O	→ `comp1.var1`	...
`var2` (present variable connected twice: default color)	x	O	`comp2.var1` → `comp1.var2`	...
`var3` (declared variable not connected: light grey color)	O	x		...
Add variable				
`var4` (variable elaborated by augmentation from *all instances* of the connector: light grey color)	O	O		...
subBus				
`var5` (present variable connected only once: red color)	x	O	`comp3.var5` →	...
Add variable				
`var6` (variable elaborated by augmentation from *all instances* of the connector: light grey color)	O	O		...

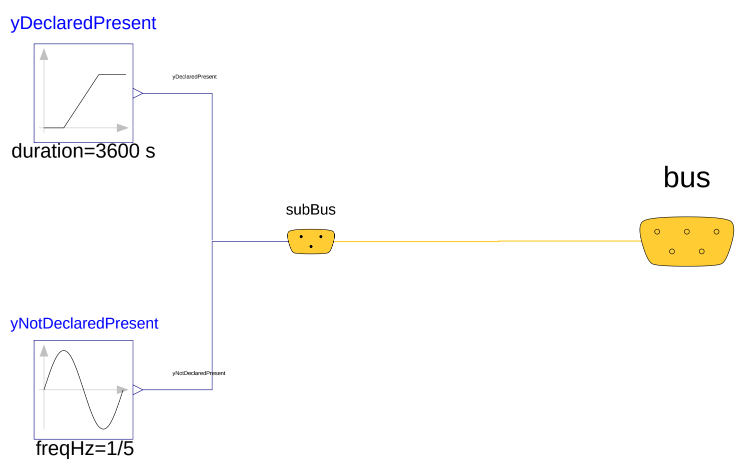

Fig. 3.12: Minimal example of sub-bus to bus connection illustrating how the bus variables are exposed in Dymola – case of outside connectors

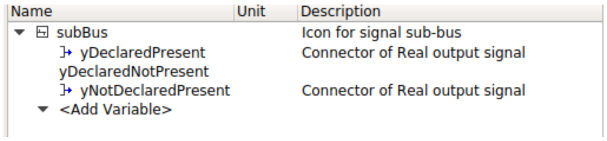

Fig. 3.13: Sub-bus variables being exposed in case the sub-bus is an outside connector

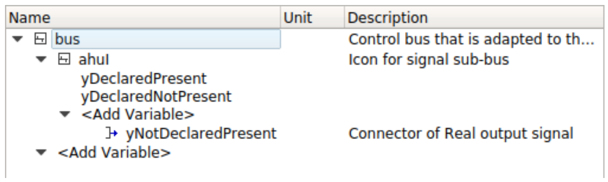

Fig. 3.14: Bus variables being exposed in case the bus is an outside connector

3.4.5 Parameters Setting

To be updated.

The name and comment of the instance must be displayed in the parameters tab.

3.4.6 Control Sequence Configuration

In theory the configuration widget specified previously should allow building custom control sequences based on elementary control blocks (e.g. from the CDL Library) and automatically generating connections between those blocks. However:

- it would require to distinguish between low-level control blocks (e.g. `Buildings.Controls.OBC.CDL.Continuous.LimPID`) composing a system controller – which must be connected with direct connect equations and not with expandable connectors variables that are not part of the CDL specification – and high-level control blocks (e.g. `Buildings.Controls.OBC.ASHRAE.G36_PR1.AHUs.MultiZone.VAV.Controller`) – which can be connected to other high-level controllers (e.g. `Buildings.Controls.OBC.ASHRAE.G36_PR1.TerminalUnits.Controller`) using expandable connectors variables (the CDL translation will be done for each high-level controller individually),
- the complexity of some sequences makes it hard to validate the reliability of such an approach without extensive testing.

Therefore in practice and at least for the first version of LinkageJS it has been decided to rely on pre-assembled high-level control blocks. For each system type (e.g. AHU) one (or a very limited number) of control block(s) should be instantiated by the configuration widget for which the connections can be generated using expandable connectors as described before.

The example of the configuration file for a VAV system in Section 5.1 illustrates that use case.

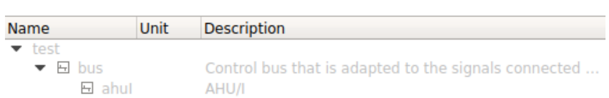

Fig. 3.15: Bus variables being exposed in case the bus is an inside connector

3.5 Schematics Export

The schematics export encompasses three items:

1. Engineering schematics of the equipment including the controls points
2. Control points list
3. Control sequence description

The composition level at which the functionality will typically be used is the same as the one considered for the configuration widget e.g. primary plant, air handling unit, terminal unit, etc. No specific mechanism to guard against an export call at different levels is required.

Fig. 3.16 illustrates the typical diagram model generated by the configuration widget and Fig. 3.17 mocks up the corresponding export that should be generated. The actual export output may consist in three different files.

