BOPTEST Reference Test Case Peer Review Document

This document serves a peer review template for a reference test case emulation model.

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Section I is to be completed by the Model Developer. The remaining sections are to be completed by the designated Model Reviewer, and returned to the Model Developer so that they may make the appropriate edits. This process should be repeated until all concerns of the reviewer are addressed. Each review should be documented using a separate version of this document, specified by the Review # in Section 1 below.

# I. General Information

|  |  |
| --- | --- |
| **Reference Case** | Multizone Office Simple Air (5-Zone) |
| **Current Location** | Test Case Directory: <https://github.com/ibpsa/project1-boptest/tree/issue273_tesCasMulZonOffSimAir>  Modelica Model Package: <https://github.com/ibpsa/project1-boptest/tree/issue273_tesCasMulZonOffSimAir/testcases/multizone_office_simple_air/models/MultiZoneOfficeSimpleAir>   Model Path: MultiZoneOfficeSimpleAir.TestCases.TestCase  Buildings Library Version:  See <https://github.com/ibpsa/project1-boptest/blob/issue273_tesCasMulZonOffSimAir/testcases/multizone_office_simple_air/models/library_versions.json> |
| **Model Developer** (Name, Institution, Email) | David Blum, LBNL, dhblum@lbl.gov |
| **Model Reviewer**  (Name, Institution, Email) | Filip Jorissen, KU Leuven, filip.jorissen@kuleuven.be |
| **Review #** | 2 |

# II. General Comments

List each comment in separate row with number. Additional rows may be added as needed. They should be supported by the responses in Sections III and IV.

