

Performance-based control of an adaptive hybrid IAQ system

The influence of the user on system performance

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Is ventilation the answer to indoor air quality control in buildings? *Do we need performance based approaches?*

Answering the first question defines the boundaries of IAQ performance of a ventilation system

Is ventilation the answer to indoor air quality control in buildings? *Do we need performance based approaches?*

Ventilation should dilute and remove pollutants from
unavoidable sources



source avoidance / control / containment are the
best control strategies

Do we need performance based approaches?

Do we monitor? \leftrightarrow Do we model?

What is the decisive parameter for selecting a modelling approach (CFD \leftrightarrow AFN)

How to compare systems?

Do we monitor? \leftrightarrow do we model?

All models are wrong. The practical question is how wrong do they have to be to not be useful.

(George E. P. Box — *Empirical Model-Building and Response Surfaces*, 1987)

Introduction to PhD Research

Context = NZEB, Importance ventilation losses ↗ +
user ↗ (comfort)

Focus = Hybrid Ventilation

Topics = user comfort, energy consumption, IAQ,
control strategies

Goal = more comfort using less energy

Introduction to PhD Research

Comfort ↗

Temperature

Relative Humidity

Carbon Dioxide

Noise

...

User Interaction/Control ↗

Energy ↘

Auxiliary energy consumption for HVAC ↘

Energy demand for heating and cooling ↘

Natural Ventilation

Natural supply/exhaust = windows and grilles

no direct heat recovery

more difficult to control

thermal discomfort (low winter supply temperatures)

limited sound insulation

BUT (under favourable outdoor conditions)

Optimal air quality at very low (auxiliary)
energy use

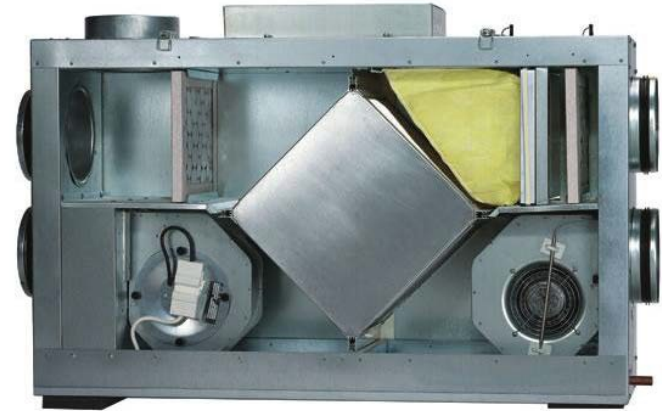


(Demand-controlled) Mechanical ventilation

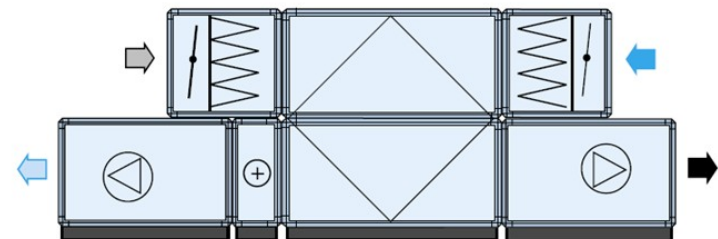
mechanical supply, mechanical
exhaust, heat recovery, air filters

reduction of ventilation energy
losses

increase of auxiliary energy use of
fans



Supply air and exhaust air installation with plate heat exchanger

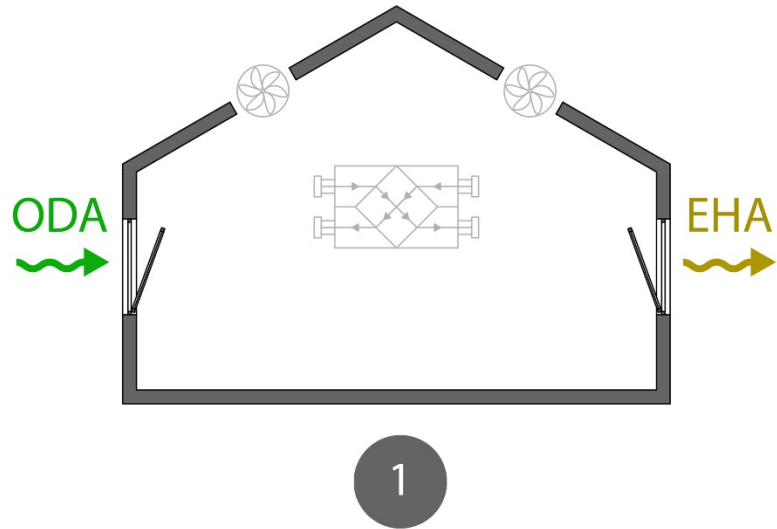


Why hybrid?

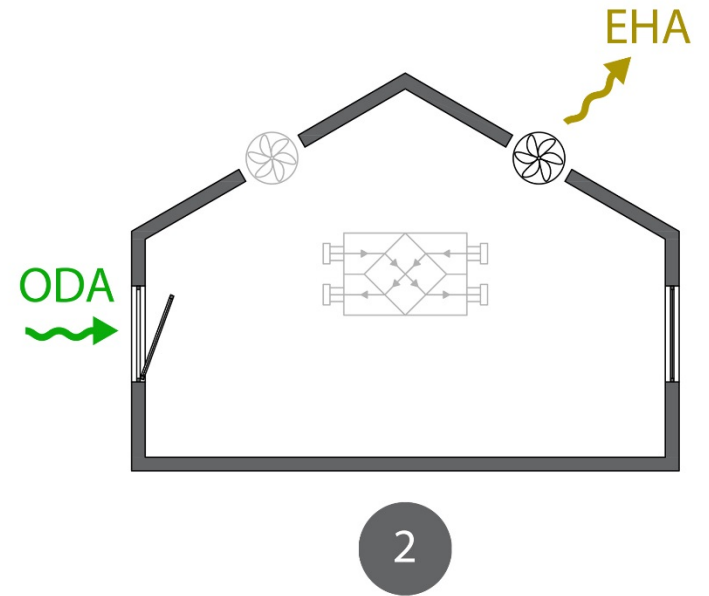
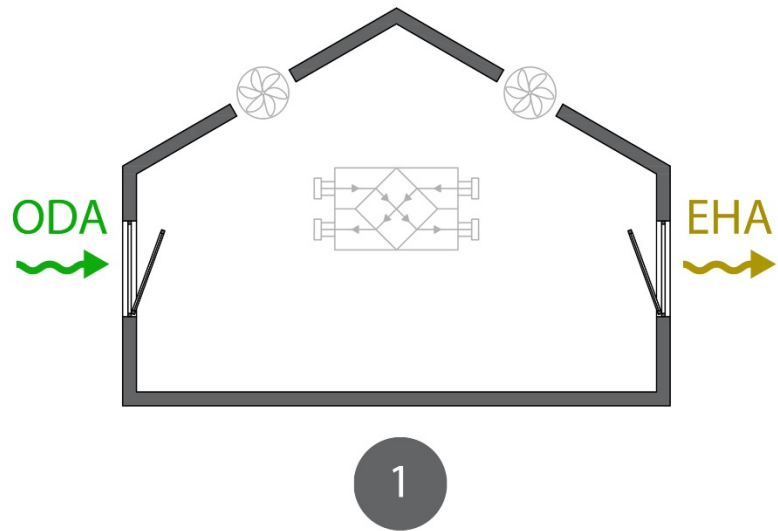
To combine the advantages of natural and mechanical ventilation systems while minimizing the drawbacks

=

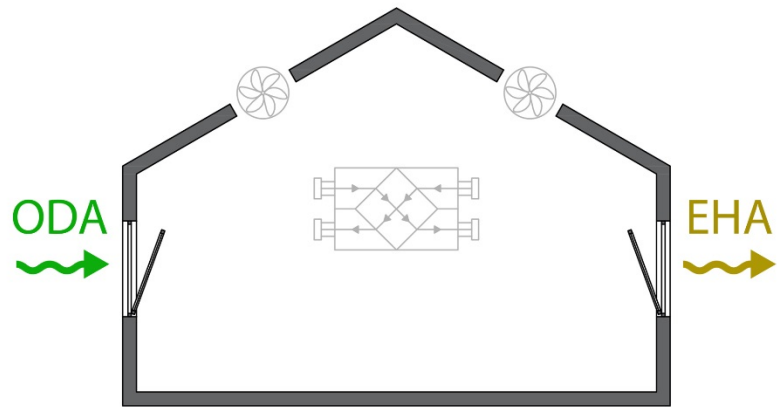
To combine IAQ with energy efficiency



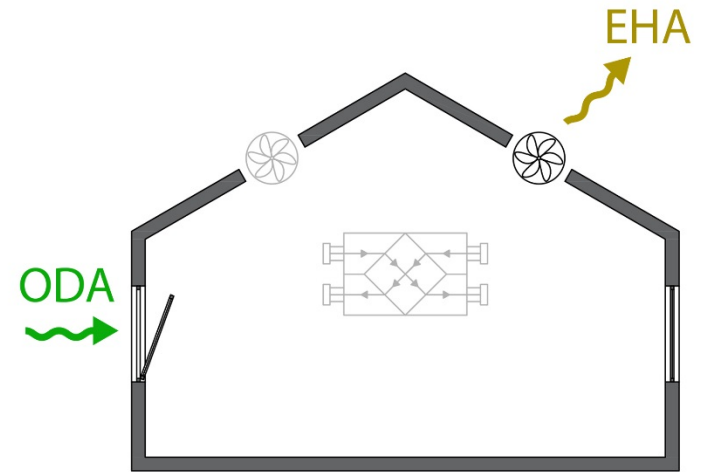
hygienic ventilation with natural
supply- and outlet-openings



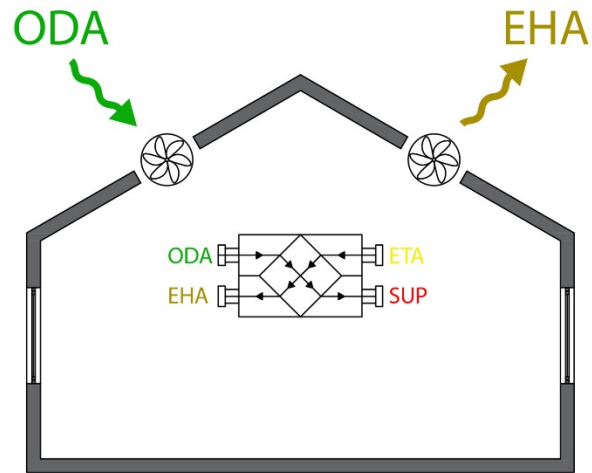
hygienic ventilation with natural supply and mechanical extraction



