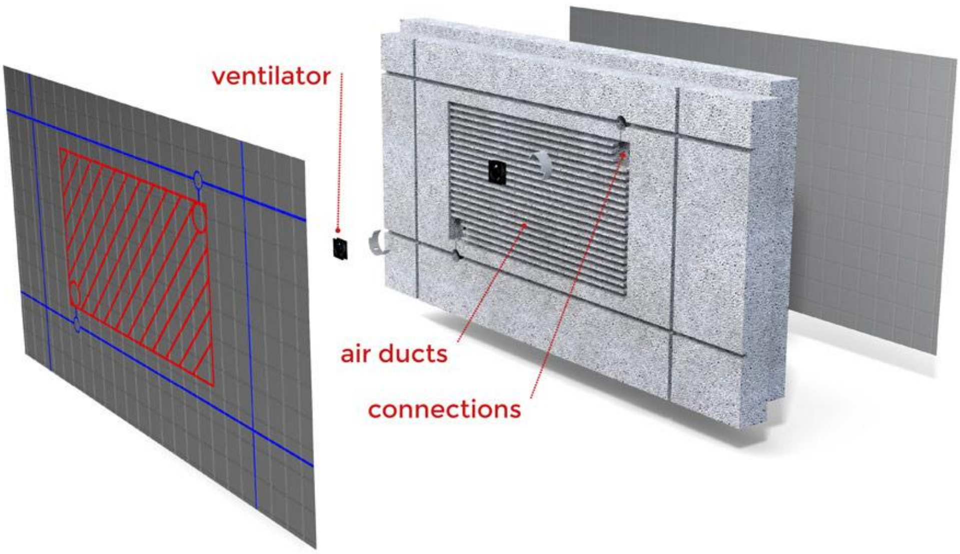
Active Insulation

Computational assessment of the performance of a dynamic insulation system



How to model Active Insulation in EnergyPlus

Where innovation starts

1. Downloading and adapting EnergyPlus

First of all, the developer version of EnergyPlus should be downloaded as some adjustments to the source code should be made. The most recent developer version of EnergyPlus can be found on https://github.com/NREL/EnergyPlus. Having the source code of EnergyPlus allows for modifying the source code and building your own adapted version of EnergyPlus. To build your own version of EnergyPlus follow the steps given on the Wiki page for building EnergyPlus: https://github.com/NREL/EnergyPlus/wiki/BuildingEnergyPlus. Keep in mind that you need to install Visual Studio and CMake to build the developer version. Links and steps are all in the description. Each time you adjust a piece of source code, you need to rebuild EnergyPlus for the adjustments to work.

For the Active Insulation model, the source code of the Ventilated Slab module should be adjusted. The Ventilated Slab module has a built-in check that shuts down the air flow if the direction of the heat flow is incorrect. This internal check appeared to be the reason why Active Insulation deactivated early and did not use the full potential. An extensive description and verification can be found in the graduation thesis *Active Insulation – Computational assessment of the performance of a forced convective dynamic insulation system* in chapter 2.4.3. Source code for all modules can be found in the folder of the developer version of EnergyPlus, most of the time located in a location similar to:

C:\EnergyPlus-developer\src\EnergyPlus

Find the "VentilatedSlab.cc" file in this folder and open it. Search for the part of code starting with *""Temperature Comparison" Cut-off:"*. This part of code should be found twice in the overall code of the Ventilated Slab module, first around line 3300 and a second time around line 3535. The full line of code that should be disabled can be found in Appendix I – Heat flow direction control loop. A repository is made on Github with all the files needed, including the adapted Ventilated Slab file and some example files. The repository can be found in the following location: https://github.com/StefanKoenders92/Active_Insulation. When this code is disabled, save the file and rebuild EnergyPlus according to the Wiki guide. EnergyPlus functions now with the adapted source code. Just keep in mind that .idf files of EnergyPlus should be executed from the location stated below (or similar) with the energyplus.exe file.

C:\EnergyPlus-8.6.0-developer\Build\Products\Release

2. Modelling the building/object to simulate

As Active Insulation is modelled as two internal sources divided over two surfaces, modelling the building/object in any pre-processing program should follow this same principle. As a result, any exterior surface that will be outfitted with Active Insulation need to be modelled as two separate layers, separated by a very small cavity. This cavity is dimensioned at 2 cm, as this is the minimal distance between two layers in EnergyPlus. Which pre-process program you use does not really matter. In the research into the performance of Active Insulation, Google SketchUp in combination with the [Euclid 0.9.3. Plugin] was used. Two very simple examples are shown here: a cube with one façade outfitted with Active Insulation and a cube having all surfaces outfitted with Active Insulation, as pictured in Figure 1.

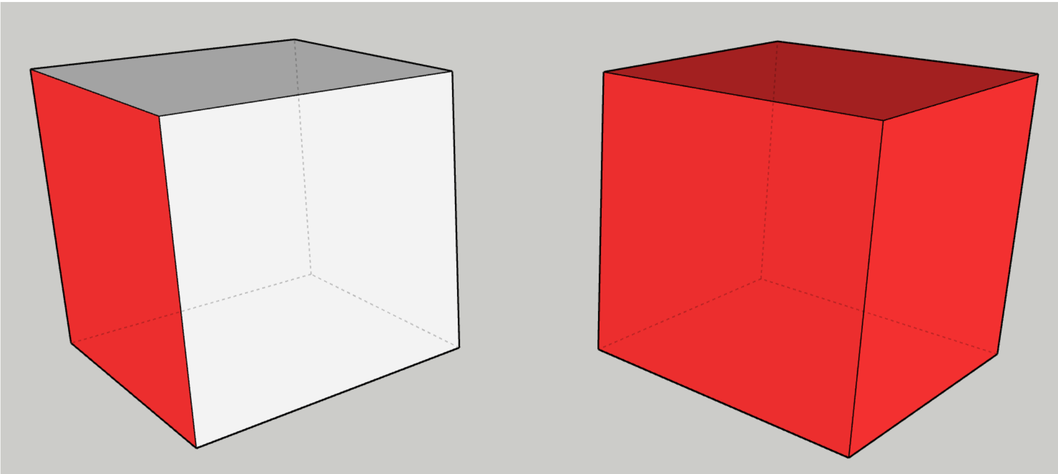


Figure 1: A simple cube with one surface on which Active Insulation will be applied and a simple cube where Active Insulation will be applied to all surfaces. In red the surfaces that will be applied with Active Insulation.