|  |  |
| --- | --- |
| **#** | **Comment** |
| 1 | ‘Simulate and plot’ command runs the model Buildings.Examples.VAVReheat.ASHRAE2006 instead of MultiZoneOfficeSimpleAir.TestCases.TestCase, which is unlikely to be the intention?  Not the intention. Added proper ‘Simulate and plot’ script to “MultiZoneOfficeSimpleAir/Resources/Scripts/Dymola/TestCases/Testcase.mos” |
| 2 | Flow rate control at the primary side of the cooling coil and the heating coil is idealized to a large extent: there exists a linear relation between the control signal and the mass low rate, which is not the case in practice. It would be better if a pump + valve with a linear valve characteristic and some series pressure drop were modelled since this causes a more realistic relation between the control signal and heat flow rate. Furthermore, the pump electrical power(s) should be considered in the model objective/KPIs. Ideally, these pumps can be controlled externally too; either on/off (constant head) or modulating. The same observations hold for the VAV heating coils.  The whole base model has been refactored within the Buildings Library. See Buildings.Examples.VAVReheat.ASHRAE2006 resulting from issue https://github.com/lbl-srg/modelica-buildings/issues/2652. This test case has been refactored to build from this example.  As part of the refactoring, the cooling and heating coils are now served by circulation pumps and equal percentage valves allowing mixing from hot and chilled water sources, modeled separately (see comment 4). The terminal box reheat coils are now served by equal percentage valves controlling flow from a hot water source, modeled separately.  For the heating and cooling coil models in the Buildings Library, the circulation pumps are controlled on/off with hysteresis and delay logic based on the control signal to the valves. I have added points to control them externally. In the Buildings Library, it is required that the system be enabled to operate the pumps and coil valves, where the enabling comes from the baseline scheduling. To enable external control, I have added a switch that also allows the pumps and coil valves to be operated if the fan is enabled by detecting airflow at 5% the maximum design amount of airflow.  The power from the AHU pumps has been included in the KPI calculations. |
| 3 | The economizer controller uses a flow rate measurement as an input. Does this measurement exist in typical buildings in the US?  ASHRAE Guideline 36 specifies the need for outside airflow measurement points as being “As Applicable” (as opposed to “Required” or “Optional”). The building we implemented MPC on at LBNL uses outside air as a measurement for economizer control. A quick look at our building operational data database for LBNL, there are 5 buildings with the name “Outside Airflow” as a measurement on their AHUs. Our campus has ~90 buildings total, of all types. So, is it typical? Probably not yet. But, I think it is plausible, and with the pandemic, I think it may grow. |
| 4 | Constant COPs are used for the heating and cooling coil, which is realistic if a constant outlet temperature is used, which is a bit constraining however in terms of the optimization potential of this emulator. This could be improved but is not an absolute requirement.  Plant equipment has been added to include an air-cooled chiller providing chilled water and heat pump providing hot water. The COP of the chiller is modeled based on the ElectricEIR model in the Buildings Library (also used in EnergyPlus), using the performance map coefficients from data that is distributed for chillers with EnergyPlus. The COP of the heat pump is modeled based on the carnot efficiency model in the Buildings Library.   The distribution pumps are constant head. The focus of this test case is not on plant equipment and system control, so my intent is to not model it in detail or make it controllable. |
| 5 | The fan PI controller output cannot be overruled, which may be an interesting option for an advanced controller. I.e. such a controller may want to set the fan speed directly instead of through a pressure set point. The fan has a constant efficiency, which is not realistic.  Agreed, not sure how fan speed overwrite got missed in the first version. It is available in the new version, with point name “hvac\_oveAhu\_yFan\_u.”  We have a new hire at LBNL working on addressing the fan efficiency issues as have been discussed in IBPSA Project 1. He is working within the Buildings Library. My hope is that the implementation can be included as soon as it is completed. |
| 6 | The individual VAV volumetric flow rates are measured and outputs from the model while I cannot imagine that each zone flow rate would be measured individually? I propose to remove these model outputs since a control developer should not be able to use them. Similarly, the actual damper position is typically not an output of a VAV? Then it should not be a model output either. The heating coil thermal power should be an output to be able to compute the KPIs, but in a similar fashion it should not be accessible by the end user.  I think it is fair and necessary to include both terminal box discharge airflow and damper position points:   1. What are known as “pressure-independent” terminal boxes are typical in the U.S. for multizone VAV systems, especially for new construction. These terminal boxes operate with two feedback control loops. The first adjusts an airflow set point based on zone temperature error. The second adjusts damper position based on airflow error. It is only a matter of exposing the internal airflow measurement on BACnet or otherwise to the BMS. For VAV terminal units, ASHRAE Guideline 36 lists the discharge airflow as a “Required” point. 2. Monitoring each terminal box’s damper position is the most common method of enabling static pressure reset control for supply fans in multizone VAV systems. Static pressure reset control is required by ASHRAE Standard 90.1 and it states as needing to be provided: “Monitor zone damper positions or other indicator of need for static pressure.” Similarly, ASHRAE Guideline 36 lists the damper position as a “Required” point.   Agreed on the heating coil thermal power. With the refactor described before, KPIs are calculated using the electrical power of the heat pump, which serves all heating coils. Thermal power measurements on any coils have been removed. |
| 7 | It seems incorrect that the CO2 gains are computed based on the latent heat gain ‘gai.y[3]’ in Buildings.Examples.VAVReheat.Validation.BaseClasses.Floor. I would expect it to be a function of the total heat gains? Furthermore, a factor 80 is used. I’m not sure what this represents? Possibly it factors in the fact that the latent heat gains are used. Please replace this factor by a Constant with a comment that explains where this value comes from.  This indeed needed some correction/clarification. The latent heat gain was used to estimate the number of people in the space, since radiative and convective would also include equipment and lights. The 80 was the implied assumption of 80 W latent gain per person resulting from an assumed office building population density of 5 people per 100 m^2 (as specified as a default assumption from ASHRAE Guideline 62.1 for calculating minimum outside air flow requirements). The calculation and documentation have been revised to a more direct calculation: multiply the internal heat gain schedule fraction table output [0-1] by 0.05 people/m^2 and the zone floor area to calculate the number of people. This has been updated in the Modelica Buildings Library with issue https://github.com/lbl-srg/modelica-buildings/issues/2781. |
| 8 | Images in the documentation are not rendered on Dymola 2020. Use ‘modelica://MultiZoneOfficeSimpleAir/../../doc’ instead of ‘../../../doc’.  Done! |
| 9 | As far as I can tell, the double glazing does not have an insulating coating, resulting in a U value of about 2.8 while 1.1 is the norm in the EU. Please verify whether these values are appropriate for BOPTEST. |
|  | This building envelope is based on the medium office U.S. DOE reference building model for Chicago, IL climate new construction (see report: <https://digitalscholarship.unlv.edu/cgi/viewcontent.cgi?article=1045&context=renew_pubs>, and see website: <https://www.energy.gov/eere/buildings/new-construction-commercial-reference-buildings>). Granted, the spec is based on ASHRAE Standard 90.1 2004, but even ASHRAE Standard 90.1 2013 prototype building models (<https://www.energycodes.gov/prototype-building-models>) have a U-Value of 2.4. I’d rather not change the envelope in order to keep with the spec, and also not have to then resize the whole system for new heating and cooling loads. |