1

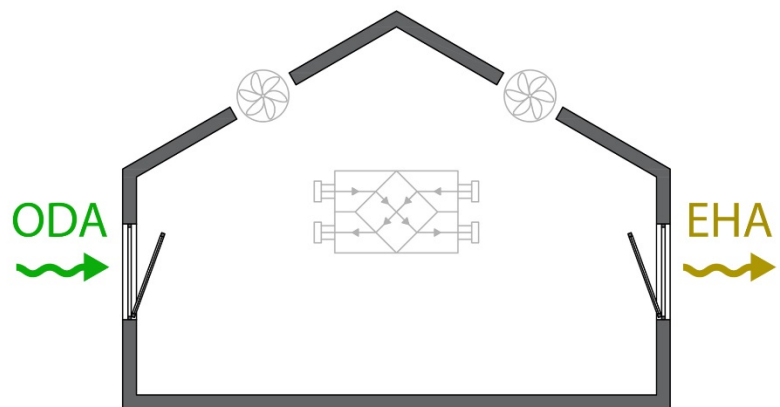


2

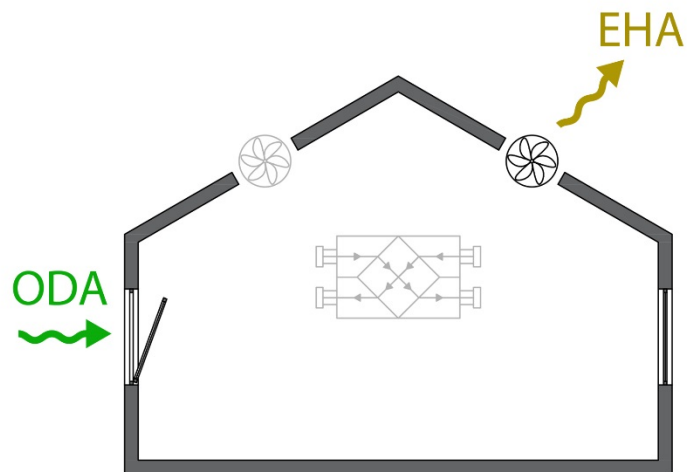


3

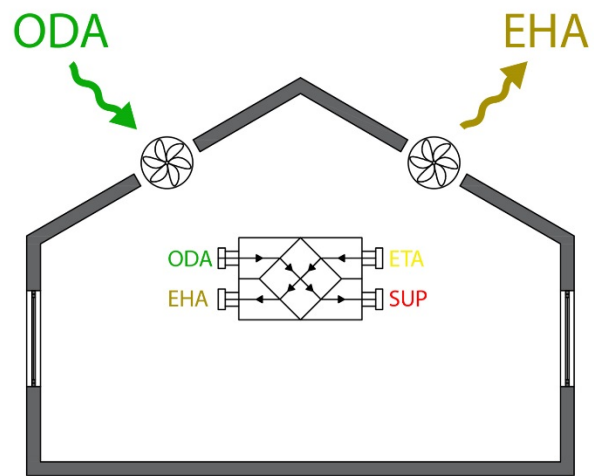
balanced *hygienic* ventilation with
mechanical supply and extraction
(extraction fan of mode 2)



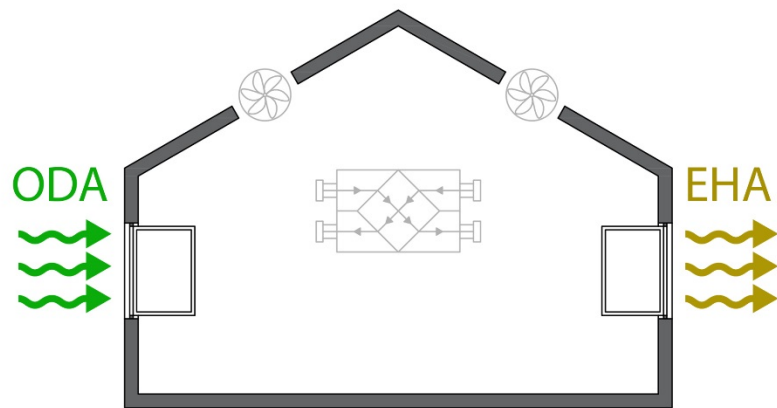
1



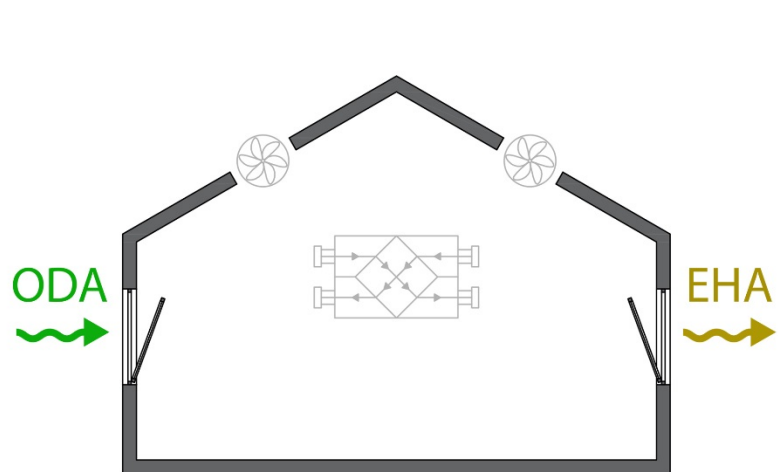
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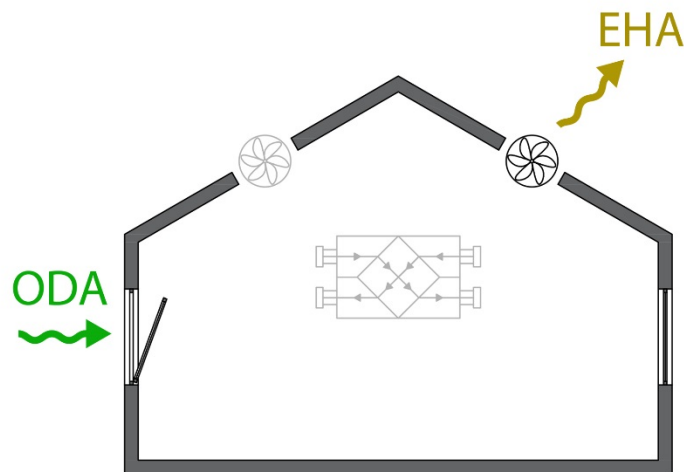
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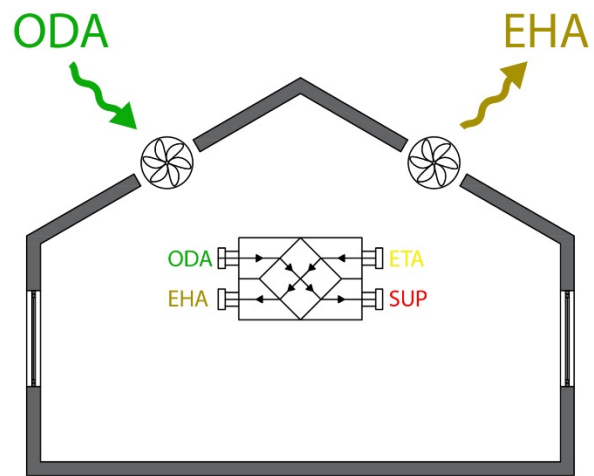
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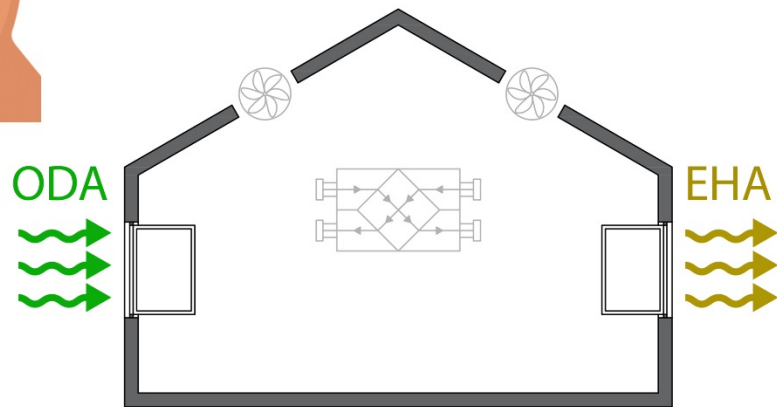
1



2



3



4

To achieve our goal we need

Smart Controls



A test environment that can ‘simultaneously’ model the thermal and ventilation performance of the operating modes
+ that can vary multiple parameters

building typology, environment, control strategy, occupant behaviour...

Model validation



Case studies

EnergyPlus as a test environment

A simulation tool for transient building energy demand (and use) simulations

Solves 2 main equations of thermodynamics (energy and mass balance) at given timesteps = Typically one year or a relevant period.

Rooms are represented as a node → One node = one value for T, RH, CO₂ ...

Why EnergyPlus?

Widely used

Integrated Airflow Network model (similar to contam)

Integrated Programming Language (ERL) for Energy Management Systems

Open Source → Versatility/adaptability

EnergyPlus

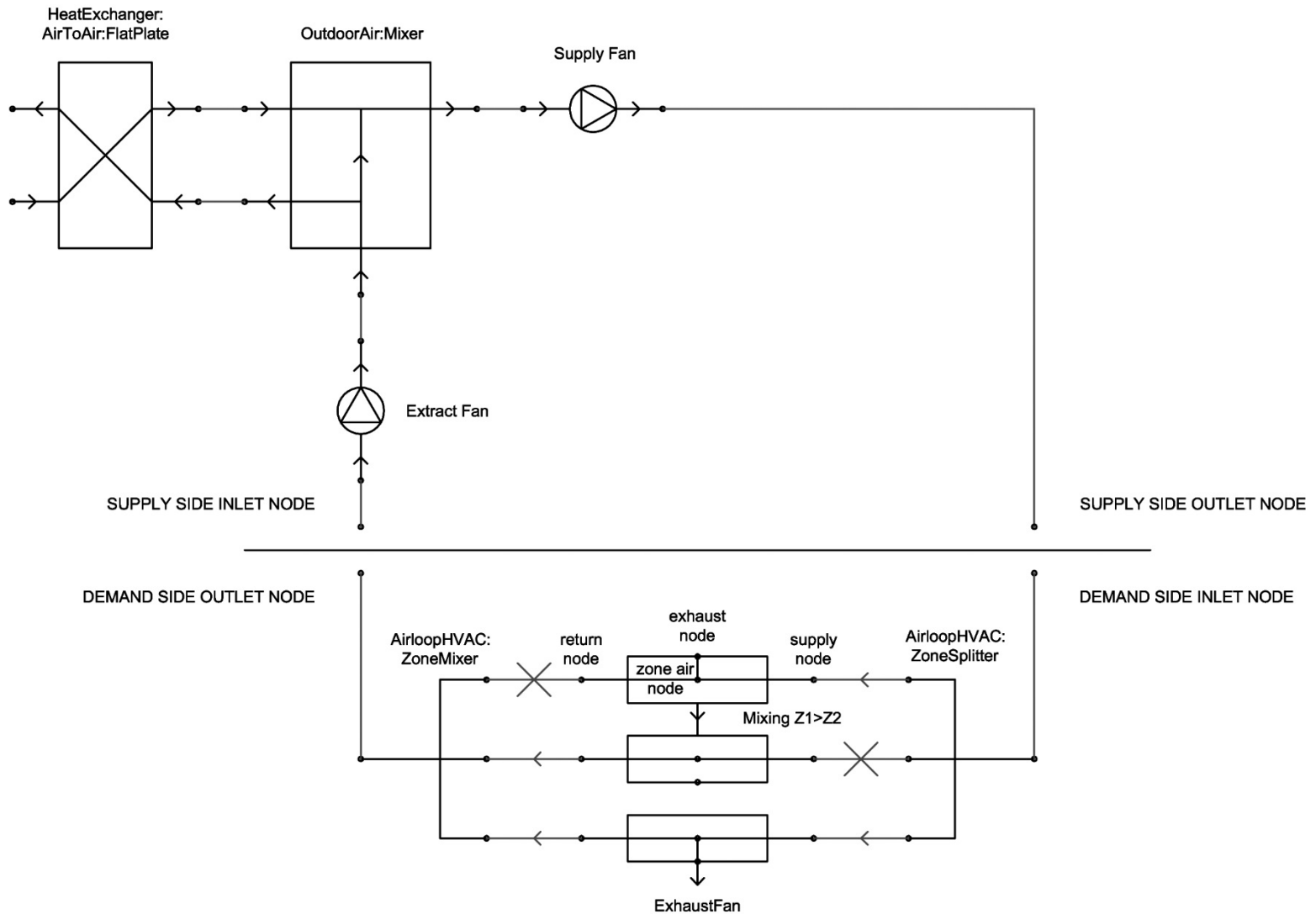
INPUT

Geometry
Building Envelope
Boundary Conditions
Technical Installations
Occupancy Schedules
Weather Data
...