The way these two cubes should be modelled is shown in Figure 2. For the first cube it can be seen that a simple cavity is created and a second (façade) layer in front of it. This is also done for all surfaces of the other cube, resulting in a fully enclosed cube. The inner cube is the cube with the original dimensions.

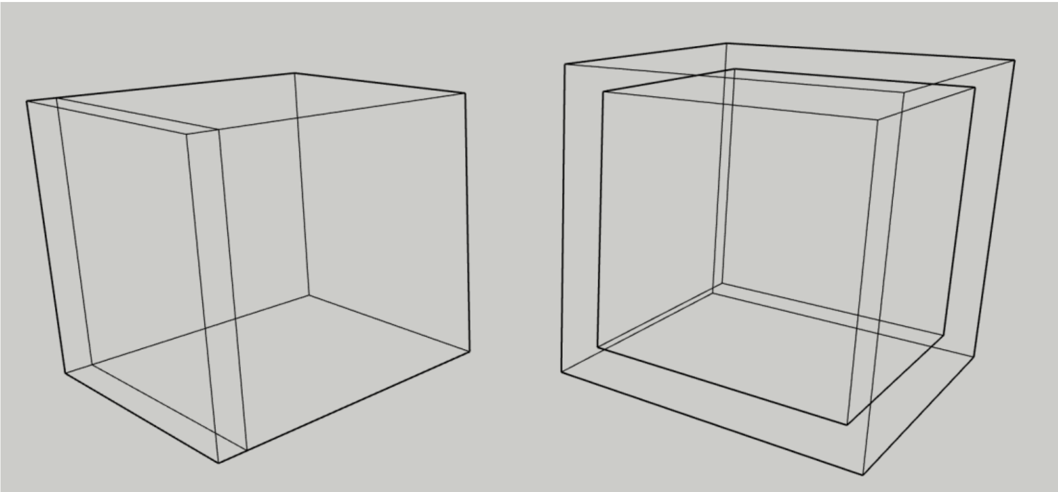


Figure 2: Schematic representation of the way the model should be built for both cubes. The size of the cavity is in this case exagarated for sake of clarity.

Things get more complex when a surface with a window/door needs to be modelled. To ensure a correct heat balance, the window should be separation point between the indoor and outdoor conditions. Modelling the window in both layers of the construction would result in incorrect results, as a limitation of the way EnergyPlus handles light and radiation as it has passed a glass surface. A simple example with a cube with a window is discussed below and shown in Figure 3.

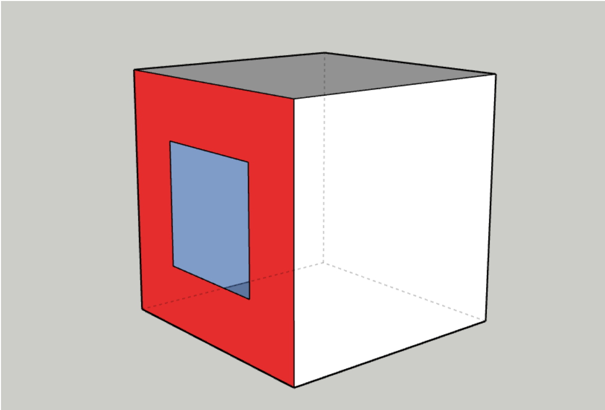


Figure 3: A cube where one surface will be outfitted with Active Insulation and has a window in the same surface.

As the window can be placed in only one surface, the window surface should be extended from the original surface with the same distance as the size of the cavity (normally 2 cm). After this, the second façade layer can be modelled as is shown in Figure 4. A diagonal line can be seen on both surfaces, connecting the lower corner of the façade with the lower corner of the window. This is needed as we create a 'hole' in both surfaces. EnergyPlus does not allow for holes in a surface as each surface is defined in a single set of vertices. In this way, we create a polygon with a hole which is allowed in EnergyPlus.

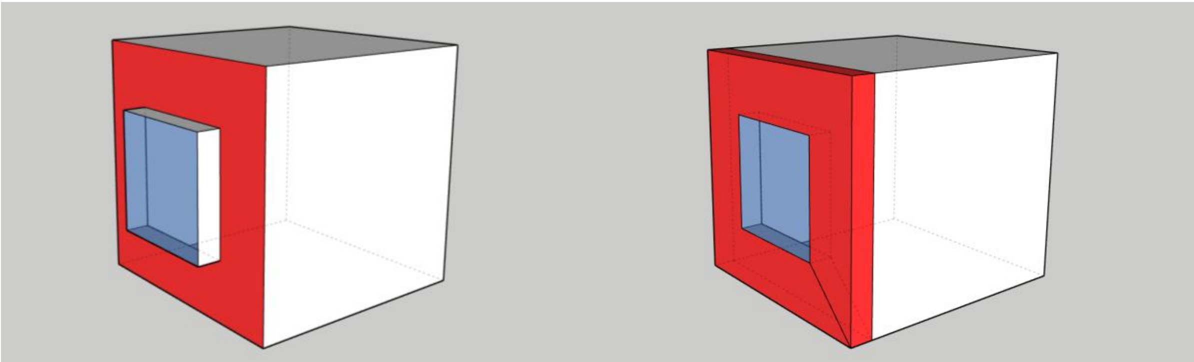


Figure 4: The first step is to extend the surface of the window, after which the second façade layer can be build.

3. Active Insulation in EnergyPlus

To model Active Insulation in EnergyPlus, the Ventilatied Slab module will be used as a base. The following components are needed to model Active Insulation.

- *Construction:InternalSource*
  Here, the location of the channels of Active Insulation in a construction is specified.
- *BuildingSurface:Detailed*
  The surfaces applied with Active Insulation are specified in this component.
- *ZoneHVAC:VentilatedSlab*
  This is the actual specification of the system, including setpoints etc.
- *ZoneHVAC:VentilatedSlab:SlabGroup*
  Specification for coordinated control of multiple surfaces with Active Insulation.
- *Fan:ConstantVolume*
  Specifying the characteristics of the fan used in the system.