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# III. Model Checks

|  |  |
| --- | --- |
| **Criteria** | **Reviewer Response** |
| **Reference Case Representation** |  |
| Does the model represent overall intent of reference case?  Are the relevant thermal systems, heat loads, and control signals accounted for? | Yes |
| **Climate** |  |
| Complete weather data file, similar to TMY? | Yes |
| Sufficiently long period, e.g. one year? | Yes |
| **Internal Gains** |  |
| Occupancy schedule? | It would make sense to have zero occupancy during weekends? |
| Occupancy gain values reasonable for building type? | Yes |
| Lighting schedule/control? | Yes, merged with occupants |
| Lighting gain values reasonable for building type? | Yes, merged with occupants |
| Equipment schedule? | Yes, merged with occupants |
| Equipment gain values reasonable for building type? | Yes, merged with occupants |
| **Envelope Modeling** |  |
| Are IDEAS, Buildings, or AixLib component models used for building envelope and window modeling? | Yes |
| If not IDEAS, Buildings, or AixLib component models, are dynamic wall heat transfer models used? | N/A |
| If not IDEAS, Buildings, or AixLib component models, are complex fenestration models used? | N/A |
| If not IDEAS, Buildings, or AixLib component models, is latitude and longitude consistent with intended region or weather file? | N/A |
| If not IDEAS, Buildings, or AixLib component models, are convection models for inside and outside nonlinear? | N/A |
| If not IDEAS, Buildings, or AixLib component models, are the inside and outside radiation models appropriate? | N/A |
| Are window surface areas reasonable? | Yes |
| Are insulation levels reasonable? | 8.7 cm of material with k=0.049 W/m2K is considered low in Belgium for new buildings. As far as I can tell, the double glazing does not have an insulating coating, resulting in a U value of about 2.8 while 1.1 is the norm in the EU. Please verify whether these values are appropriate for BOPTEST. |
| Are all surfaces accounted for? (e.g. the roof is not forgotten) | Yes |
| Which of the following is used for modeling air infiltration?  *None*  *Constant*  *Pressure-driven flow*  *Buoyancy-driven flow*  *Mixed pressure and buoyancy-driven flow* | Pressure-driven |
| Inter-zone airflow and common wall heat transfer properly accounted for? | Yes |
| **HVAC Modeling** |  |
| Are moisture and condensation effects properly accounted for? | Yes, the cooling coil considers condensation. |
| Are fluid components such as ducts, pipes, actuators, pumps, fans, and heat exchangers modeled with pressure-flow relationships? Are pressure drops reasonable? | Valve/pipe pressure drops are not yet reasonable.  Damper pressure drops are reasonable.  AHU coil pressure drops are reasonable.  Wall pressure drops are reasonable. |
| Is the heat transfer performance of other equipment such as heat exchangers and plant equipment modeled reasonably? | Yes |
| Are equipment capacities reasonable? | Yes |
| Are equipment efficiencies such as COP, heating, hydraulic, and motor reasonable? | Yes |
| Is reasonable baseline control provided in the model? Can the model be simulated without an external controller? | Yes, realistic default controller. |
| **External Control Input Signals** |  |
| Are Modelica signal exchange blocks used? | Yes |
| Reasonable set of external control signals? | Yes |
| Units assigned?  In SignalExchange.Overwrite assign a unit to the input variable u. | Yes |
| Descriptions assigned?  In SignalExchange.Overwrite use the parameter description. | Yes |
| Min/max assigned?  In SignalExchange.Overwrite assign a min and max to the input variable u. | Yes |
| **Measurement Output Signals** |  |
| Are Modelica signal exchange blocks used? | Yes |
| Reasonable set of measurement output signals? | Some volumetric flow rates seem unrealistic but can be allowed. |
| Is at least one, and more if necessary, of the following KPI labels used to account for equipment power/fuel consumptions for KPI calculation? Is power consumption from all relevant equipment tagged? {ElectricPower, DistrictHeatingPower, GasPower, BiomassPower, or SolarThermalPower}  In SignalExchange.Read, use the parameter KPIs. | Yes |
| Are all necessary zone temperatures tagged with one of the following KPI labels for KPI calculations and appropriate zone identifier(s) given? {AirZoneTemperature or OperativeZoneTemperature}  In SignalExchange.Read, use the parameters KPIs and zone. | Yes |
| Are all zone CO2 measurements tagged with the following KPI label for KPI calculations and appropriate zone identifier(s) given? {CO2Concentration}  In SignalExchange.Read, use the parameters KPIs and zone. | Yes |
| Units assigned?  In SignalExchange.Read assign a unit to the output variable y. | Yes |
| Descriptions assigned?  In SignalExchange.Read use the parameter description. | Yes |
| **Compilation and Simulation** |  |
| Uses official library release versions (with Modelica “Uses” statement)? | Yes |
| Can be compiled into model-exchange or co-simulation FMU that can be simulated without use of commercial licensing? | I presume so but ran out of memory when compiling on my laptop using Dymola 2020. |
| What is the intended solver, tolerance, and timestep (if constant timestep solver)? Are these reasonable to simulate the model dynamics? | The solver is appropriate but the model is fairly slow using these settings. |
| Simulates for full year? | Yes |