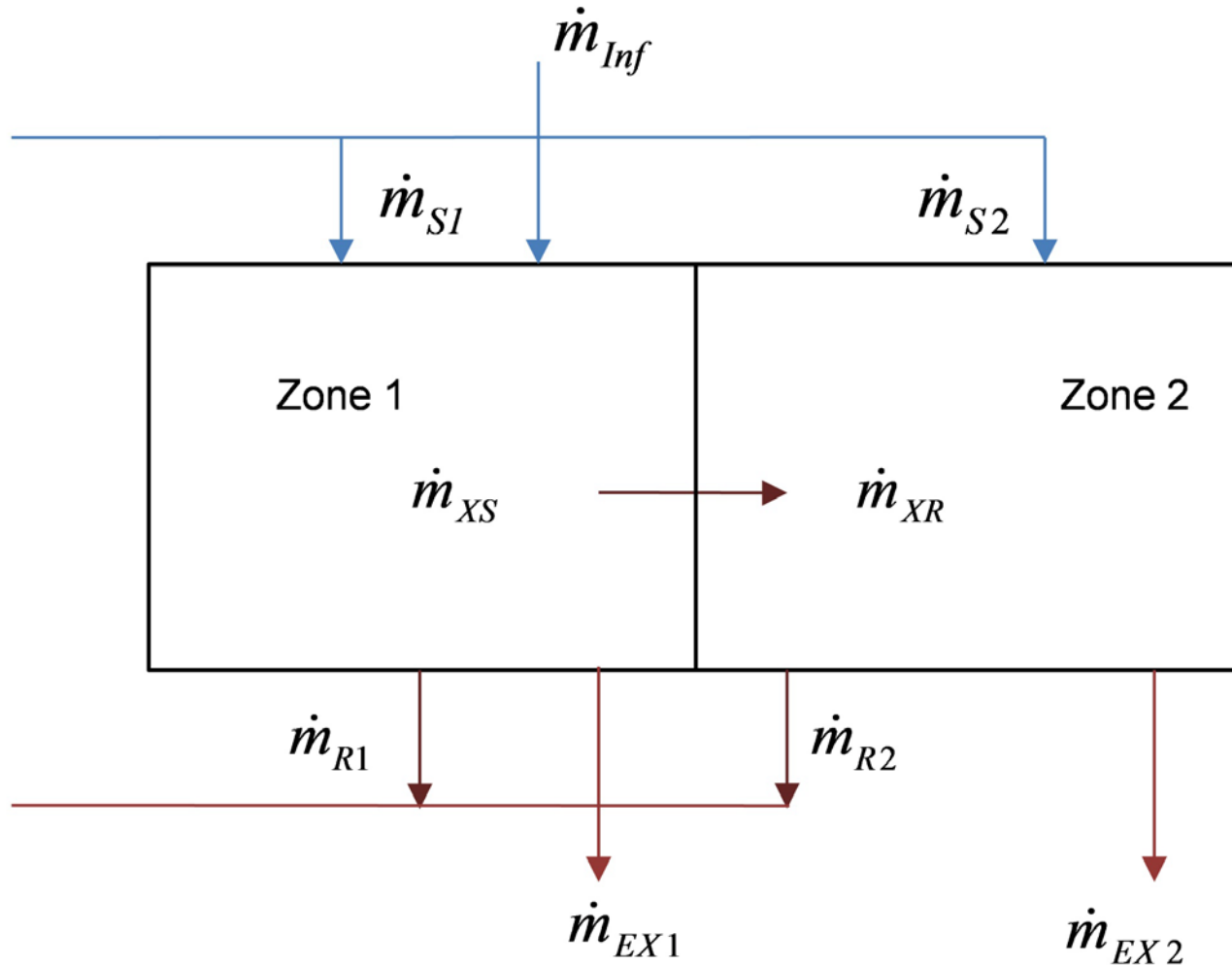
OUTPUT

Temperature
Relative Humidity
Pollutant Concentrations
Heat gains
Heat losses
Ventilation Flow rates
Infiltration Flow rates
Energy Consumption
...
→ For each zone
→ For each timestep

Modelling the HV's Balanced ventilation mode



Modelling the HV's Balanced ventilation mode



Modelling the HV's Natural and Extract ventilation modes

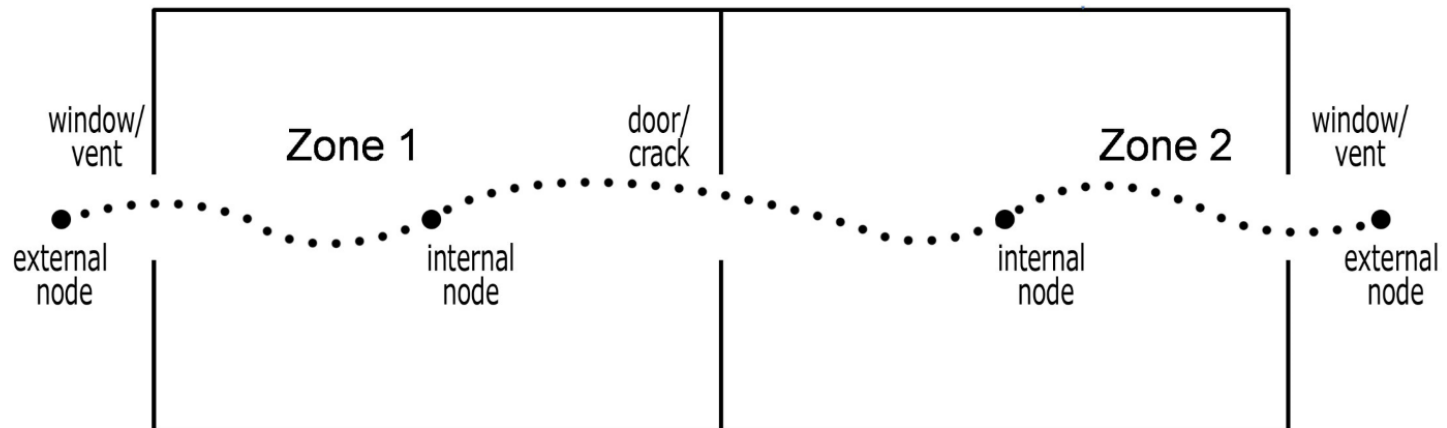
Building = series of zones = nodes, interconnected by flow paths = links

Flow equations relate the pressure difference accross each flow path to the resultant air flow through the opening

The Network is solved for mass flow balance between incoming and outgoing air

Cp coefficients on the building envelope need to be determined → CFD, wind tunnel

Modelling the HV's Natural and Extract ventilation modes



EnergyPlus drawbacks

No information on pollutant distribution within the individual zones (well-mixed)

EnergyPlus loses flexibility when using available GUI's
↔

It is almost impossible to draw accurate network models without a GUI

EnergyPlus GUI drawback → solution

Custom energyplus preprocessing software based on widely used .dxf format and energyplus .idf format to automate Airloop and Airflow Network generation.

Custom postprocessing software based on .csv output and energyplus .idf input to visualize resulting airflows in 3D. (per timestep, min, mean, max, per wind direction...)

No possibility to switch between airflow calculation methods during a simulation

Solution 1

External coupling using the E+ Functional Mock-up Unit (FMU) for co-simulation

e.g. BCVTB →

Energyplus+Contam

Solution 2

Altering the E+ Source Code to allow precalculation of different operating modes within one simulation timestep

Switching between operating modes/calculation methods made possible in source code → Loop over zones

```
END Precalculation of AFN for Zone 1
```

← Zone1 Precalculation

```
DAK ZONE1
```

```
outgoing volumeflow = 0.0237202 m3/s
```

```
incoming volumeflow = 0 m3/s
```

```
pressure difference = 0.216258 Pa
```

```
-----  
RAAMZONE1
```

```
outgoing volumeflow = 0 m3/s
```

```
incoming volumeflow = 0.000120019 m3/s
```

```
pressure difference = -0.978148 Pa
```

```
-----  
BINNENDEUR ZONE1/2
```

```
outgoing volumeflow = 0 m3/s
```

```
incoming volumeflow = 0.00979653 m3/s
```

```
pressure difference = -3.37138e-06 Pa
```

```
-----  
ZIJGEVEL ZONE1
```

```
outgoing volumeflow = 0 m3/s
```

```
incoming volumeflow = 0.0138053 m3/s
```

```
pressure difference = -0.978148 Pa
```

```
-----  
Volume flow out of zone = 0.0237 m3/s
```

```
Volume flow into zone = 0.0237 m3/s
```

```
required flow into/out of zone = 0.0120 m3/s
```

```
SimAirNetworkKey2 = MultizoneWithoutDistribution
```

→ Zone1 Precalculation Result = Multizone =
use AFN = Natural or Extract ventilation

```
-----  
ZONE2
```

```
=====
```

```
ZonePeopleScheduleName = ZONE2PEOPLESCHEDULE
```

```
Zone Floor Area = 9.0000m2
```

```
Call to ManageAirflowNetworkBalance() in CalcHybridVentSysAvailMgr()
```

```
-----  
BEGIN Precalculation of AFN for Zone 2
```

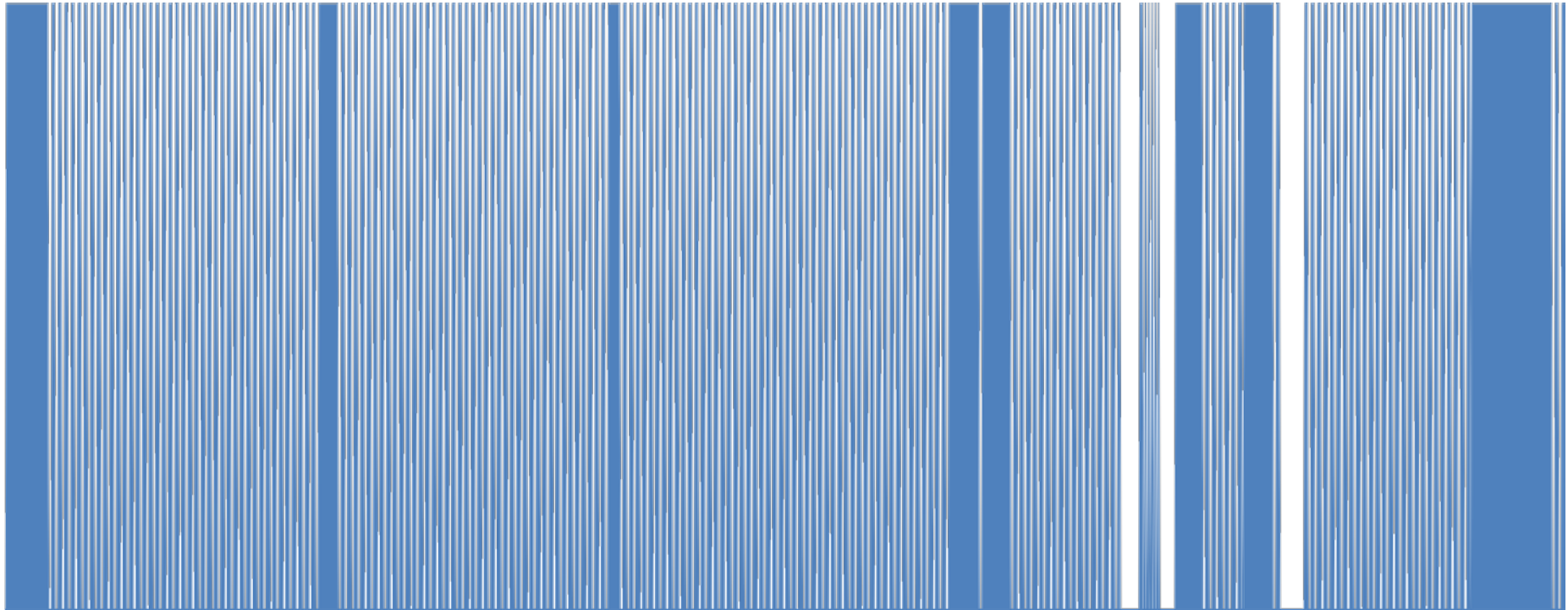
→ Start Zone2 Precalculation

```
ManageAirflowNetworkBalance()
```