Construction:InternalSource

In this section the layers of the construction are specified and the location of the channels in the Active Insulation system are specified. For example: the façade construction shown in Figure 5. It is a very simple construction with only three layers of materials. However, EnergyPlus can only model one internal source per surface, thus we need two separate surfaces: one for each side of the Active Insulation panel with air channels. As a result, the façade construction needs to be modelled as shown in the right side of Figure 5. There will be an exterior part, with plaster and one half of the Active Insulation panel, and an interior part with the other half of the insulation and the limestone. The actual Active Insulation part needs to be modelled as two separate surfaces: the aluminium foil seal and the actual insulation material. A very thin layer of aluminium cannot be modelled when using the internal source component, so this is modelled as a very thin layer (1mm) of insulation material instead. As the layer is this thin, the influence on the results is minimal.

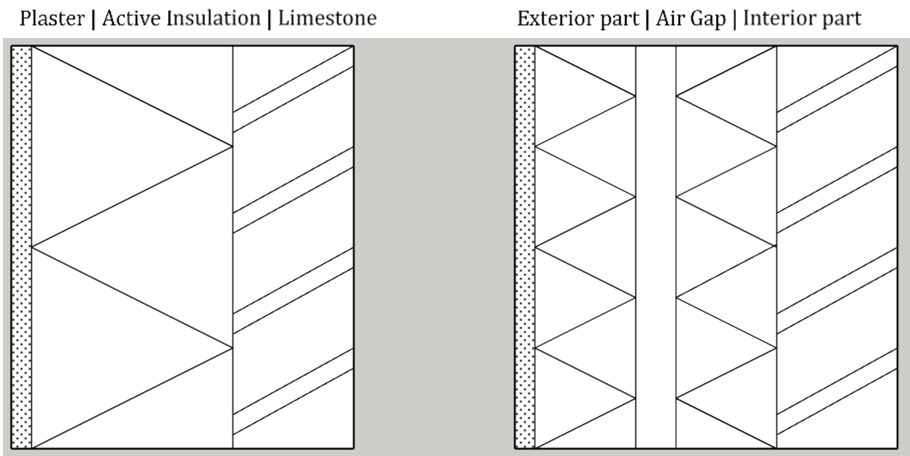


Figure 5: Left: a simple facade construction in which Active Insulation will be applied. Right: the way the construction should be modelled in EnergyPlus.

Figure 7 shows how the façade construction is then modelled in EnergyPlus. *Name:* user defined, but should have a logical name as you will have multiple of these internal sources if you have different types of constructions. Choosing a logical name allows for much easier coupling of components in EnergyPlus. *Source Present After Layer Number:* the layer of the construction at which the air channels of Active Insulation are present. *Temperature calculation Requested After Layer Number:* can be used for detailed temperature calculations between two layers in the construction. *Dimensions for the CTF Calculation:* Almost always 1, as we are only interested in 1 dimensional calculations. *Tube spacing:* only relevant if CTF calculations is 2 dimensional. *Outside Layer:* the outer layer of the construction. *Layer 2:* the layer following the outer layer etc.

For the construction discussed before, we need to build 3 internal sources. Two surfaces need to be specified for the A.I. Zone: surface 1 (connected to outdoor) and surface 2 (connected to indoor). For the indoor zone, only one surface needs to be specified: surface 3 (connected to A.I. Zone). Constructions and Internal Sources in EnergyPlus need be built up from the outer layer. The outer layer of a construction depends on the view direction, as is shown in Figure 6. The direction of the arrows of surface 2 and surface 3 indicated that the view direction is different and thus two separate internal sources need to be defined with material layers in the opposite directions. These internal sources will be connected to the corresponding surfaces in a later step.

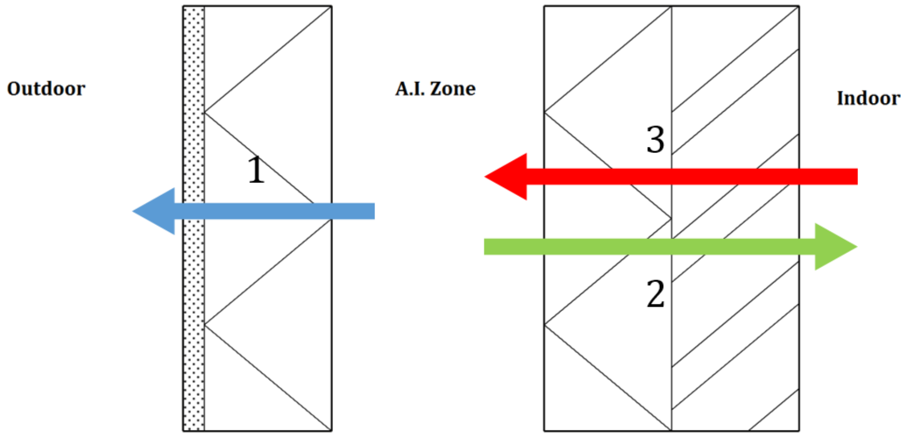


Figure 6: Schematic representation of the three surfaces that need to be modelled in EnergyPlus.

The exterior construction consists of gypsum, the foil and the insulation material for the example in this document. Air channels will in this case be present between the foil and insulation, which is after layer 2. The internal part consists of limestone, foil and insulation, whereas the direction depends on the surface. Again, the air channels are between the foil and insulation, which is after layer 1 or 2. Figure 7 shows the three corresponding internal sources modelled in EnergyPlus: one for the exterior part and two for the interior part.

Field	Units	Obj1	Obj2	Obj3
Name		A.I.-Exterior	A.I.-InteriorToZone	A.I.-InteriorToOutside
Source Present After Layer Number		2	2	1
Temperature Calculation Requested After Layer Numbe		1	2	1
Dimensions for the CTF Calculation		1	1	1
Tube Spacing	m	0,02	0,02	0,02
Outside Layer		Gypsum	Limestone	ActiveInsulation_Insulation
Layer 2		ActiveInsulation_Foil	ActiveInsulation_Foil	ActiveInsulation_Foil
Layer 3		ActiveInsulation_Insulation	ActiveInsulation_Insulation	Limestone
Layer 4				

Figure 7: Modelling the internal source in EnergyPlus.