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# IV. Test Case Checks

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| --- | --- |
| **Criteria** | **Response** |
| **Documentation** |  |
| Building Design and Use (including architecture, constructions, occupancy schedules and comfort, internal loads and schedules, climate) | Construction types should be mentioned instead of citing the standard Ashrae 90.1-2004. |
| HVAC System Design (including primary and secondary system designs, equipment specifications and performance maps, rule based and/or local loop controllers) | Good documentation! The duct pressure flow network description could be extended a bit. The documentation mentions that relative humidity is tracked but I did not spot this logic in the model, or the required RH sensor in the documentation? |
| Additional System Design  (such as lighting, shading, onsite generation and storage) | Ok |
| Points List (including control inputs signals with descriptions, units, min/max, and default values, and measurement output signals with descriptions and units) | Defaults seem to be missing? Though I’m not sure when those would actually have a use? |
| Important Model Assumptions  (such as infiltration models, moist/dry air assumptions, well-mixed assumptions, CO2 generation from occupants and concentration in outside air) | Ok |
| Scenario Information (including time periods, energy pricing, and emission factors) | Ok |
| HTML template followed (see Appendix A)? | Yes |
| **BOPTEST Data Requirements** |  |
| If model DOES NOT make use of signal exchange Modelica blocks, is a KPI JSON provided for matching output signals to KPI keywords (see Appendix B)? | N/A |
| Is a Days JSON provided for specifying scenario time periods (see Appendix B)? | Yes, empty |
| Data for weather provided as csv with correct header names (see Appendix C)?  Does the data of this type used within the model match the data provided in the csv? | Yes |
| Data for zone comfort setpoint temperature(s) for each zone provided as csv with correct header names (see Appendix C)? Does the data of this type used within the model match the data provided in the csv? | Yes |
| Data for occupancy (number of occupants) schedule for each zone provided as csv with correct header names (see Appendix C)?  Does the data of this type used within the model match the data provided in the csv? | The number of occupants doesn’t seem to match the number of occupants in the model? E.g. on row 0 the occupancy is 0.05\*0.05 occ/m2\*984m2=2.46 while the file contains ‘2’. Other zones have 0 occupancy while it is decimal. The values thus seem to be rounded off, which seems inconsistent with the model. |
| Data for internal gains for each zone provided as csv with correct header names (see Appendix C)? Does the data of this type used within the model match the data provided in the csv? | Yes |
| Data for GHG emission factors for each fuel source provided as csv with correct header names (see Appendix C)? | Yes |
| Data for energy pricing provided as csv with correct header names (see Appendix C)? | Yes |

# Appendix A: Documentation Template

<html>

General model description.