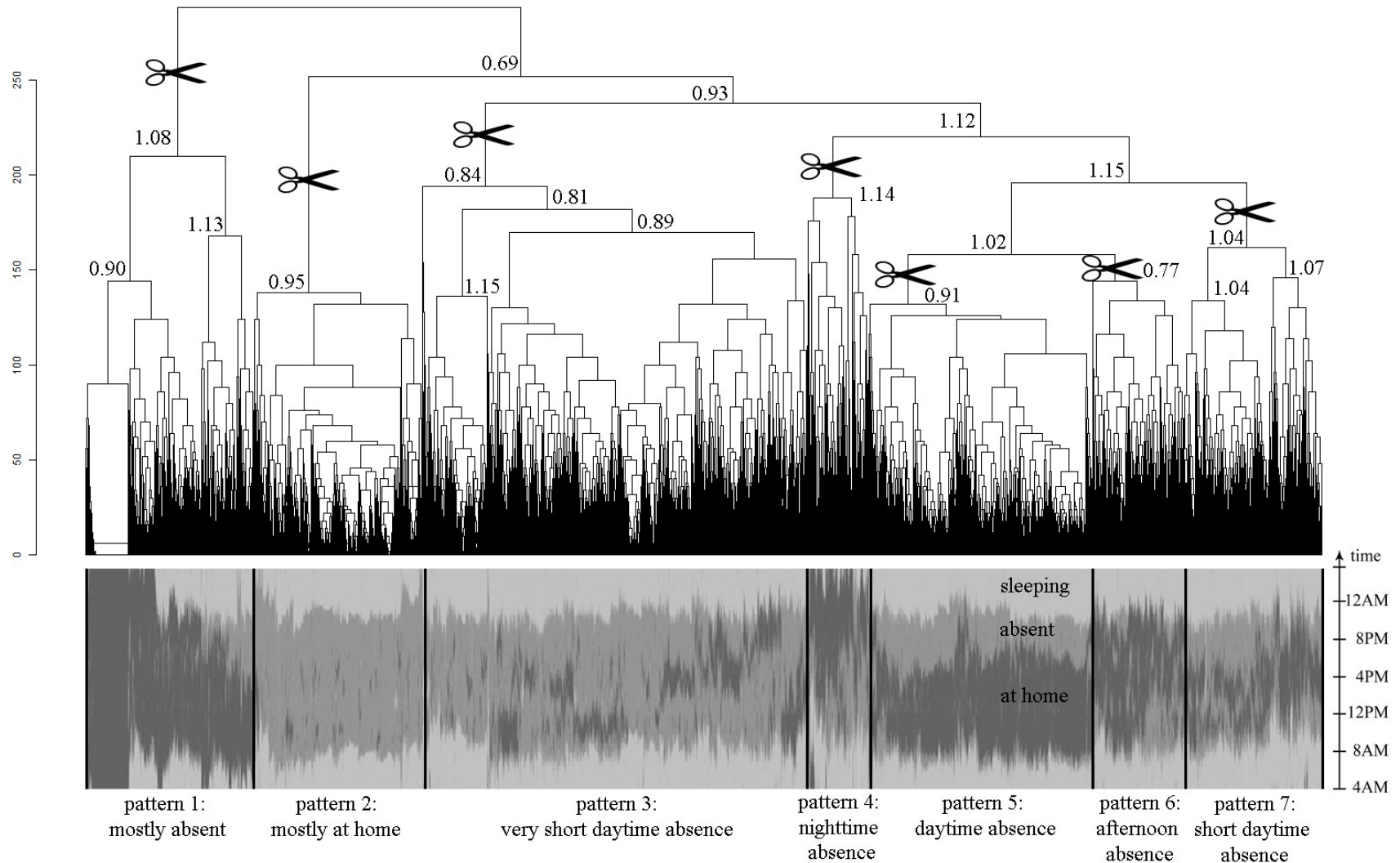
```
AirflowNetworkGetInputFlag = 0
```

Natural ventilation potential (white) based on airflow rate for a summer day

HYBRIDVENTMODE



Integrating generic user profiles (1 Zone, Research D. Aerts)



Integrating generic user profiles (Multizone)

Further research is needed to improve location accuracy.

At present the predicted user population in a timestep (one zone) is allocated to the 'active zones' based on activity schedules, electricity use schedules and the time of day.

Integrating generic user profiles (Multizone)

```
!- ===== ALL OBJECTS IN CLASS: PEOPLE =====
```

```
People,
  8.0.1.People,      !- Name
  8.0.1,             !- Zone or ZoneList Name
  MPS_ZONE801,       !- Number of People Schedule Name
  People,           !- Number of People Calculation Method
  2,                !- Number of People
  ,                !- People per Zone Floor Area {person/m2}
  ,                !- Zone Floor Area per Person {m2/person}
  0.3,              !- Fraction Radiant
  ,                !- Sensible Heat Fraction
  ActivitySched,     !- Activity Level Schedule Name
  0.0000000382,     !- Carbon Dioxide Generation Rate {m3/s-W}
  ,                !- Enable ASHRAE 55 Comfort Warnings
  ZoneAveraged,     !- Mean Radiant Temperature Calculation Type
  ,                !- Surface Name/Angle Factor List Name
  WorkEfficiencySched, !- Work Efficiency Schedule Name
  ClothingInsulationSchedule, !- Clothing Insulation Calculation Method
  AlwaysAvailable,   !- Clothing Insulation Calculation Method Schedule Name
  ClothingInsulationSched, !- Clothing Insulation Schedule Name
  Airvelocitysched;  !- Air Velocity Schedule Name
```

```
People,
  8.0.2.People,      !- Name
  8.0.2,             !- Zone or ZoneList Name
  MPS_ZONE802,       !- Number of People Schedule Name
  People,           !- Number of People Calculation Method
  2,                !- Number of People
  ,                !- People per Zone Floor Area {person/m2}
  ,                !- Zone Floor Area per Person {m2/person}
  0.3,              !- Fraction Radiant
  ,                !- Sensible Heat Fraction
  ActivitySched,     !- Activity Level Schedule Name
  0.0000000382,     !- Carbon Dioxide Generation Rate {m3/s-W}
  ,                !- Enable ASHRAE 55 Comfort Warnings
  ZoneAveraged,     !- Mean Radiant Temperature Calculation Type
  ,                !- Surface Name/Angle Factor List Name
  WorkEfficiencySched, !- Work Efficiency Schedule Name
  ClothingInsulationSchedule, !- Clothing Insulation Calculation Method
  AlwaysAvailable,   !- Clothing Insulation Calculation Method Schedule Name
  ClothingInsulationSched, !- Clothing Insulation Schedule Name
  Airvelocitysched;  !- Air Velocity Schedule Name
```

```
People,
  8.0.3.People,      !- Name
  8.0.3,             !- Zone or ZoneList Name
  MPS_ZONE803,       !- Number of People Schedule Name
  People,           !- Number of People Calculation Method
  2,                !- Number of People
  ,                !- People per Zone Floor Area {person/m2}
  ,                !- Zone Floor Area per Person {m2/person}
  0.3,              !- Fraction Radiant
```

```
Schedule:Year,
  Ventingsched824,   !- Name
  Fraction Type,     !- Schedule Type Limits Name
  MyPeopleSchedule-Week1, !- Schedule:Week Name 1
  1,                !- Start Month 1
  1,                !- Start Day 1
  1,                !- End Month 1
  7,                !- End Day 1
  MyPeopleSchedule-Week2, !- Schedule:Week Name 2
  1,                !- Start Month 2
  8,                !- Start Day 2
  1,                !- End Month 2
  14,               !- End Day 2
  MyPeopleSchedule-Week3, !- Schedule:Week Name 3
  1,                !- Start Month 3
  15,               !- Start Day 3
  1,                !- End Month 3
  21,               !- End Day 3
  MyPeopleSchedule-Week4, !- Schedule:Week Name 4
  1,                !- Start Month 4
  22,               !- Start Day 4
  1,                !- End Month 4
  28,               !- End Day 4
  MyPeopleSchedule-Week5, !- Schedule:Week Name 5
  1,                !- Start Month 5
  29,               !- Start Day 5
  2,                !- End Month 5
  4,                !- End Day 5
  MyPeopleSchedule-Week6, !- Schedule:Week Name 6
  2,                !- Start Month 6
  5,                !- Start Day 6
  2,                !- End Month 6
  11,               !- End Day 6
  MyPeopleSchedule-Week7, !- Schedule:Week Name 7
  2,                !- Start Month 7
  12,               !- Start Day 7
  2,                !- End Month 7
  18,               !- End Day 7
  MyPeopleSchedule-Week8, !- Schedule:Week Name 8
  2,                !- Start Month 8
  19,               !- Start Day 8
  2,                !- End Month 8
  25,               !- End Day 8
  MyPeopleSchedule-Week9, !- Schedule:Week Name 9
  2,                !- Start Month 9
  26,               !- Start Day 9
  3,                !- End Month 9
  4,                !- End Day 9
  MyPeopleSchedule-Week10, !- Schedule:Week Name 10
  3,                !- Start Month 10
  5,                !- Start Day 10
  3,                !- End Month 10
  11,               !- End Day 10
  MyPeopleSchedule-Week11, !- Schedule:Week Name 11
```