BuildingSurface:Detailed

Now that the internal sources have been modelled, they need to be connected to a surface. This is done in the *BuildingSurface:Detailed* component. Figure 8 shows a simple setup for the façade construction discussed before. *Name:* is similar as before. *Surface type:* define the type of surface from the dropdown box. *Construction name:* is the name of the construction that will be used for this type of surface. *Zone name:* the zone to which this surface belongs. *Outside Boundary Condition:* define the outside boundary condition from the dropdown box e.g. outdoors, adiabatic, surface etc. *Outside Boundary Condition Object:* depending on the choice in the previous field, an object needs to be coupled to this surface. *Sun Exposure* & *Wind Exposure:* specify if the surface is reached by sun and/or wind. Other fields will be filled in by the pre-process modelling program.

Field	Units	Obj1	Obj2	Obj3
Name		ExteriorWall	Int.Part.Cavity-Indoor	Int.Part.Indoor-Cavity
Surface Type		Wall	Wall	Wall
Construction Name		A.I.-Exterior	A.I.-InteriorToZone	A.I.-InteriorToOutside
Zone Name		A.I.Cavity	A.I.Cavity	Indoor
Outside Boundary Condition		Outdoors	Surface	Surface
Outside Boundary Condition Object			Int.Part.Indoor-Cavity	Int.Part.Cavity-Indoor
Sun Exposure		SunExposed	NoSun	NoSun
Wind Exposure		WindExposed	NoWind	NoWind
View Factor to Ground				
Number of Vertices				

Figure 8: Connecting the internal sources to the corresponding surfaces.

So for our example we have three surfaces: one exterior surface, one surface from the air gap (called A.I.Cavity here) to indoors and one surface from indoors to the air gap. All three surfaces are walls but have different constructions. The exterior wall has the corresponding internal source as the coupled construction. It is connected to the zone 'A.I.Cavity' and has direct contact with the outdoor environment. As it is an exterior partition, both sun and wind can reach the surface.

The surface from the cavity to indoor is connected with the A.I.Cavity zone and has the corresponding internal source coupled to it. As it is an indoor partition, the outside boundary condition is another surface. In this case, the surface from indoor to A.I.Cavity. This surface is also specified in the *Outside Boundary Condition Object* field. The surface from indoor to A.I.Cavity works vice versa. Both surfaces are indoor surfaces and thus have no sun or wind exposure.

ZoneHVAC:VentilatedSlab

Next step is to specify the actual properties of Active Insulation in the *ZoneHVAC:VentilatedSlab* component. Figure 9 shows a filled in setup for Active Insulation applied to the façade structure as discussed before. *Name:* similar as before. *Availability Schedule Name:* in the schedule section of EnergyPlus, a schedule should defined for the availability of Active Insulation. *Zone Name:* is the name of the zone that is connected to the Active Insulation system. *Surface Name or Radiant Surface Group Name:* the surface that will be specified in the next component (*ZoneHVAC:VentilatedSlab:SlabGroup*) should be selected. *Maximum Air Flow Rate:* define the air flow rate in the Active Insulation system. Keep in mind that the specified air flow rate here is the total air flow rate of all panels. *Outdoor Air Control Type:* always select "FixedAmount". *Minimum/Maximum Outdoor Air Flow Rate:* always zero as Active Insulation does not use outdoor air.

Minimum/Maximum Outdoor Air Schedule Name: a schedule needs to be selected as EnergyPlus otherwise doesn't run, but the value of the schedule does not matter as the air flow rate is always zero. *System Configuration Type:* always select "SeriesSlabs" as Active Insulation consists of two slabs in series. *Hollow Core Diameter, Hollow Core Length* & *Number of Cores*: does not need to specified here when "SeriesSlabs" is chosen, but will be specified in the next component. *Temperature Control Type*: user can select the temperature on which Active Insulation is controlled. The control algorithm that will be defined by the user will override this control, but it is best to choose a similar temperature that will be used in the control algorithm.

The following eight schedules in the component can be found in the EnergyPlus example file of the Ventilated Slab (mostly located here: *C:\EnergyPlusV8-6-0\ExampleFiles*). What values should be used for these schedules will be discussed in the chapter 4:

Other components needed

- *HeatBalanceAlgorithm:* when using the internal source component, you will always need to select ConductionTransferFunction. Other algorithms do not function with this component.
- *ZoneHVAC:EquipmentList:* in this list, all equipment connected to a zone should be inserted in order of simulation. As the Active Insulation is a passive system, it should always be simulated before any active system, such as an ideal load system.
- *OutdoorAir:Node:* The outdoor air node as specified in the *ZoneHVAC:VentilatedSlab* should be specified here, even though the outdoor air is not used.

User defined control algorithm Active Insulation.

Next, seven system nodes should be specified, where *Zone Supply Air Node Name* is not needed to specify. These nodes are needed for a correct air flow through the system and should be named in a logic way as they need to be coupled to multiple other components. The most important thing is to notice that *Slab In Node Name* is exactly the same as *Fan Outlet Node Name*. As there are no heating or cooling coils, the outlet of the fan is the inlet of Active Insulation. *Fan Name:* select the fan that will be used in the system. *Coil Option Type:* should always be "None" as Active Insulation does not use any active cooling or heating system to treat the air.

Field	Units	Obj1
Name		Active_Insulation
Availability Schedule Name		AlwaysON
Zone Name		Indoor
Surface Name or Radiant Surface Group Name		A.I.-Facade
Maximum Air Flow Rate	m3/s	0,1
Outdoor Air Control Type		FixedAmount
Minimum Outdoor Air Flow Rate	m3/s	0
Minimum Outdoor Air Schedule Name		AlwaysON
Maximum Outdoor Air Flow Rate	m3/s	0
Maximum Outdoor Air Fraction or Temperature Schedul		AlwaysON
System Configuration Type		SeriesSlabs
Hollow Core Inside Diameter	m	0
Hollow Core Length	m	0
Number of Cores		0
Temperature Control Type		OperativeTemperature
Heating High Air Temperature Schedule Name		HeatTempHighInlet
Heating Low Air Temperature Schedule Name		HeatTempLowInlet
Heating High Control Temperature Schedule Name		HeatControlTempHigh
Heating Low Control Temperature Schedule Name		HeatControlTempLow
Cooling High Air Temperature Schedule Name		CoolTempHighInlet
Cooling Low Air Temperature Schedule Name		CoolTempLowInlet
Cooling High Control Temperature Schedule Name		CoolControlTempHigh
Cooling Low Control Temperature Schedule Name		CoolControlTempLow
Return Air Node Name		A.I.-RAN
Slab In Node Name		A.I.-FON
Zone Supply Air Node Name		
Outdoor Air Node Name		A.I.-OAN
Relief Air Node Name		A.I.-RELIEF
Outdoor Air Mixer Outlet Node Name		A.I.-OAMON
Fan Outlet Node Name		A.I.-FON
Fan Name		A.I.-Fan
Coil Option Type		None
Heating Coil Object Type		

Figure 9: Specifications of the Active Insulation system in the ZoneHVAC:VentilatedSlab component.