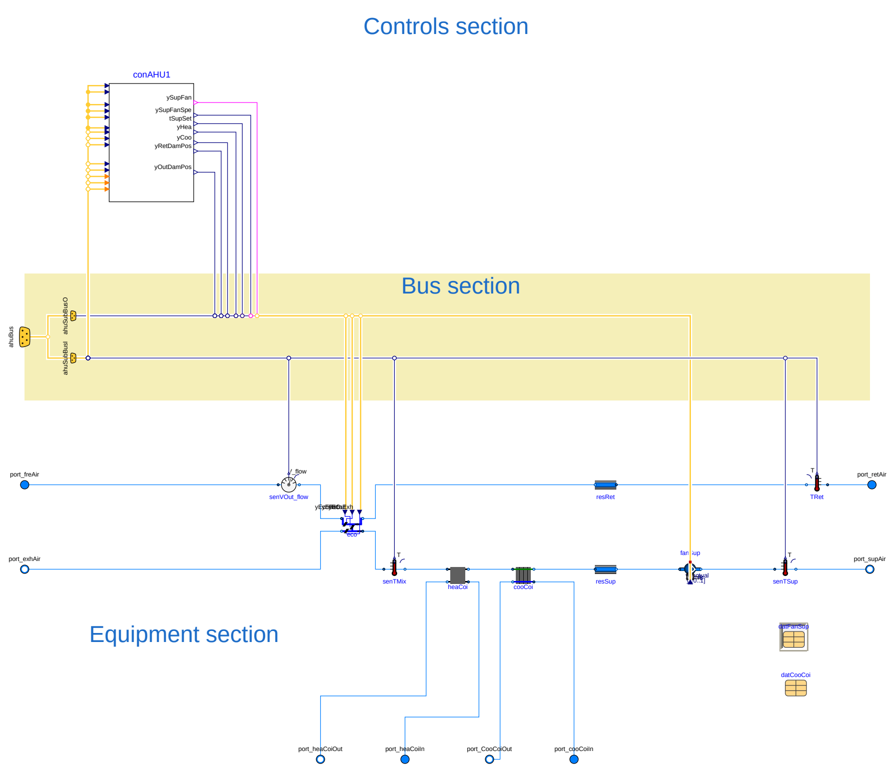

Fig. 3.16: Mockup of the schematics export – Input Modelica file

3.5.1 Engineering Schematics

Objects of the original model to be included in the final export must have a declaration annotation providing the SVG file path for the corresponding engineering symbol e.g. `annotation(__Linkage(symbol_path="value of symbol_path"))`. That annotation may be:

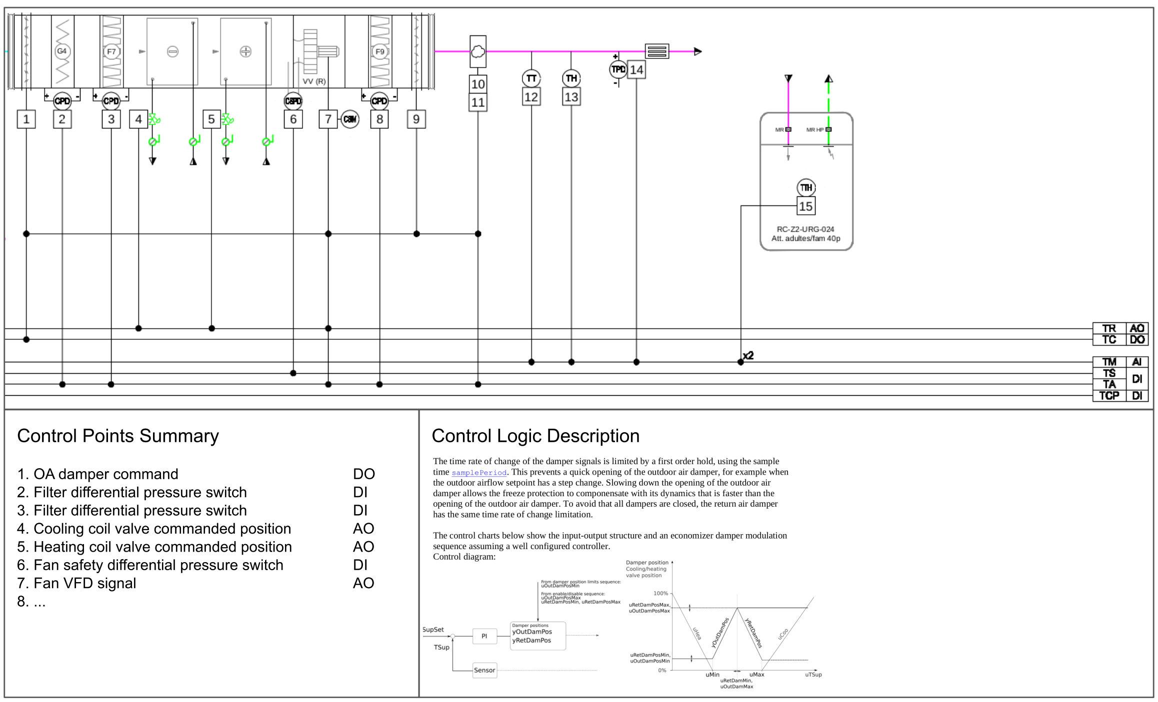

Fig. 3.17: *Mockup of the schematics export – Output file (format to be specified: Word or PDF)*

- specified in the configuration file, see `symbol_path` in *Configuration API*,
- specified manually by the user for potentially any instantiated component.

Note: It is expected that LinkageJS will eventually be used to generate design documents included in the invitation to tender for HVAC control systems. The exported schematics should meet the industry standards and they must allow for further editing in CAD softwares e.g. AutoCAD®.

Due to geometry discrepancies between Modelica icons and engineering symbols a perfect alignment of the latter is not expected by simply mapping the diagram coordinates of the former to the SVG layout. A mechanism should be developed to automatically correct small alignment defaults.

For the exported objects:

- the connectors connected to the control input and output sub buses must be split into two groups depending on their type – boolean or numeric,
- an index tag is then generated based on the object position, from top to bottom and left to right,
- eventually connection lines are drawn to link those tags to the four different control points buses (AI, AO, DI, DO). The line must be vertical, with an optional horizontal offset from the index tag to avoid overlapping any other object.

SVG is the required output format.

See Fig. 3.17 for the typical output of the schematics export process.

3.5.2 Control Points List

Generating the control points list is done by calling a module developed by LBL (ongoing development) which returns an HTML or Word document.

3.5.3 Control Sequence Description

Generating the control sequence description is done by calling a module developed by LBL which returns an HTML or Word document.

3.6 Working with Tagged Variables

The requirements for tagging variables and performing some queries on the set of tagged variables will be specified by LBL in a second version of this document.