Integrating generic user profiles (Multizone)

```
Schedule:Week:Daily,
  MyPeopleSchedule-Week24, !- Name
  MyPeopleSchedule-Day162, !- Sunday Schedule:Day Name
  MyPeopleSchedule-Day163, !- Monday Schedule:Day Name
  MyPeopleSchedule-Day164, !- Tuesday Schedule:Day Name
  MyPeopleSchedule-Day165, !- Wednesday Schedule:Day Name
  MyPeopleSchedule-Day166, !- Thursday Schedule:Day Name
  MyPeopleSchedule-Day167, !- Friday Schedule:Day Name
  MyPeopleSchedule-Day168, !- Saturday Schedule:Day Name
  MyPeopleSchedule-Day162, !- Holiday Schedule:Day Name
  MyPeopleSchedule-Day162, !- SummerDesignDay Schedule:Day Name
  MyPeopleSchedule-Day162, !- WinterDesignDay Schedule:Day Name
  MyPeopleSchedule-Day162, !- CustomDay1 Schedule:Day Name
  MyPeopleSchedule-Day162, !- CustomDay2 Schedule:Day Name
```

```
Schedule:Week:Daily,
  MyPeopleSchedule-Week25, !- Name
  MyPeopleSchedule-Day169, !- Sunday Schedule:Day Name
  MyPeopleSchedule-Day170, !- Monday Schedule:Day Name
  MyPeopleSchedule-Day171, !- Tuesday Schedule:Day Name
  MyPeopleSchedule-Day172, !- Wednesday Schedule:Day Name
  MyPeopleSchedule-Day173, !- Thursday Schedule:Day Name
  MyPeopleSchedule-Day174, !- Friday Schedule:Day Name
  MyPeopleSchedule-Day175, !- Saturday Schedule:Day Name
  MyPeopleSchedule-Day169, !- Holiday Schedule:Day Name
  MyPeopleSchedule-Day169, !- SummerDesignDay Schedule:Day Name
  MyPeopleSchedule-Day169, !- WinterDesignDay Schedule:Day Name
  MyPeopleSchedule-Day169, !- CustomDay1 Schedule:Day Name
  MyPeopleSchedule-Day169, !- CustomDay2 Schedule:Day Name
```

```
Schedule:Week:Daily,
  MyPeopleSchedule-Week26, !- Name
  MyPeopleSchedule-Day176, !- Sunday Schedule:Day Name
  MyPeopleSchedule-Day177, !- Monday Schedule:Day Name
  MyPeopleSchedule-Day178, !- Tuesday Schedule:Day Name
  MyPeopleSchedule-Day179, !- Wednesday Schedule:Day Name
  MyPeopleSchedule-Day180, !- Thursday Schedule:Day Name
  MyPeopleSchedule-Day181, !- Friday Schedule:Day Name
  MyPeopleSchedule-Day182, !- Saturday Schedule:Day Name
  MyPeopleSchedule-Day176, !- Holiday Schedule:Day Name
  MyPeopleSchedule-Day176, !- SummerDesignDay Schedule:Day Name
  MyPeopleSchedule-Day176, !- WinterDesignDay Schedule:Day Name
  MyPeopleSchedule-Day176, !- CustomDay1 Schedule:Day Name
  MyPeopleSchedule-Day176, !- CustomDay2 Schedule:Day Name
```

```
Schedule:Week:Daily,
  MyPeopleSchedule-Week27, !- Name
  MyPeopleSchedule-Day183, !- Sunday Schedule:Day Name
  MyPeopleSchedule-Day184, !- Monday Schedule:Day Name
  MyPeopleSchedule-Day185, !- Tuesday Schedule:Day Name
  MyPeopleSchedule-Day186, !- Wednesday Schedule:Day Name
  MyPeopleSchedule-Day187, !- Thursday Schedule:Day Name
  MyPeopleSchedule-Day188, !- Friday Schedule:Day Name
  MyPeopleSchedule-Day189, !- Saturday Schedule:Day Name
```

```
!- ===== ALL OBJECTS IN CLASS: ENERGYMANAGEMENTSYSTEM:PROGRAM =====
```

```
!DistributeMPS is the program that reads the hours of the days (and takes into account if it is a day in the week or weekend) and
!distributes the total people in different zones. For example during supper hours everybody present in the house will be in the kitchen.
!Another example is that at night they are distributed in their proper bedrooms.
```

```
EnergyManagementSystem:Program,
  DistributeMPS, !- Name
  SET locHour = Hour, !- Program Line 1
  SET locDay = DayOfWeek, !- Program Line 2
  IF (Hour >= 0) && (Hour < 7) && (DayOfWeek >=2) && (DayOfWeek <=6), !- A4
  SET MPS_ZONE80 = GLOBALMPS_6464*0, !- A5
  ELSEIF (Hour >= 7) && (Hour < 8) && (DayOfWeek >=2) && (DayOfWeek <=6), !- A6
  SET MPS_ZONE80 = GLOBALMPS_6464*0, !- A7
  ELSEIF (Hour >= 8) && (Hour < 12) && (DayOfWeek >=2) && (DayOfWeek <=6), !- A8
  SET MPS_ZONE80 = GLOBALMPS_6464*0, !- A9
  ELSEIF (Hour >= 12) && (Hour < 13) && (DayOfWeek >=2) && (DayOfWeek <=6), !- A10
  SET MPS_ZONE80 = GLOBALMPS_6464*0, !- A11
  ELSEIF (Hour >= 13) && (Hour < 18) && (DayOfWeek >=2) && (DayOfWeek <=6), !- A12
  SET MPS_ZONE80 = GLOBALMPS_6464*0, !- A13
  ELSEIF (Hour >= 18) && (Hour < 19) && (DayOfWeek >=2) && (DayOfWeek <=6), !- A14
  SET MPS_ZONE80 = GLOBALMPS_6464*0, !- A15
  ELSEIF (Hour >= 19) && (Hour < 22) && (DayOfWeek >=2) && (DayOfWeek <=6), !- A16
  SET MPS_ZONE80 = GLOBALMPS_6464*0, !- A17
  ELSEIF (Hour >= 22) && (Hour <= 23) && (DayOfWeek >=2) && (DayOfWeek <=6), !- A18
  SET MPS_ZONE80 = GLOBALMPS_6464*0, !- A19
  ENDIF, !- A20
  IF (Hour >= 0) && (Hour < 8) && ((DayOfWeek <2) || (DayOfWeek >6)), !- A21
  SET MPS_ZONE80 = GLOBALMPS_6464*0, !- A22
  ELSEIF (Hour >= 8) && (Hour < 9) && ((DayOfWeek <2) || (DayOfWeek >6)), !- A23
  SET MPS_ZONE80 = GLOBALMPS_6464*0, !- A24
  ELSEIF (Hour >= 9) && (Hour < 12) && ((DayOfWeek <2) || (DayOfWeek >6)), !- A25
  SET MPS_ZONE80 = GLOBALMPS_6464*0, !- A26
  ELSEIF (Hour >= 12) && (Hour < 13) && ((DayOfWeek <2) || (DayOfWeek >6)), !- A27
  SET MPS_ZONE80 = GLOBALMPS_6464*0, !- A28
  ELSEIF (Hour >= 13) && (Hour < 18) && ((DayOfWeek <2) || (DayOfWeek >6)), !- A29
  SET MPS_ZONE80 = GLOBALMPS_6464*0, !- A30
  ELSEIF (Hour >= 18) && (Hour < 19) && ((DayOfWeek <2) || (DayOfWeek >6)), !- A31
  SET MPS_ZONE80 = GLOBALMPS_6464*0, !- A32
  ELSEIF (Hour >= 19) && (Hour <= 23) && ((DayOfWeek <2) || (DayOfWeek >6)), !- A33
  SET MPS_ZONE80 = GLOBALMPS_6464*0, !- A34
  ENDIF, !- A35
  IF (Hour >= 0) && (Hour < 7) && (DayOfWeek >=2) && (DayOfWeek <=6), !- A36
  SET MPS_ZONE801 = GLOBALMPS_6464*0, !- A37
  ELSEIF (Hour >= 7) && (Hour < 8) && (DayOfWeek >=2) && (DayOfWeek <=6), !- A38
  SET MPS_ZONE801 = GLOBALMPS_6464*1, !- A39
  ELSEIF (Hour >= 8) && (Hour < 12) && (DayOfWeek >=2) && (DayOfWeek <=6), !- A40
  SET MPS_ZONE801 = GLOBALMPS_6464*0.5, !- A41
  ELSEIF (Hour >= 12) && (Hour < 13) && (DayOfWeek >=2) && (DayOfWeek <=6), !- A42
  SET MPS_ZONE801 = GLOBALMPS_6464*1, !- A43
  ELSEIF (Hour >= 13) && (Hour < 18) && (DayOfWeek >=2) && (DayOfWeek <=6), !- A44
  SET MPS_ZONE801 = GLOBALMPS_6464*0.5, !- A45
  ELSEIF (Hour >= 18) && (Hour < 19) && (DayOfWeek >=2) && (DayOfWeek <=6), !- A46
  SET MPS_ZONE801 = GLOBALMPS_6464*1, !- A47
  ELSEIF (Hour >= 19) && (Hour < 22) && (DayOfWeek >=2) && (DayOfWeek <=6), !- A48
  SET MPS_ZONE801 = GLOBALMPS_6464*0, !- A49
```


Model Validation – Case Study House FD

Free standing single family house (low-energy)

2 adults, 2 small children

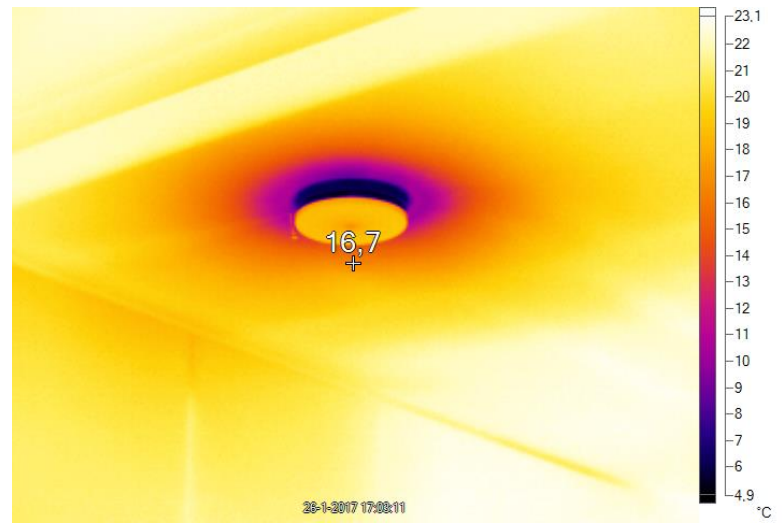
Countryside

Balanced ventilation system with crossflow heat recovery

Monitoring



Monitoring



Monitoring



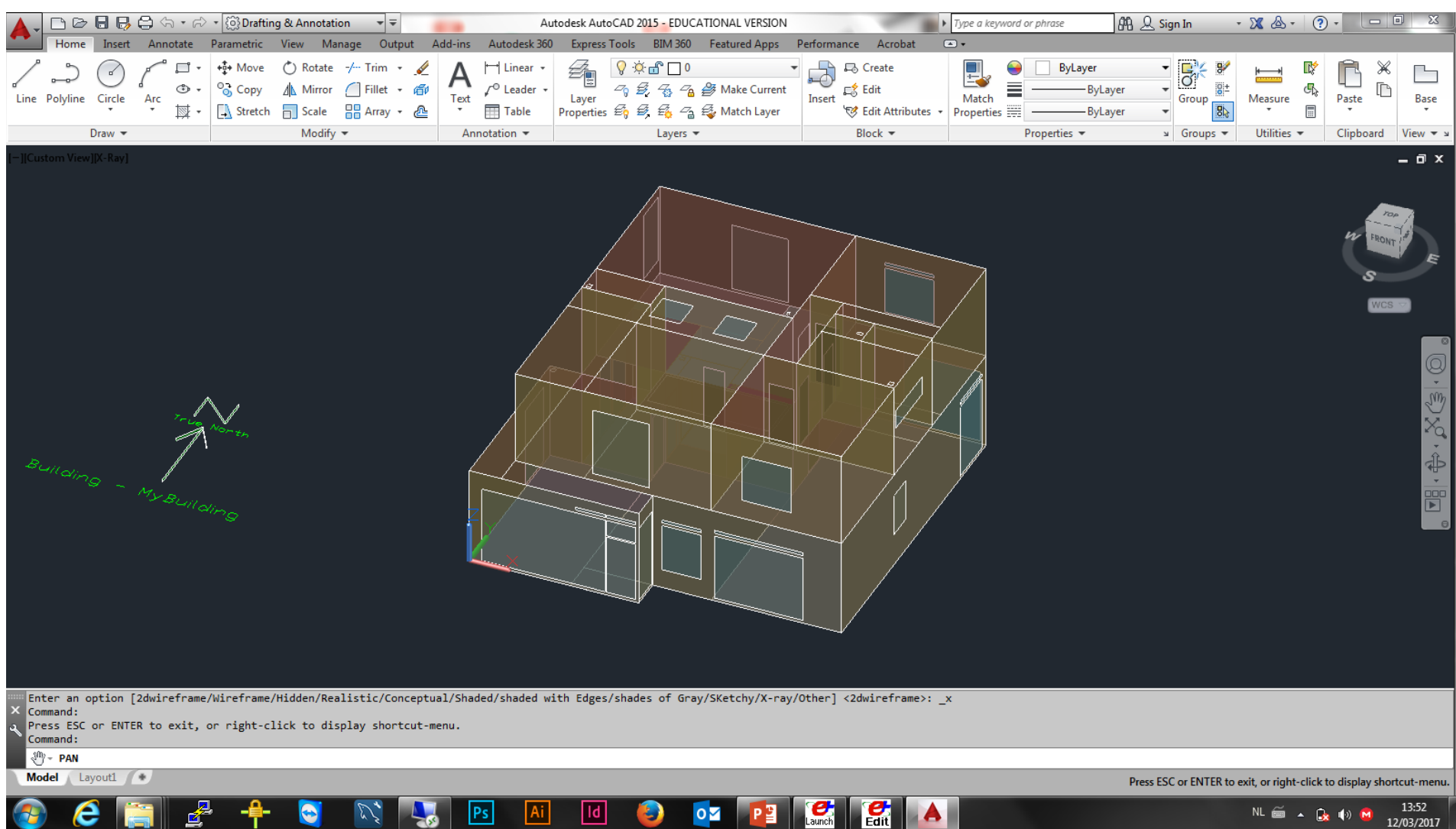
Monitoring



Monitoring



Generating EnergyPlus .idf input from CAD data



Generating EnergyPlus .idf input from CAD data

EnergyPlus .idf Editor - [E:\Euterpev3\Fried\NTest6.IDF]