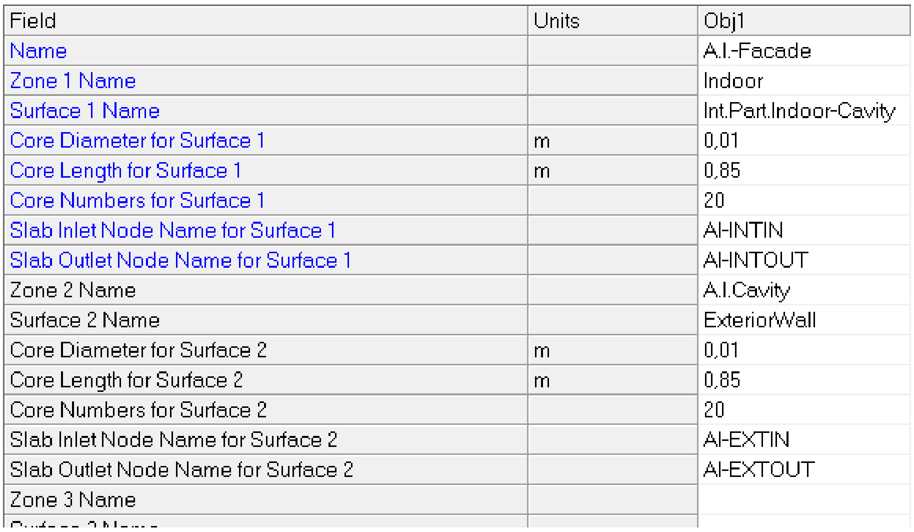
We want Active Insulation always active for our example as it should function as a heating and cooling system. The schedule selected for the availability is defined in such a way that the system will be always active. Active Insulation has an effect on the zone "Indoor" and is connected to the façade system. This façade system is defined as "A.I.-Facade" and will be explained in the next component.

ZoneHVAC:VentilatedSlab:SlabGroup

In this component, the Active Insulation system will be coupled to the corresponding surfaces. Figure 10 shows the filled in fields for the SlabGroup component. *Zone 1 Name:* select the first zone which is connected to Active Insulation, which will always be the zone that will be influenced by Active Insulation. *Surface 1 Name:* the surface in the Zone 1 which will be applied with Active Insulation, in this case the interzone surface. *Zone 2 Name:* select the second zone which is connected to Active Insulation, which will be the modelled cavity zone. *Surface 2 Name:* the surface in the cavity zone connected to the outdoor conditions should be selected here.

The following field should be similar for both surfaces discussed before: *Core Diameter for Surface X*, *Core Length for Surface X* and *Core Numbers for Surface X.* The first one describing the diameter of a single air channel of Active Insulation. Secondly, the length of a single channels is defined and thirdly the amount of these channels. Keep in mind that the first and second field depend on the actual design of an Active Insulation panel, while the third field depends on how many panels will be used in the design.

Slab Inlet Node Name and *Slab Outlet Node Name* field describe the name for the actual inlet and outlet node of a single side of the Active Insulation system. These can be used to output temperatures, mass flow rates, enthalpy in a specific location in the system.



Field	Units	Obj1
Name		A.I.-Facade
Zone 1 Name		Indoor
Surface 1 Name		Int.Part.Indoor-Cavity
Core Diameter for Surface 1	m	0,01
Core Length for Surface 1	m	0,85
Core Numbers for Surface 1		20
Slab Inlet Node Name for Surface 1		AI-INTIN
Slab Outlet Node Name for Surface 1		AI-INTOUT
Zone 2 Name		A.I.Cavity
Surface 2 Name		ExteriorWall
Core Diameter for Surface 2	m	0,01
Core Length for Surface 2	m	0,85
Core Numbers for Surface 2		20
Slab Inlet Node Name for Surface 2		AI-EXTIN
Slab Outlet Node Name for Surface 2		AI-EXTOUT
Zone 3 Name		

Figure 10: Modelling Active Insulation in the facade structure using the ZoneHVAC:VentilatedSlab:SlabGroup component.

Table 1 Shows an example of simulation of a single Active Insulation panel and the simulation of a façade with five Active Insulation panels. As can be seen, the diameter and core length stay the same, while the amount of cores increases.

Table 1: Example of changing parameters with different simulations.

	1 Active Insulation panel	***5 Active Insulation panels***
Amount of panels	1	5
Channel diameter	0.01 m	0.01 m
Channel length	0.85 m	0.85 m
Amount of channels	20	100

For the example used in this document, Active Insulation need to have an air circulation from the interior side to the exterior side. It can be seen that Active Insulation first passes through the air channels on the side of the interior zone, specified as the surface "Int.Part.Indoor-Cavity". The channel diameter is 1 cm with a channel length of 85 cm. In this case, a single Active Insulation panel will be applied, having a total of 20 channels per side. After passing through the channels in contact with the interior zone, the air travels through the channels in the surface "ExteriorWall", which is in direct contact with the outdoor conditions. Specifications of the channels is exactly the same for the first and second surface.

Fan:ConstantVolume

In this component the actual fan that will be used to circulate the air through the air channels is described. Figure 11 shows the characteristics of *Fan:ConstantVolume* component. *Availability Schedule Name:* the same schedule as selected in the *ZoneHVAC:VentilatedSlab* should be selected. *Fan Total Efficiency:* the overall efficiency of the fan used for circulating the air. *Pressure Rise:* should be kept at zero for correct functioning of the system. Effect of pressure rise is minimal in the system and thus neglected. *Maximum Flow Rate:* should be the same as defined in the *ZoneHVAC:VentilatedSlab* component. *Motor In Airstream Fraction:* always one as the fan is fully in the air stream. *Air Inlet Node Name:* is the exact same node as the *Outdoor Air Mixer Outlet Node Name* specified in the *ZoneHVAC:VentilatedSlab* component. *Air Outlet Node Name:* is the exact same node as the *Fan Outlet Node Name* specified in the *ZoneHVAC: VentilatedSlab* component.