Those additional requirements should at least address the following typical use cases:

- Setting up parameters values with OS measures e.g. nominal electrical loads or boiler efficiency
- Plotting variables selected by a description string e.g. “indoor air temperature for all zones of the first floor”
- Mapping with equipment characteristics and sizing from data sheets or calculation spreadsheets

An algorithm based on the variables names (similar to the one proposed for generating automatic connections for signal variables, see Section 3.4.4) is envisioned.

3.7 OpenStudio Integration

LinkageJS must eventually be integrated as a specific *tab* in the OpenStudio (OS) modeling platform. This will provide editing capabilities of HVAC equipment and control systems models in the future Spawn of EnergyPlus (SOEP) workflow. (In the curent EnergyPlus workflow those capabilities are provided by the HVAC Systems tab).

In SOEP workflow a building multi-zone model (EnergyPlus input file `idf`) is configured within OpenStudio. The OpenStudio model `osm` exposes functions to access `idf` parameters e.g. zone names and characteristics. Modelica classes are created by extending SOEP zone model and referencing the `idf` file and the zone names. Instances of those classes allow the user to select the thermal zone (as an item of an enumeration) and connect its fluid ports to the HVAC system model that is edited with LinkageJS.

The only requirement to embed in OS app is for LinkageJS to be built down to a single page HTML document.

An API must also be developed to access LinkageJS functionalities and data model in a programmatic way. The preferred language is Python (largely used in the Modelica users' community) or Ruby (largely used in the OpenStudio users' community).

Iterations between the UI developer, NREL (OpenStudio developer) and LBL will be required to:

- devise the read and write access to the local file system e.g. by means of OS API (functions to be developed by LBL or NREL),
- specify LinkageJS API (to be developed by the UI developer).

This is illustrated in Fig. 4.4.

3.8 Interface with URBANopt GeoJSON

A seamless integration of LinkageJS into URBANopt modeling workflow is required. To support that feature additional requirements will be specified by LBL in a second version of this document.

The URBANopt-Modelica project has adopted the Modelica language to interface the upstream UI-GeoJSON workflow and the downstream Modelica-LinkageJS workflow. Therefore the requirements should mainly address the persistence of modeling data and shared resources between the two processes.

3.9 Licensing

As a project funded by the U.S. Department of Energy's Building Technologies Office (BTO) LinkageJS core components (e.g. *Editor Layer* in Section 4) must be open sourced: **under BSD 3/4-clause?**.

Different licensing options are then envisioned depending on the integration target and the engagement of third-party developers and distributors:

- Desktop app
  Subscription-based
- Standalone web app
  - Free account allowing access to Modelica libraries preloaded by default e.g. Modelica Standard and Buildings: the user can only upload and download single Modelica files (not a package).

  - Pro account allowing access to server storage of Modelica files (packages uploaded and models saved by the user): the user can update the stored libraries and reopen saved models between sessions.
- Third party application embedding
  Licensing will depend on the application distribution model.
  For OpenStudio there is currently a shift in the licensing strategy. For this integration target the specification will be precised to comply with the distribution options after the transition period (no entity has yet announced specific plans to continue support for the OS app).

3.10 Encryption

Need for any specific requirement regarding "total model export"?

See current standardization effort in #1868.

Chapter 4

Software Architecture

Fig. 4.1 to Fig. 4.4 provide simplified architecture diagrams for the three integration targets. Those are not hard and fast, they are rather provided to give an idea of the main modules to develop and how they interface with LBL in-house developments.