File Edit View Jump Window Help

New Obj Dup Obj Del Obj Copy Obj Paste Obj

Class List

- [0001] SimulationControl
- [0001] Building
- [0001] Timestep
- [0001] ConvergenceLimits
- [0001] Site:Location
- [0002] RunPeriod
- [0008] ScheduleTypeLimits
- [0004] Schedule:Compact
- [0020] Schedule:Constant
- [0001] Material
- [0001] WindowMaterial:Glazing
- [0001] WindowMaterial:Gas
- [0009] Construction
- [0001] GlobalGeometryRules
- [0011] Zone
- [0001] ZoneList
- [0136] BuildingSurface:Detailed
- [0055] FenestrationSurface:Detailed
- [0002] ZoneMixing
- [0001] AirflowNetwork:SimulationControl
- [0011] AirflowNetwork:MultZone:Zone
- [0036] AirflowNetwork:MultZone:Surface
- [0001] AirflowNetwork:MultZone:ReferenceCrackConditions
- [0006] AirflowNetwork:MultZone:Surface:Crack
- [0023] AirflowNetwork:MultZone:Component:DetailedOpening
- [0007] AirflowNetwork:MultZone:Component:ZoneExhaustFan
- [0025] AirflowNetwork:MultZone:ExternalNode
- [0001] AirflowNetwork:MultZone:WindPressureCoefficientArray
- [0025] AirflowNetwork:MultZone:WindPressureCoefficientValues
- [0011] AirTerminal:SingleDuct:Uncontrolled
- [0011] ZoneHVAC:EquipmentList
- [0011] ZoneHVAC:EquipmentConnections
- [0002] Fan:VariableVolume
- [0007] Fan:ZoneExhaust
- [0001] HeatExchanger:AirToAir:SensibleAndLatent
- [0001] Controller:OutdoorAir
- [0001] AirLoopHVAC:ControllerList

Comments from IDF

Name

Explanation of Object and Current Field

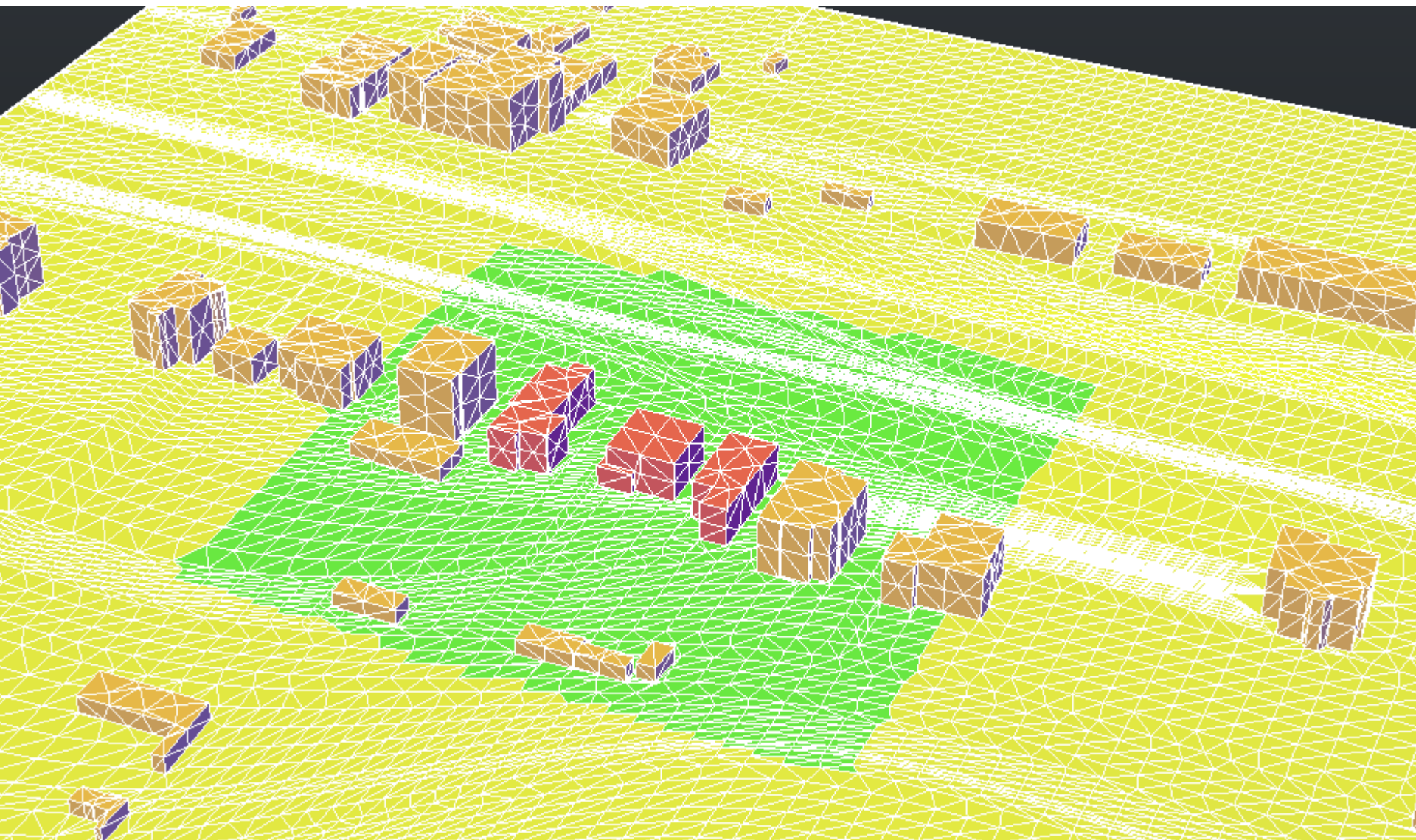
Object Description: Allows for detailed entry of building heat transfer surfaces. Does not include subsurfaces such as windows or doors.

Field Description:
ID: A1
Enter a alphanumeric value
This field is required.

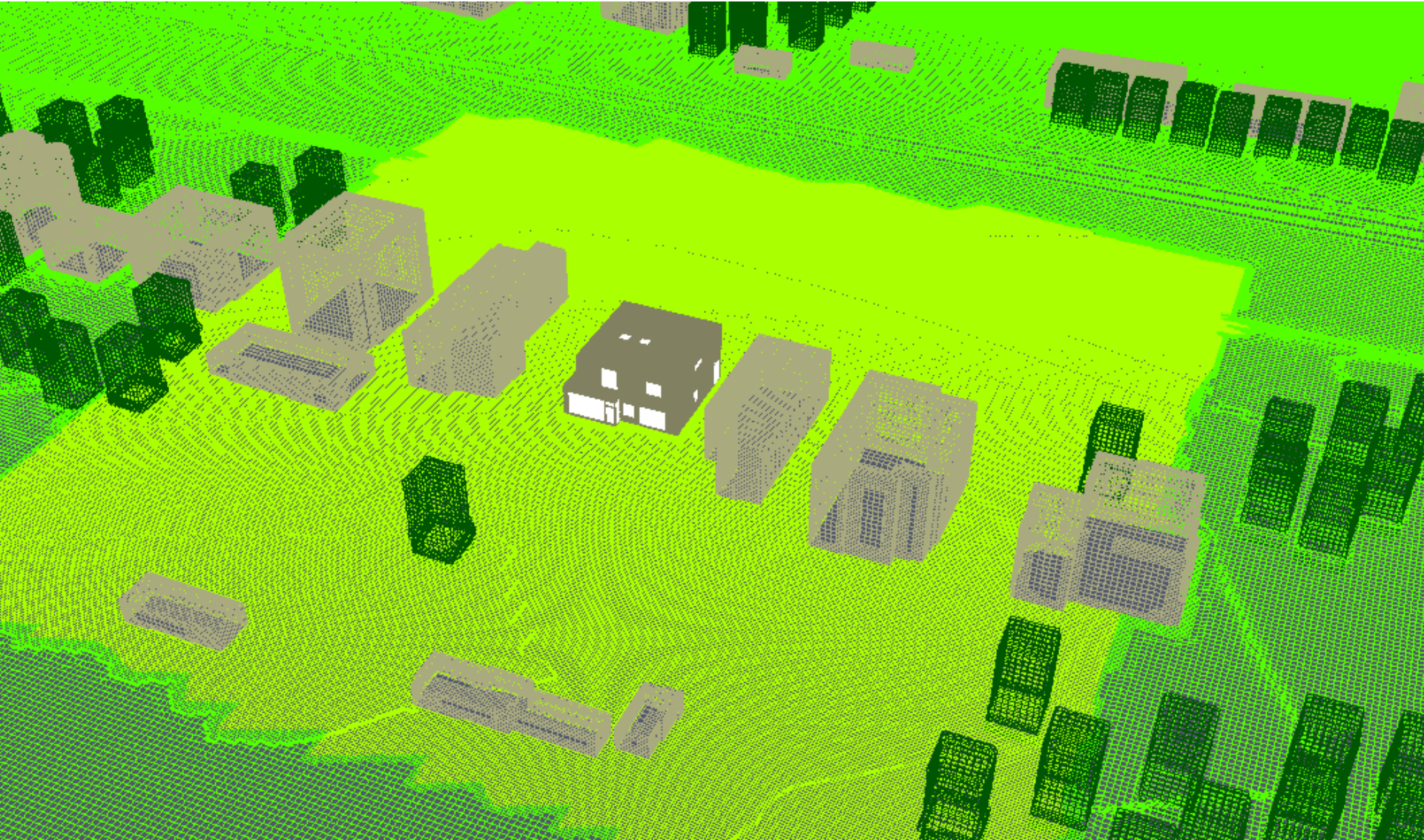
Field	Units	Obj1	Obj2	Obj3	Obj4	Obj5	Obj6	Obj7	Obj8	Obj9	Obj10	Obj11	Obj12
Name		Z1-EXT-W-EW.000	Z1-EXT-W-EW.000	Z1-Z2-W-IW.0003	Z1-Z2-W-IW.0004	Z1-Z3-W-IW.0005	Z1-GRO-F-GF.0006	Z1-GRO-F-GF.0007	Z1-Z4-W-IW.0008	Z1-Z3-W-IW.0009	Z1-Z4-W-IW.0010	Z1-GRO-F-GF.0011	Z2-EXT-W-EW.001
Surface Type		WALL	WALL	WALL	WALL	WALL	FLOOR	FLOOR	WALL	WALL	WALL	FLOOR	WALL
Construction Name		EW	EW	IW	IW	IW	GF	GF	IW	IW	IW	GF	EW
Zone Name		Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z1	Z2
Outside Boundary Condition		Outdoors	Outdoors	SURFACE	SURFACE	SURFACE	Ground	Ground	SURFACE	SURFACE	SURFACE	Ground	Outdoors
Outside Boundary Condition Object				Z2-Z1-W-IW.0013	Z2-Z1-W-IW.0014	Z3-Z1-W-IW.0019			Z4-Z1-W-IW.0042	Z3-Z1-W-IW.0020	Z4-Z1-W-IW.0043		
Sun Exposure		SunExposed	SunExposed	NoSun	NoSun	NoSun	NoSun	NoSun	NoSun	NoSun	NoSun	NoSun	SunExposed
Wind Exposure		WindExposed	WindExposed	NoWind	NoWind	NoWind	NoWind	NoWind	NoWind	NoWind	NoWind	NoWind	WindExposed
View Factor to Ground		autocalculate	autocalculate	autocalculate	autocalculate	autocalculate	autocalculate	autocalculate	autocalculate	autocalculate	autocalculate	autocalculate	autocalculate
Number of Vertices		4	4	4	4	4	4	4	4	4	4	4	4
Vertex 1 X-coordinate	m	1.04	1.04	3.28	3.28	5.28	5.28	5.28	7.43	5.28	7.43	7.43	1.04
Vertex 1 Y-coordinate	m	11.69	9.69	9.69	8.06	8.06	9.69	11.69	7.01	7.01	11.69	11.69	5.96
Vertex 1 Z-coordinate	m	0	0	0	0	0	0	0	0	0	0	0	0