Field	Units	Obj1
Name		A.I.-Fan
Availability Schedule Name		AlwaysON
Fan Total Efficiency		0,7
Pressure Rise	Pa	0
Maximum Flow Rate	m3/s	0,1
Motor Efficiency		0,9
Motor In Airstream Fraction		1
Air Inlet Node Name		A.I.-OAMON
Air Outlet Node Name		A.I.-FON
End-Use Subcategory		General

Figure 11: Specification of the fan used for Active Insulation.

Other components needed

- *HeatBalanceAlgorithm:* when using the internal source component, you will always need to select ConductionTransferFunction. Other algorithms do not function with this component.
- *ZoneHVAC:EquipmentList:* in this list, all equipment connected to a zone should be inserted in order of simulation. As the Active Insulation is a passive system, it should always be simulated before any active system, such as an ideal load system.
- *OutdoorAir:Node:* The outdoor air node as specified in the *ZoneHVAC:VentilatedSlab* should be specified here, even though the outdoor air is not used.

4. User defined control algorithm Active Insulation

As the built-in control algorithm of the Ventilated Slab component is not sufficient enough for simulating the fluctuating complex behaviour of Active Insulation, a new control algorithm should be defined in the EnergyManagementSystem (EMS) section of EnergyPlus. The complete code for control of a single surface can be found in Appendix II – Control Algorithm EMS code. Multiple components need to be added to the EMS section of EnergyPlus for a proper functioning of the algorithm. A separate document called Application Guide for EMS (found in documentation of EnergyPlus) contains much more information on how to use the EMS. The EMS uses the EnergyPlus Runtime Language (Erl) for custom programming of control routines. It is an advanced feature of EnergyPlus and is not for beginners. The following components will be used:

- *EnergyManagementSystem:Sensor*
- *EnergyManagementSystem:Actuator*
- *EnergyManagementSystem:ProgramCallingManager*
- *EnergyManagementSystem:Program*
- *EnergyManagementSystem:Subroutine*
- *EnergyManagementSystem:GlobalVariable*

EnergyManagementSystem:Sensor

In this section, the sensors that are needed for the control of Active Insulation will be defined. Sensors are the output variables that will be used for controlling the actuators in the EMS. Active Insulation will be controlled based on the operative temperature indoors and the external surface temperature. As can be seen in Figure 12, the operative temperature of the "Indoor" zone and the surface outside face temperature of the "ExteriorWall" are used as sensor values.

Field	Units	Obj1	Obj2
Name		OperativeTemperature	SurfTemp_A.I.
Output:Variable or Output:Meter Index Key Name		Indoor	ExteriorWall
Output:Variable or Output:Meter Name		Zone Operative Temperature	Surface Outside Face Temperature

Figure 12: Sensors needed for the Active Insulation control defined in the EMS.

EnergyManagementSystem:Actuator

Actuators are components that can be controlled by the EMS code to actuate selected features inside EnergyPlus. For Active Insulation, the only component that needs to be actuated is the fan. For this, the 'Fan Air Mass Flow Rate' of the *Fan:ConstantVolume* component will be controlled as shown in Figure 13.

Field	Units	Obj1
Name		A.I.-FAN_MFR
Actuated Component Unique Name		A.I.-Fan
Actuated Component Type		Fan
Actuated Component Control Type		Fan Air Mass Flow Rate

Figure 13: Actuator needed for the Active Insulation control defined in the EMS.

EnergyManagementSystem:Program

In the program component of the EMS, a program for controlling any variable can be written. For Active Insulation, a program is written that selects if Active Insulation should run in cooling or heating mode. Furthermore, a program that sets the control temperatures for both heating and cooling is written. The implementation of these programs in EnergyPlus can be seen in Figure 14.

The program "SetTemp" sets the low and high setpoint temperature for cooling and heating. This allows for a dual setpoint control, combined with a deadband region. The deadband for this situation lays between 22°C and 23°C. As a dual setpoint is used, the control temperatures are set in the same program at the very beginning of the simulation (line A6 & A7). In the *ZoneHVAC:VentilatedSlab* component, multiple schedules for the control of the component were needed. The *Heating/Cooling High Control Temperature* and *Heating/Cooling Low Control Temperature* should be both set to a temperature within the deadband range, in this case for example 22.5°C. The *Heating High/Low Inlet Temperature* should be set a value far above the heating setpoints, for this example 40°C. The *Cooling High/Low Inlet Temperature* should be set a value far below the cooling setpoints, for this example 1°C. Using these setpoints ensures that the built-in control algorithm does not interfere with the user defined control algorithm.

In the "SetMode" program the operative temperature is evaluated against the current cooling and heating setpoint. If the operative temperature is below the heating setpoint, Active Insulation will run in heating mode and vice versa.

Field	Units	Obj1	Obj2
Name		SetMode	SetTemp
Program Line 1		IF OperativeTemperature < HeatingTemp	SET ControlTempCoolingHigh = 25
Program Line 2		RUN HeatingControlA.I.	SET ControlTempCoolingLow = 23
A4		RETURN	SET ControlTempHeatingHigh = 22
A5		ELSEIF OperativeTemperature > CoolingTemp	SET ControlTempHeatingLow = 20
A6		RUN CoolingControlA.I.	SET HeatingTemp = ControlTempHeatingHigh
A7		RETURN	SET CoolingTemp = ControlTempCoolingLow
A8		ENDIF	
A9			

Figure 14: Specification of both programs as defined in EnergPlus.

EnergyManagementSystem:ProgramCallingManager

Not all programs should be run at the same moment. In this component, the moment the program is called/executed by EnergyPlus can be defined. The "SetTemp" program for example should only run at the beginning of a new simulation, hence the calling point "BeginNew Environment". However, the "SetMode" program should run each timestep and before any other HVAC manager. The calling point is therefore set to "AfterPredictorBeforeHVACManagers". Figure 15 shows the program calling manager in EnergyPlus.