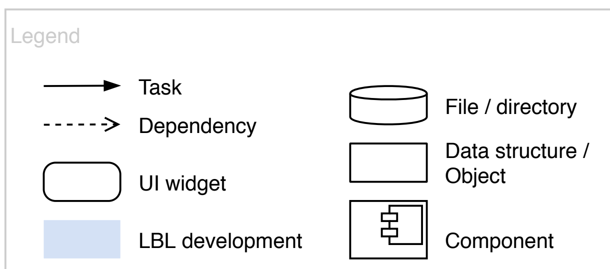

Fig. 4.1: Software architecture legend

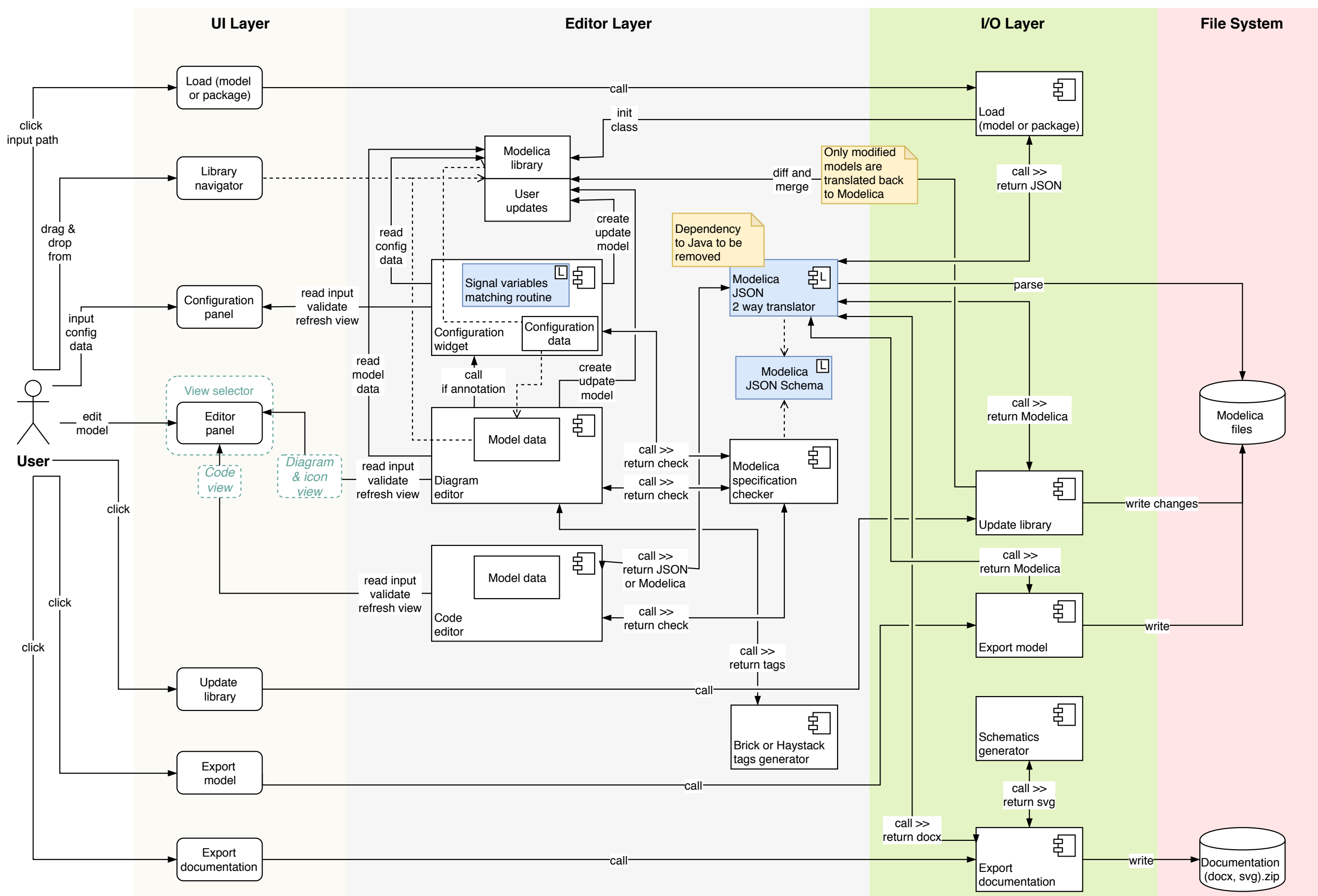

Fig. 4.2: Software architecture - Desktop app

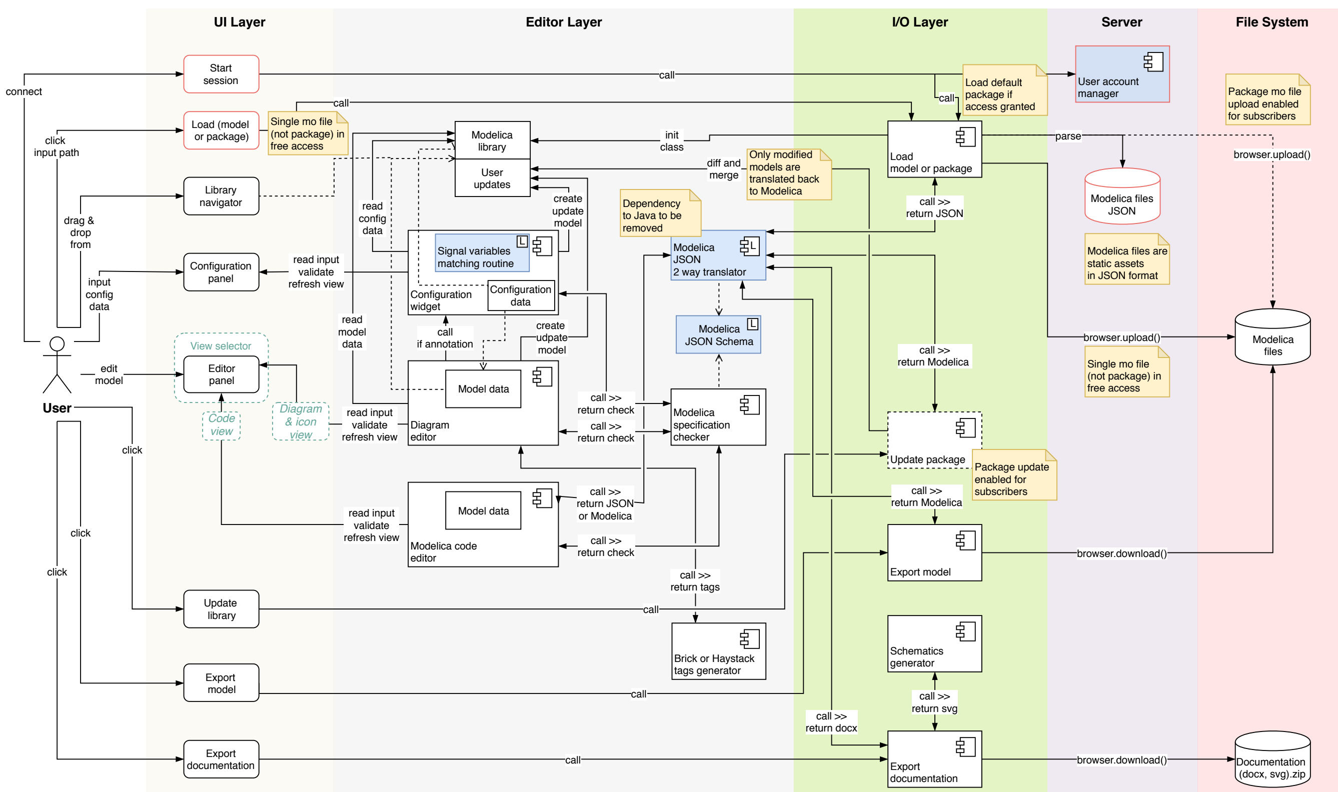

Fig. 4.3: Software architecture - Standalone web app

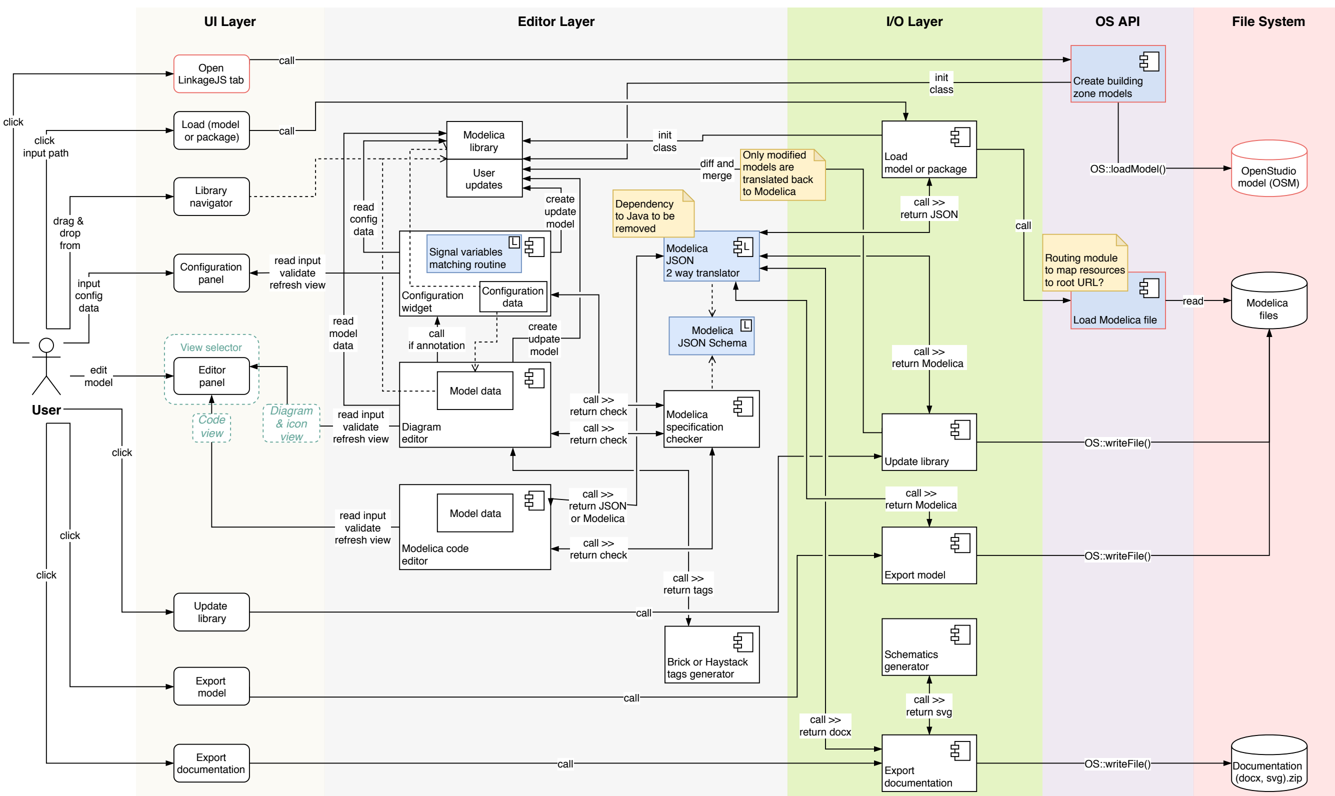

Fig. 4.4: Software architecture - Integration in third party application e.g. OpenStudio®

Chapter 5

Annex

5.1 Example of the Configuration Data Structure

Listing 5.1: Partial example of the configuration data structure for an air handling unit (pseudo-code, especially for autoreferencing the data structure and writing conditional statements)

```
{
    "type": {
        "$id": "type",
        "description": "System type",
        "value": "AHU"
    },
    "subtype": {
        "$id": "subtype",
        "description": "Type of AHU",
        "widget": {
            "type": "Dropdown",
            "options": ["VAV", "DOA", "Supply only", "Exhaust only"]
        },
        "value": "VAV"
    },
    "name": {
        "$id": "name",
        "description": "Model name",
        "widget": {
            "type": "Text input"
        },
        "value": "AHU"
    },
    "fluid_paths": [
        {
            "$id": "air_supply",
```

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```
            "direction": "east",
            "medium": "Buildings.Media.Air"
        },
        {
            "$id": "air_return",
            "direction": "west",
            "medium": "Buildings.Media.Air"
        }
    ],
    "icon": "path of icon.mo",
    "diagram": {
        "configuration": [24, 24],
        "modelica": [[-120,-200], [120,120]]
    },
    "equipment": [
        {
            "$id": "heaRec",
            "description": "Heat recovery",
            "enabled": "#subtype.value == 'DOA'",
            "widget": {
                "type": "Dropdown menu",
                "options": ["None", "Fixed plate", "Enthalpy wheel", "Sensible wheel"]
            },
            "value": "None",
            "declaration": [
                null,
                "Buildings.Fluid.HeatExchangers.PlateHeatExchangerEffectivenessNTU",
                "Buildings.Fluid.HeatExchangers.EnthalpyWheel",
                "Buildings.Fluid.HeatExchangers.EnthalpyWheel (sensible=true)"
            ],
            "icon_transformation": "flipHorizontal",
            "placement": [18, 6],
            "connect": {