<h3>Building Design and Use</h3>

<h4>Architecture</h4>

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<h4>Constructions</h4>

<p>

…

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<h4>Occupancy schedules</h4>

<p>

…

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<h4>Internal loads and schedules</h4>

<p>

…

</p>

<h4>Climate data</h4>

<p>

…

</p>

<h3>HVAC System Design</h3>

<h4>Primary and secondary system designs</h4>

<p>

…

</p>

<h4>Equipment specifications and performance maps</h4>

<p>

…

</p>

<h4>Rule-based or local-loop controllers (if included)</h4>

<p>

…

</p>

<h3>Model IO's</h3>

<h4>Inputs</h4>

The model inputs are:

<ul>

<li>

<code>Input1</code> [UNIT1]: Description

</li>

</ul>

<h4>Outputs</h4>

The model outputs are:

<ul>

<li>

<code>Output1</code> [UNIT1]: Description

</li>

<li>

<code>Output2</code> [UNIT2]: Description

</li>

</ul>

<h3>Additional System Design</h3>

<h4>Lighting</h4>

<p>

…

</p>

<h4>Shading</h4>

<p>

…

</p>

<h4>Onsite Generation and Storage</h4>

<p>

…

</p>

<h3>Model Implementation Details</h3>

<h4>Moist vs. dry air</h4>

<p>

…

</p>

<h4>Pressure-flow models</h4>

<p>

…

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<h4>Infiltration models</h4>

<p>

…

</p>

<h4>CO2 models</h4>

<p>

…

</p>

<h3>Scenario Information</h3>

<h4>Time Periods</h4>

<p>

…

</p>

<h4>Energy Pricing</h4>

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…

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<h4>Emission Factors</h4>

<p>

…

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</html>

# Appendix B: JSONs

KPI JSON

{<kpi\_ID> : // Unique identifier for KPI

[<output\_ID>] // List of FMU outputs to be included in calculation

}

Saved as “kpis.json”

For kpi\_IDs requiring zone designations, the zone designation can be appended to the end of the kpi\_ID as <kpi\_ID>[z], where z is the zone designation. These are AirZoneTemperature[z], OperativeZoneTemperature[z], and CO2Concentration[z].

Days JSON

{<time\_period\_ID> : // Unique identifier for specifying time period

<day #> // Integer value indicating day number to use for specifying time period

}

Saved as “days.json”

# Appendix C: Specifications for Data CSV Files

This information is taken from the BOPTEST Development Requirements and Guide Section IV. D.

The CSV data files should accomplish the following requirements:

1. The files can have any name.
2. The files should have a “*time*” column indicating the time since the beginning of the year in seconds.
3. The files should have column names using the key-words specified by the conventions below. Columns that do not apply to the test case may be omitted (e.g. *EmissionsGasPower* if the test case does not use gas power).
4. The files can have optional header rows for holding information about the data contained in the csv file. These header rows can be indicated by starting the row with the character "#".

Data for the CSV files may optionally be generated using the functions that are available in the module *data/data\_generator.py* located in the software repository at https://github.com/ibpsa/project1-boptest. Default parameters for these functions may be used, or modified based on the test case. If default parameters are used, care should be taken to make sure the resulting data matches that which may be used in the test case model.