Field	Units	Obj1	Obj2
Name		StartingSetPoints	AI_ZoneControl
EnergyPlus Model Calling Point		BeginNewEnvironment	AfterPredictorBeforeHVACManagers
Program Name 1		SetTemp	SetMode
Program Name 2			

Figure 15: The program calling manager in the EMS with the calling points for all programs.

EnergyManagementSystem:Subroutine

In the subroutine component of the EMS, control algorithms can be written that will be executed by the Program component of the EMS. The program “SetMode” determines if the subroutine “HeatingControlA.I.” or “CoolingControlA.I.” should run, based on a comparison of the operative temperature with the setpoint temperatures.

The “HeatingControlA.I.” subroutine checks if the operative temperature is below the current heating setpoint. If the high heating setpoint is reached (in this case 22°C), the heating setpoint is set back to the lower setpoint temperature (in this case 20°C). This allows for an activation range, and reduces the amount of activations of the system. The system is activated again if the temperature drops below the lower setpoint temperature and at this moment the heating setpoint is set back to the high heating setpoint.

If the operative temperature is below the setpoint temperature, the control algorithm also checks if the temperature difference between the operative temperature and the outside surface temperature allows for heating. When a heating potential is available the fan is activated by increasing the mass flow rate. If no (more) heating potential is available, the fan is turned off by decreasing the mass flow rate of the fan to zero.

The control algorithm for cooling works very similar as described above for heating, but checks if a cooling potential is available.

Field	Units	Obj1	Obj2
Name		HeatingControlA.I.	CoolingControlA.I.
Program Line 1		IF OperativeTemperature < (HeatingTemp - 0.1)	IF OperativeTemperature > (CoolingTemp + 0.1)
Program Line 2		SET HeatingTemp = ControlTempHeatingHigh	SET CoolingTemp = ControlTempCoolingLow
A4		IF SurfTemp_A.I. > OperativeTemperature	IF SurfTemp_A.I. < OperativeTemperature
A5		SET A.I.-FAN_MFR = 1.0	SET A.I.-FAN_MFR = 1.0
A6		ELSEIF SurfTemp_A.I. < OperativeTemperature	ELSEIF SurfTemp_A.I. > OperativeTemperature
A7		SET A.I.-FAN_MFR = 0.0	SET A.I.-FAN_MFR = 0.0
A8		ENDIF	ENDIF
A9		RETURN	RETURN
A10		ELSEIF OperativeTemperature > (HeatingTemp - 0.1)	ELSEIF OperativeTemperature < (CoolingTemp + 0.1)
A11		SET HeatingTemp = ControlTempHeatingLow	SET CoolingTemp = ControlTempCoolingHigh
A12		SET A.I.-FAN_MFR = 0.0	SET A.I.-FAN_MFR = 0.0
A13		ENDIF	ENDIF
A14		RETURN	RETURN
A15			

Figure 16: The subroutines for heating and cooling described in the subroutine component of the EMS.

5. Tips and tricks

- Each of the components described in this document are even more extensively explained in the accompanying documentation of EnergyPlus. The "InputOutputReference.pdf" file describes each component, what each field of a component means, commonly used values and the possible output variables when using a component. As the EMS in EnergyPlus is very complex, the "EMSApplicationGuide.pdf" file has an extensive description of what the EMS can do and what it cannot do.

- The application of Active Insulation as described in this documentation is for a single surface. When multiple surfaces will be used, with for example different control or orientations, these components need to be duplicated for these surfaces. Also the complete control algorithm as described in the EMS, including all components, should be duplicated for the new surfaces.

- The control algorithm as described in this documentation compares the operative temperature with the setpoint temperatures. In a later stage, it could be needed to change this so that a comparison of air temperature with setpoint temperatures is made. In this case, the control algorithm in the EMS should be adapted, but also the temperature control type in the component *"ZoneHVACH:VentilatedSlab*".

- When running the simulation and very long runtimes occur, it is possible that every single line of code of the control algorithm for each timestep is outputted. Check if in the component *"Output:EnergyManagementSystem"* the field *EMS Runtime Language Debug Output Level* is set to *Errors Only.* If *Verbose* is selected, the code is outputted at the interval of the selected simulation timestep. This is good to check if the code functions properly and for debugging, but once you are sure the code is correct this value can be changed to *Errors Only.*

- Due to modelling windows as described in Figure 4, EnergyPlus will display multiple warnings regarding non-convex surfaces. This is not a problem and will not influence your simulation results, but is merely a heads up.

- To ensure a minimal influence of the additional zone on the performance of Active Insulation, all surfaces that are not equipped with Active Insulation should be outfitted as massless high resistance insulation layers. This reduces the heat transferred to other adjacent zones and minimizes any storage of heat in structures other than Active Insulation. Such a material can be specified in the *"Material:NoMass"* component in EnergyPlus.