                "type": "tags",
                "value": {
                    "port_a1": "air_return_inlet", "port_a2": "air_supply_inlet", "port_b1":
↪"air_return_outlet", "port_b2": "air_supply_outlet"
                }
            }
        },
        {
            "$id": "eco",
            "description": "Economizer",
            "enabled": "#subtype.value == 'VAV'",
            "widget": {
                "type": "Dropdown menu",
                "options": ["None", "Dedicated OA damper", "Common OA damper"]
            },
            "value": "None",
```

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```
            "declaration": [
                null,
                "Buildings.Fluid.Actuators.Dampers.MixingBoxMinimumFlow",
                "Buildings.Fluid.Actuators.Dampers.MixingBox"
            ],
            "icon_transformation": "flipVertical",
            "placement": [18, 9],
            "connect": {
                "type": "tags",
                "value": {
                    "port_Out": "air_supply_out_inlet", "port_OutMin": "air_supply_min_inlet
↪", "port_Sup": "air_supply_outlet",
                    "port_Exh": "air_return_outlet", "port_Ret": "air_return_inlet"
                }
            }
        },
        {
            "$id": "V_flowOut_nominal",
            "description": "Nominal outdoor air volume flow rate",
            "enabled": "#eco.value != 'None'",
            "widget": {
                "type": "Numeric input"
            },
            "value": 0,
            "unit": "m3/s",
            "declaration": "Modelica.SIunits.VolumeFlowRate"
        },
        {
            "$id": "fanSup",
            "description": "Supply fan",
            "enabled": "#subtype.value != 'Exhaust only'",
            "widget": {
                "type": "Dropdown menu",
                "options": ["None", "Draw through", "Blow through"]
            },
            "value": "Draw through",
            "declaration": "Buildings.Fluid.Movers.SpeedControlled_y (m_flow_nominal=m_
↪flowSup_nominal)",
            "placement": [null, [18, 11], [18, 18]],
            "connect": {
                "value": "air_supply"
            }
        },
        {
            "$id": "V_flowSup_nominal",
            "description": "Nominal supply air volume flow rate",
            "enabled": "#fanSup.value != 'None'",
            "widget": {
                "type": "Numeric input"
```