energy+.idd | EnergyPlus 8.5.0 | Z1-EXT-W-EW.0001

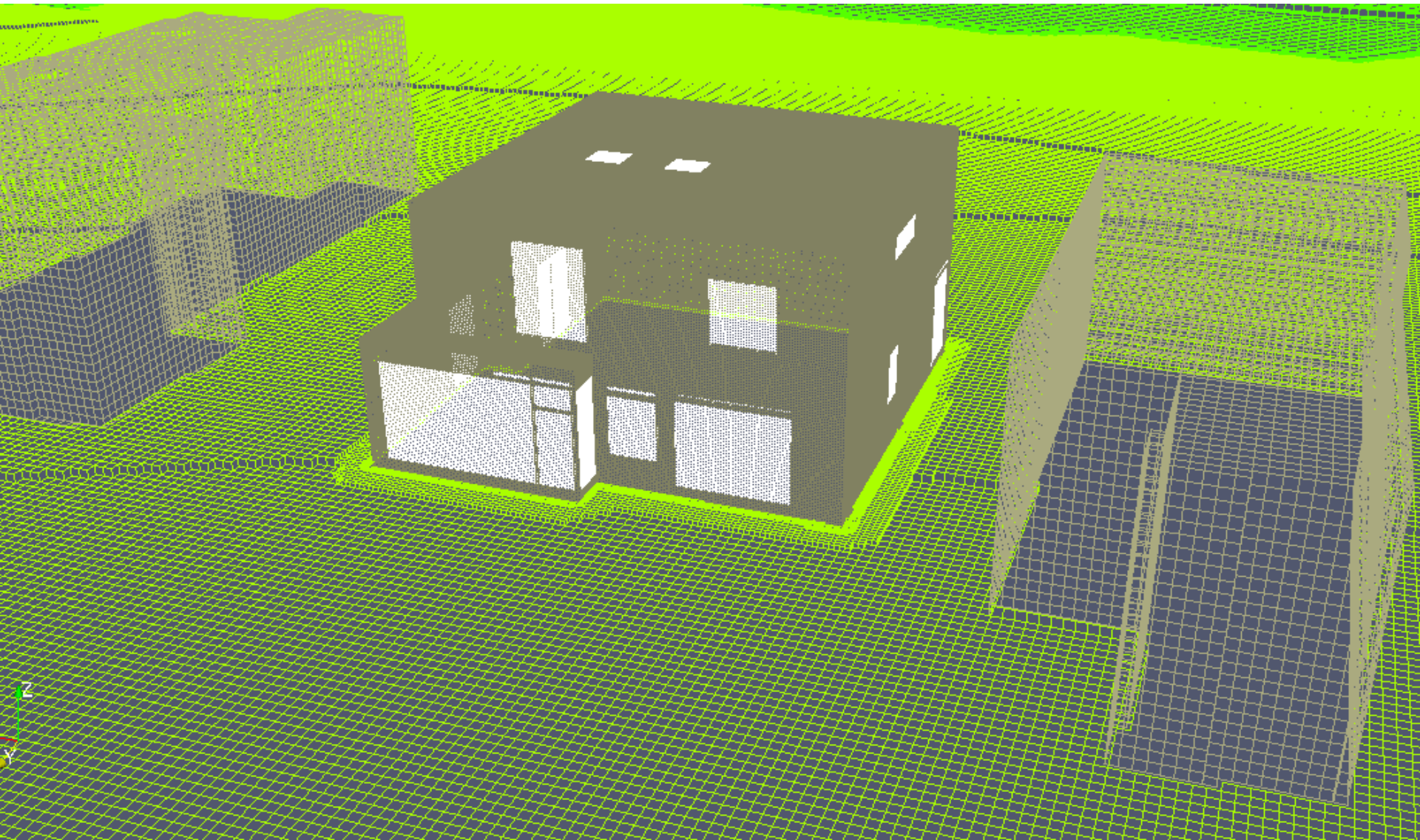
Cp values – OpenFoam CFD



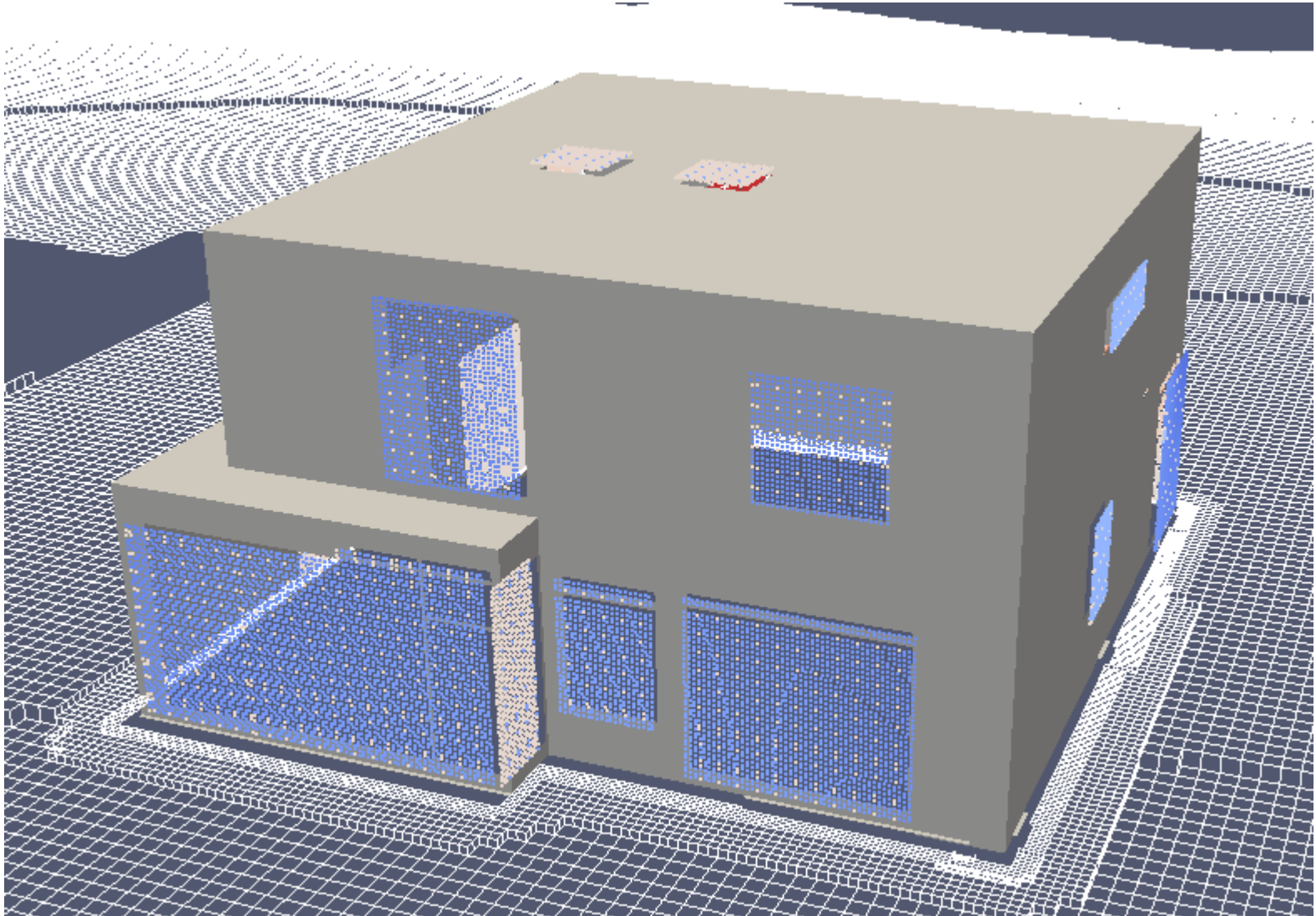
Cp values – OpenFoam CFD



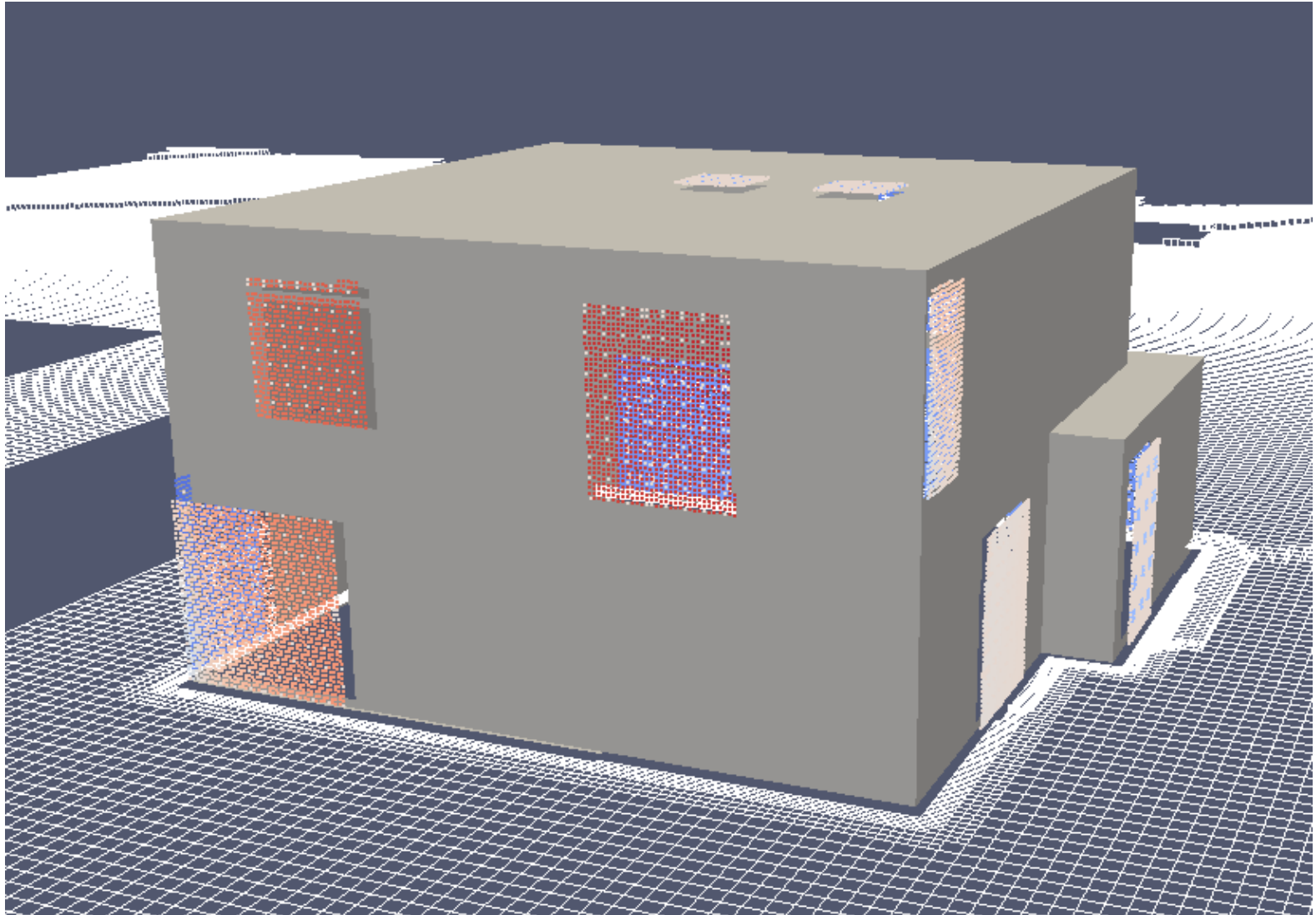
Cp values – OpenFoam CFD



Cp values – OpenFoam CFD



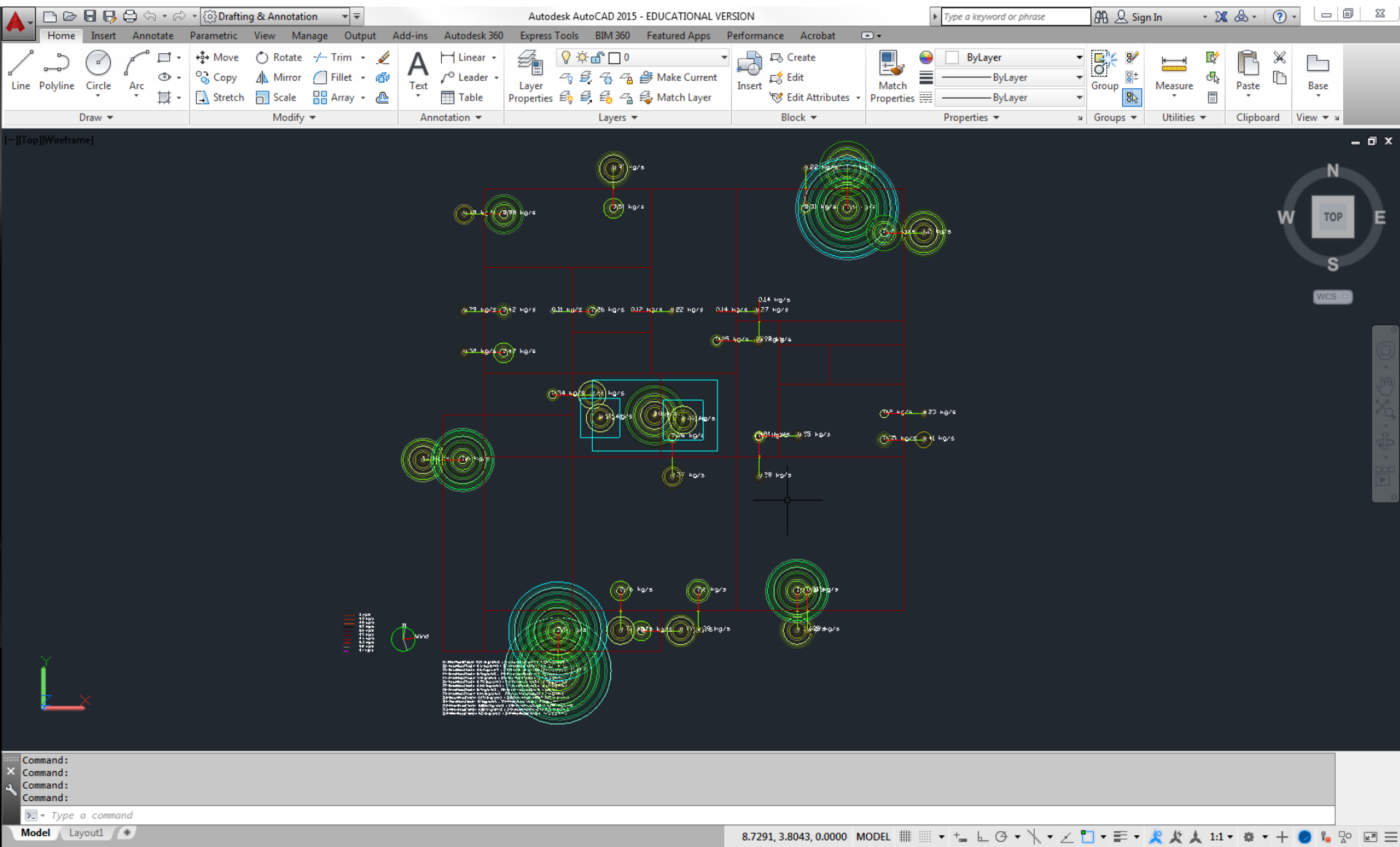
Cp values – OpenFoam CFD



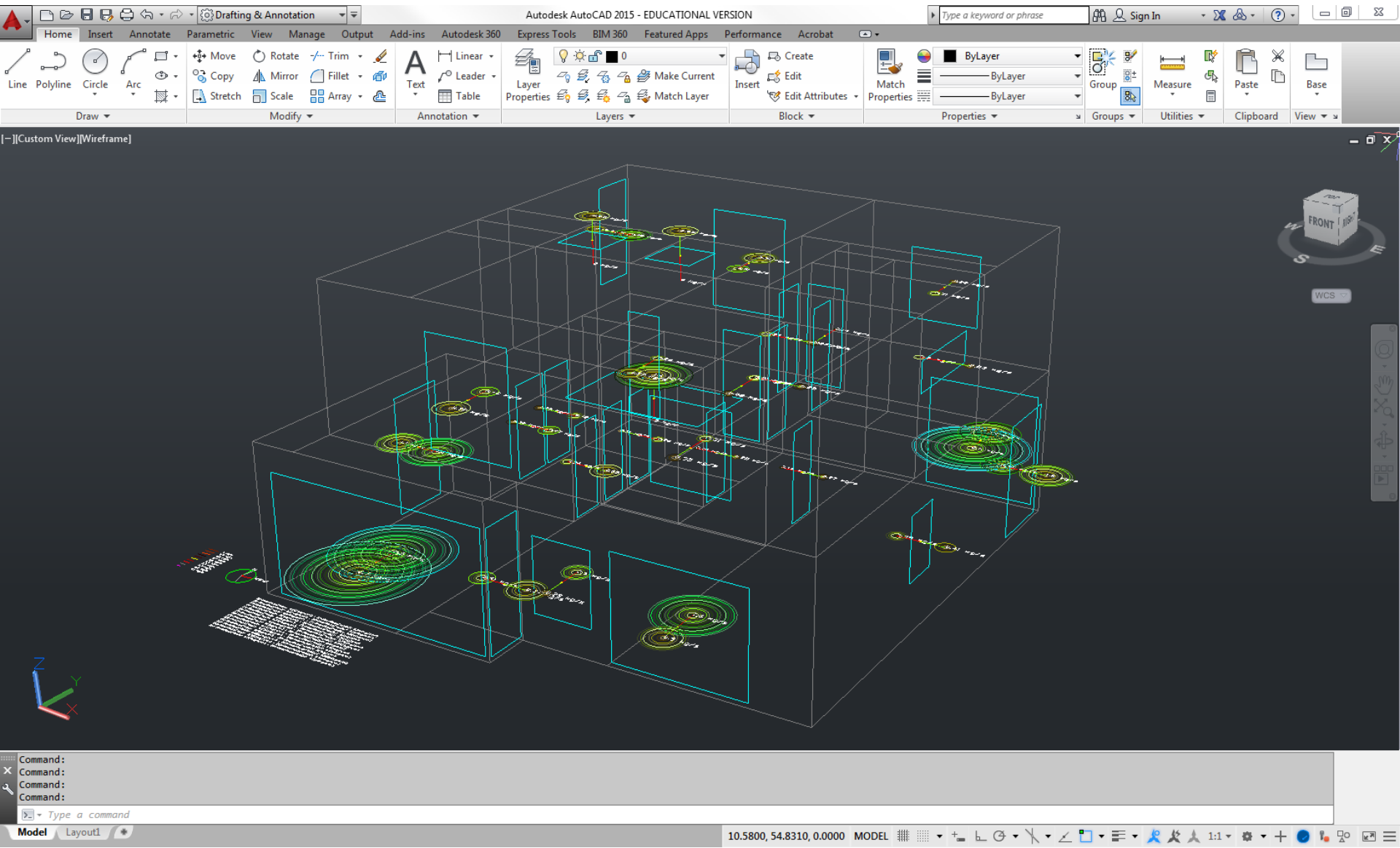
Visualizing airflow output in 3D

Test7.csv - Excel																											
FILE HOME INSERT PAGE LAYOUT FORMULAS DATA COLECTICA REVIEW VIEW ADD-INS ACROBAT TEAM Bert Belmans																											
<div>From Access From Web From Text From Other Sources Existing Connections From SPSS From Stata Refresh All Properties Edit Links Connections Sort Filter Clear Reapply Advanced Text to Columns Flash Fill Remove Duplicates Validation Data Tools Consolidate What-If Analysis Relationships Group Ungroup Subtotal Show Detail Hide Detail MySQL for Excel MySQL</div>																											
F14 : 0																											
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1	Date/Time	Environmer	Environment:Si	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	Z5-EXT-W	
2	07/03 07:50:	1	41,66666667	0,27671	0,66799	0,4017	1,0845	0,0205	0,23537	0,53135	0,89044	0,10224	0,2894	0,19976	0,36693	1,83331	1,22645	0,41122	0,00783	0,13622	0,43073	0,0785	0,19958	0,0412	0,0636	0,0636	
3	07/03 08:00:	1	10	0,42772	0,44551	0,29413	1,17301	0,0836	0,12357	0,50418	0,855	0,0946	0,28124	0,29415	0,24065	1,74327	1,17862	0,45119	0	0,12511	0,45311	0,0751	0,19835	0,0636	0,0636	0,0636	
4	07/03 08:10:	1,1833333	60	0,10059	0,91426	0,3392	1,11465	0	0,35117	0,64026	0,71256	0,14969	0,21333	0,0862	0,50961	0,207988	0,91836	0,46318	0,0229	0,1836	0,50698	0,10214	0,23427	0,0481	0,10214	0,10214	
5	07/03 08:20:	1,3666667	110	0,0702	0,83119	1,04672	0,23629	0	0,32143	0,32583	0,88723	0,046	0,30594	0,0628	0,46445	1,26145	1,26999	0,23847	0,20412	0,43776	0,30588	0,17323	0,11554	0,0277	0,11554	0,11554	