Appendix I – Heat flow direction control loop

```
// "Temperature Comparison" Cut-off:
// Check to see whether or not the system should really be running.  If
// QRadSysSource is negative when we are in heating mode or QRadSysSource
// is positive when we are in cooling mode, then the radiant system will
// be doing the opposite of its intention.  In this case, the flow rate
// is set to zero to avoid heating in cooling mode or cooling in heating
// mode.

if ( ( ( OperatingMode == HeatingMode ) && ( QRadSysSource( SurfNum ) <= 0.0 ) ) || ( ( OperatingMode == CoolingMode ) && ( QRadSysSource( SurfNum ) >= 0.0 ) ) ) {

        // IF (.not. WarmupFlag) THEN
        //   TempComparisonErrorCount = TempComparisonErrorCount + 1
        //   IF (TempComparisonErrorCount <= NumOfVentSlabs) THEN
        //      CALL ShowWarningError('Radaint Heat exchange is negative in Heating Mode or posive in Cooling Mode')
        //      CALL ShowContinueError('Flow to the following ventilated slab will be shut-off to avoid heating in cooling mode or cooling &
        //                             in heating mode')
        //      CALL ShowContinueError('Ventilated Slab Name = '//TRIM(VentSlab(Item)%Name))
        //      CALL ShowContinueError('All node temperature are reseted at the ventilated slab surface temperature = '// &
        //      RoundSigDigits(TH(VentSlab(Item)%SurfacePtr(RadSurfNum),1,2),2))
        //      CALL ShowContinueErrorTimeStamp(' ')
        //   ELSE
        //      CALL ShowRecurringWarningErrorAtEnd('Ventilated Slab ['//TRIM(VentSlab(Item)%Name) //  &
        //              '] Temperature Comparison Error shut-off occurrence continues.',  &
        //                  VentSlab(Item)%CondErrCount)
        //   END IF
        // END IF

        Node( SlabInNode ).MassFlowRate = 0.0;
        Node( FanOutletNode ).MassFlowRate = 0.0;
        Node( OAInletNode ).MassFlowRate = 0.0;
        Node( MixoutNode ).MassFlowRate = 0.0;
        Node( ReturnAirNode ).MassFlowRate = 0.0;
        AirMassFlow = 0.0;
```

```
for ( RadSurfNum2 = 1; RadSurfNum2 <= VentSlab( Item ).NumOfSurfaces; ++RadSurfNum2 ) {
	SurfNum2 = VentSlab( Item ).SurfacePtr( RadSurfNum2 );
	QRadSysSource( SurfNum2 ) = 0.0;
	if ( Surface( SurfNum2 ).ExtBoundCond > 0 && Surface( SurfNum2 ).ExtBoundCond != SurfNum2 ) QRadSysSource( Surface( SurfNum2 ).ExtBoundCond ) = 0.0; // Also zero the other side of an interzone

	if ( VentSlab( Item ).SysConfg == SlabOnly ) {
		//            Node(Returnairnode)%Temp = MAT(Zonenum)
		Node( ReturnAirNode ).Temp = TH( 2, 1, VentSlab( Item ).SurfacePtr( RadSurfNum ) );
		Node( FanOutletNode ).Temp = Node( ReturnAirNode ).Temp;
		Node( SlabInNode ).Temp = Node( FanOutletNode ).Temp;
	} else if ( VentSlab( Item ).SysConfg == SlabAndZone ) {
		Node( ReturnAirNode ).Temp = MAT( ZoneNum );
		Node( SlabInNode ).Temp = Node( ReturnAirNode ).Temp;
		Node( FanOutletNode ).Temp = Node( SlabInNode ).Temp;
		Node( ZoneAirInNode ).Temp = Node( SlabInNode ).Temp;
	}
}
break; // outer do loop
}
```

Appendix II – Control Algorithm EMS code

```
EnergyManagementSystem:Sensor,
    OperativeTemperature,                   !- Name
    Indoor,                                 !- Output:Variable or Output:Meter Index Key Name
    Zone Operative Temperature;             !- Output:Variable or Output:Meter Name

EnergyManagementSystem:Sensor,
    SurfTemp_A.I.,                          !- Name
    ExteriorWall,                           !- Output:Variable or Output:Meter Index Key Name
    Surface Outside Face Temperature;       !- Output:Variable or Output:Meter Name

EnergyManagementSystem:Actuator,
    A.I.-FAN_MFR,                                          !- Name
    A.I.-FAN,                                              !- Actuated Component Unique Name
    Fan,                                                   !- Actuated Component Type
    Fan Air Mass Flow Rate;                                !- Actuated Component Control Type

EnergyManagementSystem:ProgramCallingManager,
    AI_ZoneControl,                                        !- Name
    AfterPredictorBeforeHVACManagers,                      !- EnergyPlus Model Calling Point
    SetMode;                                               !- Program Name 1

EnergyManagementSystem:ProgramCallingManager,
    StartingSetPoints,                                     !- Name
    BeginNewEnvironment,                                   !- EnergyPlus Model Calling Point
    SetTemp;                                               !- Program Name 1

EnergyManagementSystem:Program,
    SetTemp,                                               !- Name
    SET ControlTempCoolingHigh = 25,                       !- Program Line 1
    SET ControlTempCoolingLow = 23,                        !- Program Line 2
    SET ControlTempHeatingHigh = 22,                       !- A4
    SET ControlTempHeatingLow = 20,                        !- A5
    SET HeatingTemp = ControlTempHeatingHigh,              !- A6
    SET CoolingTemp = ControlTempCoolingLow;               !- A7
```

```
EnergyManagementSystem:Program,
    SetMode,                                                !- Name
    IF OperativeTemperature < HeatingTemp,                  !- Program Line 1
    RUN HeatingControlA.I.,                                 !- Program Line 2
    RETURN,                                                 !- A4
    ELSEIF OperativeTemperature > CoolingTemp,              !- A5
    RUN CoolingControlA.I.,                                 !- A6
    RETURN,                                                 !- A7
    ENDIF;                                                  !- A8

EnergyManagementSystem:Subroutine,
    HeatingControlA.I.,                                     !- Name
    IF OperativeTemperature < (HeatingTemp - 0.1),          !- Program Line 1
    SET HeatingTemp = ControlTempHeatingHigh,               !- Program Line 2
    IF SurfTemp_A.I. > OperativeTemperature,                !- A4
    SET A.I.-FAN_MFR = 1.0,                                 !- A5
    ELSEIF SurfTemp_A.I. < OperativeTemperature,            !- A6
    SET A.I.-FAN_MFR = 0.0,                                 !- A7
    ENDIF,                                                  !- A8
    RETURN,                                                 !- A9
    ELSEIF OperativeTemperature > (HeatingTemp - 0.1),      !- A10
    SET HeatingTemp = ControlTempHeatingLow,                !- A11
    SET A.I.-FAN_MFR = 0.0,                                 !- A12
    ENDIF,                                                  !- A13
    RETURN;                                                 !- A14

EnergyManagementSystem:Subroutine,
    CoolingControlA.I.,                                     !- Name
    IF OperativeTemperature > (CoolingTemp + 0.1),          !- Program Line 1
    SET CoolingTemp = ControlTempCoolingLow,                !- Program Line 2
    IF SurfTemp_A.I. < OperativeTemperature,                !- A4
    SET A.I.-FAN_MFR = 1.0,                                 !- A5
    ELSEIF SurfTemp_A.I. > OperativeTemperature,            !- A6
    SET A.I.-FAN_MFR = 0.0,                                 !- A7
    ENDIF,                                                  !- A8
    RETURN,                                                 !- A9
    ELSEIF OperativeTemperature < (CoolingTemp + 0.1),      !- A10
    SET CoolingTemp = ControlTempCoolingHigh,               !- A11
    SET A.I.-FAN_MFR = 0.0,                                 !- A12
    ENDIF,                                                  !- A13
    RETURN;                                                 !- A14
```