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```
            },
            "value": 0,
            "unit": "m3/s",
            "declaration": "Modelica.SIunits.VolumeFlowRate"
        },
        {
            "$id": "fanRet",
            "description": "Return/Relief fan",
            "enabled": "#subtype.value != 'Supply only'",
            "widget": {
                "type": "Dropdown menu",
                "options": ["None", "Return", "Relief"]
            },
            "value": "Relief",
            "declaration": [
                null,
                "Buildings.Fluid.Movers.SpeedControlled_y (m_flow_nominal=m_flowRet_nominal)
↪",
                "Buildings.Fluid.Movers.SpeedControlled_y (m_flow_nominal=m_flowRel_nominal)"
            ],
            "icon_transformation": "flipHorizontal",
            "placement": [null, [14, 13], [14, 4]],
            "connect": {
                "value": "air_return"
            }
        },
        {
            "$id": "V_flowRet_nominal",
            "description": "Nominal return air volume flow rate",
            "enabled": "#fanRet.value != 'None'",
            "widget": {
                "type": "Numeric input"
            },
            "value": 0,
            "unit": "m3/s",
            "declaration": "Modelica.SIunits.VolumeFlowRate"
        }
    ],
    "controls": [
        {
            "$id": "conAHURef",
            "description": "Reference guideline for control sequences",
            "widget": {
                "type": "Dropdown menu",
                "options": ["ASHRAE 2006", "ASHRAE G36"],
                "options.enabled": [
                    "Set of conditional statements allowing the use of ASHRAE 2006 SOO",
                    "Set of conditional statements allowing ASHRAE G36 SOO"
                ]
```

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```
            },
            "value": null
        },
        {
            "$id": "numZon",
            "description": "Total number of served VAV boxes",
            "enabled": "#conAHURef.value == 'ASHRAE G36'",
            "widget": {
                "type": "Numeric input"
            },
            "value": null
        },
        {
            "$id": "AFlo[numZon]",
            "description": "Floor area of each zone",
            "enabled": "#conAHURef.value == 'ASHRAE G36'",
            "widget": {
                "type": "Numeric vector input"
            },
            "value": null
        },
        {
            "$id": "have_occSen",
            "description": "Set to true if zones have occupancy sensor",
            "enabled": "#conAHURef.value == 'ASHRAE G36'",
            "widget": {
                "type": "Boolean select"
            },
            "value": false
        },
        {
            "$id": "have_winSen",
            "description": "Set to true if zones have occupancy sensor",
            "enabled": "#conAHURef.value == 'ASHRAE G36'",
            "widget": {
                "type": "Boolean select"
            },
            "value": false
        },
        {
            "$id": "have_perZonRehBox",
            "description": "Set to true if zones have occupancy sensor",
            "enabled": "#conAHURef.value == 'ASHRAE G36'",
            "widget": {
                "type": "Boolean select"
            },
            "value": false
        },
        {
```


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```
            "$id": "have_duaDucBox",
            "description": "Check if the AHU serves dual duct boxes",
            "enabled": "#conAHURef.value == 'ASHRAE G36'",
            "widget": {
                "type": "Boolean select"
            },
            "value": false
        },
        {
            "$id": "have_airFloMeaSta",
            "description": "Check if the AHU has AFMS (Airflow measurement station)",
            "enabled": "#conAHURef.value == 'ASHRAE G36'",
            "widget": {
                "type": "Boolean select"
            },
            "value": false,
            "declaration": [
                null,
                "Buildings.Fluid.Sensors.VolumeFlowRate (redeclare package Medium=#air_
↪supply.medium)",