|  |  |  |
| --- | --- | --- |
| **CATEGORY: *weather*** | | |
| **NAME** | **UNIT** | **DESCRIPTION** |
| *HDifHor* | W/m2 | Horizontal diffuse solar radiation. |
| *HDifNor* | W/m2 | Direct normal radiation. |
| *HGloHor* | W/m2 | Horizontal global radiation. |
| *HHorIR* | W/m2 | Horizontal infrared irradiation. |
| *TBlaSky* | K | Output temperature. |
| *TDewPoi* | K | Dew point temperature. |
| *TDryBul* | K | Dry bulb temperature at ground level. |
| *TWetBul* | K | Wet bulb temperature. |
| *celHei* | m | Ceiling height. |
| *cloTim* | s | One-based day number in seconds. |
| *lat* | rad | Latitude of the location. |
| *lon* | rad | Longitude of the location. |
| *nOpa* | 1 | Opaque sky cover [0, 1]. |
| *nTot* | 1 | Total sky Cover [0, 1]. |
| *pAtm* | Pa | Atmospheric pressure. |
| *relHum* | 1 | Relative Humidity |
| *solAlt* | rad | Altitude angel. |
| *solDec* | rad | Declination angle. |
| *solHouAng* | rad | Solar hour angle. |
| *solTim* | s | Solar time. |
| *solZen* | rad | Zenith angle. |
| *winDir* | rad | Wind direction. |
| *winSpe* | m/s | Wind speed |

|  |  |  |
| --- | --- | --- |
| **CATEGORY: *prices*** | | |
| **NAME** | **UNIT** | **DESCRIPTION** |
| *PriceElectricPowerConstant* | ($/€)/kWh | Completely constant electricity price |
| *PriceElectricPowerDynamic* | ($/€)/kWh | Electricity price for a day/night tariff |
| *PriceElectricPowerHighlyDynamic* | ($/€)/kWh | Spot electricity price |
| *PriceGasPower* | ($/€)/kWh | Price to produce 1 kWh thermal from gas |
| *PriceDistrictHeatingPower* | ($/€)/kWh | Price of 1 kWh thermal from district heating |
| *PriceBiomassPower* | ($/€)/kWh | Price to produce 1 kWh thermal from biomass |
| *PriceSolarThermalPower* | ($/€)/kWh | Price to produce 1 kWh thermal from solar irradiation |

|  |  |  |
| --- | --- | --- |
| **CATEGORY: *emissions*** | | |
| **NAME** | **UNIT** | **DESCRIPTION** |
| *EmissionsElectricPower* | kgCO2-eq/kWh | Kilograms of carbon dioxide equivalent to produce 1 kWh of electricity |
| *EmissionsGasPower* | kgCO2-eq/kWh | Kilograms of carbon dioxide equivalent to produce 1 kWh thermal from gas |
| *EmissionsDistrictHeatingPower* | kgCO2-eq/kWh | Kilograms of carbon dioxide equivalent to produce 1 kWh thermal from district heating |
| *EmissionsBiomassPower* | kgCO2-eq/kWh | Kilograms of carbon dioxide equivalent to produce 1 kWh thermal from biomass |
| *EmissionsSolarThermalPower* | kgCO2-eq/kWh | Kilograms of carbon dioxide equivalent to produce 1 kWh thermal from solar irradiation |

|  |  |  |
| --- | --- | --- |
| **CATEGORY: *occupancy*** | | |
| **NAME** | **UNIT** | **DESCRIPTION** |
| *Occupancy[z]* | Number of occupants | Number of occupants at zone ‘z’ |

|  |  |  |
| --- | --- | --- |
| **CATEGORY: *internalGains*** | | |
| **NAME** | **UNIT** | **DESCRIPTION** |
| *InternalGainsRad[z]* | W | Radiative internal gains at zone ‘z’ |
| *InternalGainsCon[z]* | W | Convective internal gains at zone ‘z’ |
| *InternalGainsLat[z]* | W | Latent internal gains at zone ‘z’ |

|  |  |  |
| --- | --- | --- |
| **CATEGORY: *setpoints*** | | |
| **NAME** | **UNIT** | **DESCRIPTION** |
| *LowerSetp[z]* | K | Lower temperature set point of the comfort range at zone ‘z’ |
| *UpperSetp[z]* | K | Upper temperature set point of the comfort range at zone ‘z’ |
| *UpperCO2[z]* | ppm | Upper CO2 concentration limit for zone ‘z’ |