            ],
            "placement": "if #eco.value == 'Dedicated OA damper' then [20, 5] else [18, 5]",
            "connect": {
                "value": "if #eco.value == 'Dedicated OA damper' then 'air_supply_min' else
↪'air_supply_out'"
            }
        },
        {
            "$id": "minZonPriFlo[numZon]",
            "description": "Minimum expected zone primary flow rate",
            "enabled": "#conAHURef.value == 'ASHRAE G36'",
            "widget": {
                "type": "Numeric vector input"
            },
            "value": null
        },
        {
            "$id": "VPriSysMax_flow[numZon]",
            "description": "Maximum expected system primary airflow at design stage",
            "enabled": "#conAHURef.value == 'ASHRAE G36'",
            "widget": {
                "type": "Numeric input"
            },
            "value": null
        }
    ],
    "dependencies": [
        {
```

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```
            "$id": "port_outAir",
            "description": "Outside air port",
            "enabled": "#subtype.value != 'Exhaust only'",
            "declaration": "Modelica.Fluid.Interfaces.FluidPort_a (redeclare package Medium=
↪#air_supply.medium)",
            "placement": [18, 1],
            "connect": {
                "value": "air_supply"
            }
        },
        {
            "$id": "port_supAir",
            "description": "Supply air port",
            "enabled": "#subtype.value != 'Exhaust only'",
            "declaration": "Modelica.Fluid.Interfaces.FluidPort_b (redeclare package Medium=
↪#air_supply.medium)",
            "placement": [18, 24],
            "connect": {
                "value": "air_supply"
            }
        },
        {
            "$id": "m_flowOut_nominal",
            "description": "Nominal outdoor air mass flow rate",
            "enabled": "#V_flowOut_nominal.enabled",
            "declaration": "Modelica.SIunits.MassFlowRate",
            "value": "(#air_supply.medium).rho_default * V_flowOut_nominal",
            "protected": true
        },
        {
            "$id": "m_flowSup_nominal",
            "description": "Nominal supply air mass flow rate",
            "enabled": "#V_flowSup_nominal.enabled",
            "declaration": "Modelica.SIunits.MassFlowRate",
            "value": "(#air_supply.medium).rho_default * V_flowSup_nominal",
            "protected": true
        },
        {
            "$id": "m_flowRet_nominal",
            "description": "Nominal return air mass flow rate",
            "enabled": "#V_flowRet_nominal.enabled",
            "declaration": "Modelica.SIunits.MassFlowRate",
            "value": "(#air_supply.medium).rho_default * V_flowRet_nominal",
            "protected": true
        },
        {
            "$id": "m_flowRel_nominal",
            "description": "Nominal relief air mass flow rate",
            "enabled": "#eco.value != 'None'",
```

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```
            "declaration": "Modelica.SIunits.MassFlowRate",
            "value": "m_flowRet_nominal - m_flowSup_nominal + m_flowOut_nominal",
            "protected": true
        }
    ]
}
```


5.2 Main Features of the Expandable Connectors

The main features of the expandable connectors (as described in Section 3.4.4) are illustrated with a minimal example described in the figures below where:

- a controlled system consisting in a sensor (idealized with a real expression) and an actuator (idealized with a simple block passing through the value of the input control signal) is connected with,
- a controller system which divides the input variable (measurement) by itself and thus outputs a control variable equal to one.
- The same model is first implemented with an expandable connector and then with a standard connector.

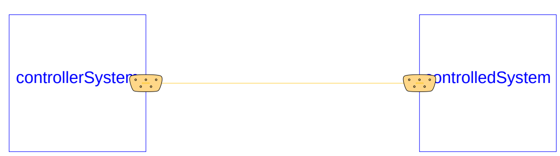

Fig. 5.1: Minimal example illustrating the connection scheme with an expandable connector – Top level

```
model BusTestExp
BusTestControllerExp controllerSystem;
BusTestControlledExp controlledSystem;
equation
      connect(controllerSystem.ahuBus, controlledSystem.ahuBus);
end BusTestExp;
```

```
model BusTestControlledExp
Modelica.Blocks.Sources.RealExpression sensor(y=2 + sin(time*3.14));
Buildings.Experimental.Templates.BaseClasses.AhuBus ahuBus;
Modelica.Blocks.Routing.RealPassThrough actuator;
equation
      connect(sensor.y, ahuBus.yMea);
      connect(ahuBus.yAct, actuator.u);
end BusTestControlledExp;
```

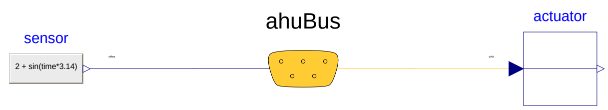

Fig. 5.2: Minimal example illustrating the connection scheme with an expandable connector – Controlled component sublevel

```
expandable connector AhuBus
extends Modelica.Icons.SignalBus;
end AhuBus;
```

Note: The definition of `AhuBus` in the code snippet here above does not include any variable declaration. However the variables `ahuBus.yAct` and `ahuBus.yMea` are used in `connect` equations. That is only possible with an expandable connector.

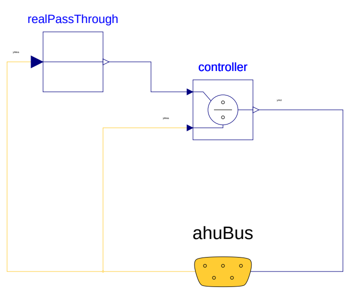

Fig. 5.3: Minimal example illustrating the connection scheme with an expandable connector – Controller component sublevel

```
model BusTestControlledExp
      Modelica.Blocks.Sources.RealExpression sensor(y=2 + sin(time*3.14));
      Buildings.Experimental.Templates.BaseClasses.AhuBus ahuBus;
      Modelica.Blocks.Routing.RealPassThrough actuator;
equation
      connect(ahuBus.yAct, actuator.u);
      connect(sensor.y, ahuBus.yMea)
end BusTestControlledExp;
```

```
model BusTestNonExp
BusTestControllerNonExp controllerSystem;
BusTestControlledNonExp controlledSystem;
```

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Fig. 5.4: Minimal example illustrating the connection scheme with a standard connector – Top level

(continued from previous page)

```
equation
      connect(controllerSystem.nonExpandableBus, controlledSystem.nonExpandableBus);
end BusTestNonExp;
```

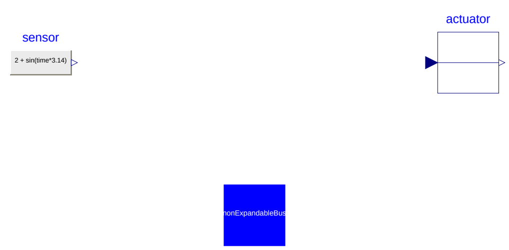

Fig. 5.5: Minimal example illustrating the connection scheme with a standard connector – Controlled component sublevel

```
model BusTestControlledNonExp
Modelica.Blocks.Sources.RealExpression sensor(y=2 + sin(time*3.14));
Modelica.Blocks.Routing.RealPassThrough actuator;
BaseClasses.NonExpandableBus nonExpandableBus;
equation
      nonExpandableBus.yMea = sensor.y;
      actuator.u = nonExpandableBus.yAct;
end BusTestControlledNonExp;
```

```
connector NonExpandableBus
// The following declarations are required.
// The variables are not considered as connectors: they cannot be part of connect equations.
Real yMea;
Real yAct;
end NonExpandableBus;
```

```
model BusTestControllerNonExp
Controls.OBC.CDL.Continuous.Division controller;
Modelica.Blocks.Routing.RealPassThrough realPassThrough;
```

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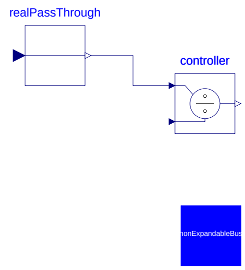

Fig. 5.6: Minimal example illustrating the connection scheme with a standard connector – Controller component sublevel

(continued from previous page)

```
BaseClasses.NonExpandableBus nonExpandableBus;
equation
      connect(realPassThrough.y, controller.u1);
      controller.u2 = nonExpandableBus.yMea;
      nonExpandableBus.yAct = controller.y;
      realPassThrough.u = nonExpandableBus.yMea;
end BusTestControllerNonExp;
```

5.3 Validating the Use of Expandable Connectors

The use of expandable connectors (control bus) is validated in case of a complex controller (`Buildings.Controls.OBC.ASHRAE.G36_PR1.AHUs.MultiZone.VAV.Controller`).

The validation is performed:

- with Dymola (Version 2020, 64-bit, 2019-04-10) and JModelica (revision numbers from svn: JModelica 12903, Assimulo 873);
- first with a single instance of the controller and then with multiple instances corresponding to different parameters set up (see validation cases of the original controller `Validation.Controller` and `Validation.ControllerConfigurationTest`),
- with nested expandable connectors: a top-level control bus composed of a first sub-level control bus for control output variables and another for control input variables.

Simulation succeeds for the two tests cases with the two simulation tools. The results comparison to the original test case (without control bus) is presented in Fig. 5.7 for Dymola.

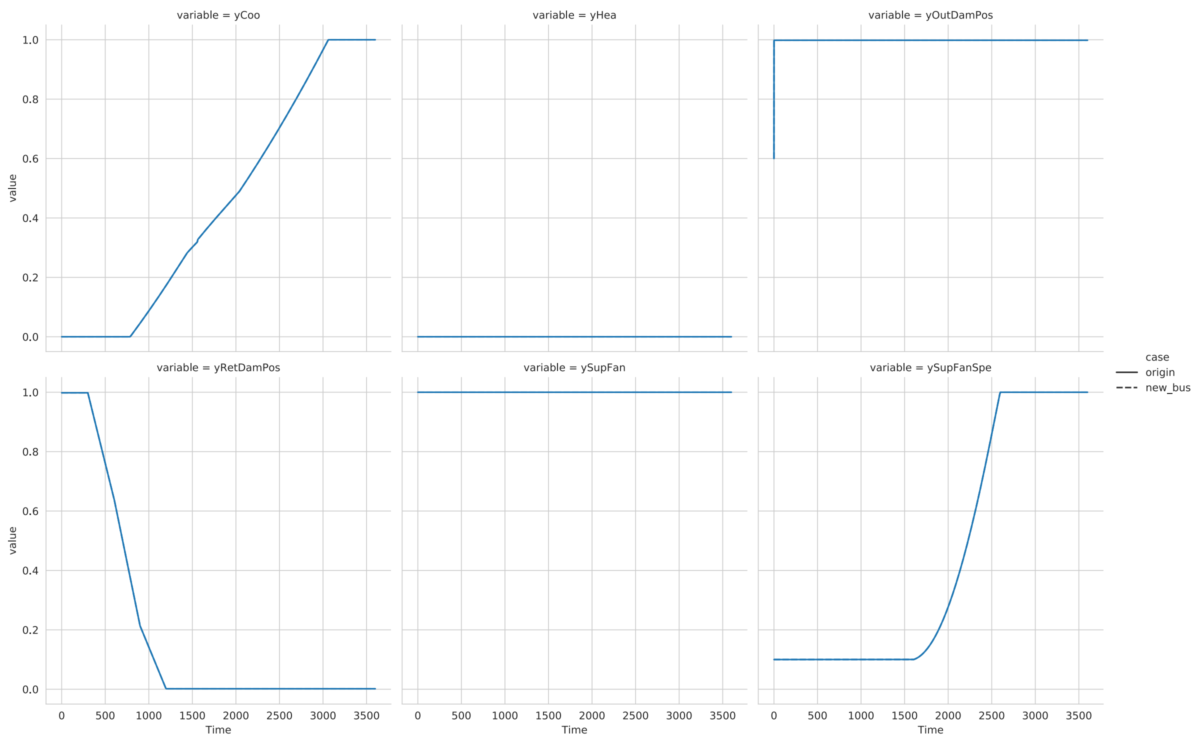

Fig. 5.7: *G36 AHU controller model: comparison of simulation results (Dymola) between implementation without (`origin`) and with (`new_bus`) expandable connectors*

Chapter 6

Glossary

To be updated.

Analog Value In CDL, we say a value is analog if it represents a continuous number. The value may be presented by an analog signal such as voltage, or by a digital signal.

Binary Value In CDL, we say a value is binary if it can take on the values 0 and 1. The value may however be presented by an analog signal that can take on two values (within some tolerance) in order to communicate the binary value.

Building Model Digital model of the physical behavior of a given building over time, which accounts for any elements of the building envelope and includes a representation of internal gains and occupancy. Building model has connectors to be coupled with an environment model and any HVAC and non-HVAC system models pertaining to the building.

Chapter 7

Acknowledgments

To be updated.

Chapter 8

References

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