6	07/03 08:30:	1,55	160	0,56235	0,3203	1,34398	0,18776	0,13713	0,0723	0,0686	1,61106	0	0,59706	0,37307	0,17106	0,58448	2,54598	0,48428	0,0212	0,22763	0,46572	0,19932	0,14452	0,0294	0,0294	0,0294	
7	07/03 08:40:	1,7333333	210	1,24098	0,00008	1,42013	0,0535	0,41111	0,00004	0,0179	1,52414	0	0,55362	0,77183	0,00007	0,37782	2,43245	0,00254	0,6104	0,701	0,0997	0,17721	0,10294	0,13326	0,13326	0,13326	
8	07/03 08:50:	1,9166667	260	0,52774	0,33094	1,17158	0,26806	0,15226	0,0574	0,35454	1,01436	0,0555	0,33407	0,35757	0,1741	1,43364	1,40962	0	0,99212	0,91236	0	0,21619	0,0999	0,1168	0,1168	0,1168	
9	07/03 09:00:	2,1	310	0,49411	0,26365	0	2,19269	0,16556	0,0288	0,76499	0,40297	0,23845	0,0811	0,33496	0,13463	2,35349	0,39193	0,11571	0,31808	0,39576	0,29855	0,13685	0,13653	0,15009	0,15009	0,15009	
10	07/03 09:10:	2,1833333	308,3333333	0,5032	0,33569	0	2,57239	0,16537	0,0443	0,8967	0,41654	0,28846	0,0772	0,34523	0,17332	2,74768	0,38595	0,0507	0,34905	0,36886	0,22639	0,10319	0,23301	0,13715	0,13715	0,13715	
11	07/03 09:20:	2,2666667	306,6666667	0,39233	0,33003	0	2,39646	0,12803	0,0483	0,84787	0,30229	0,29017	0,0427	0,27273	0,17069	2,57695	0,23765	0,00271	0,53772	0,54305	0,15224	0,0829	0,31219	0,22834	0,22834	0,22834	
12	07/03 09:30:	2,35	305	0,36535	0,38208	0	2,28522	0,10566	0,0715	0,83622	0,34706	0,27759	0,0584	0,25608	0,20036	2,54909	0,29464	0	0,68696	0,47783	0,17141	0,0742	0,30799	0,14132	0,14132	0,14132	
13	07/03 09:40:	2,4333333	303,3333333	0,23255	0,49226	0	3,00614	0,0803	0,089	1,18258	0,099	0,46346	0,00001	0,17675	0,25604	3,41788	0,00784	0	0,88348	0,78081	0,0446	0,24318	0,0962	0,0531	0,0531	0,0531	
14	07/03 09:50:	2,5166667	301,6666667	0,26897	0,48147	0	2,55078	0,0721	0,10351	1,05195	0,19194	0,38858	0,00782	0,19737	0,25478	3,08636	0,0779	0	0,95979	0,55424	0,0933	0,00162	0,37564	0,0103	0,0103	0,0103	
15	07/03 10:00:	2,6	300	0,0989	0,79305	0	3,62621	0,0294	0,18453	1,73811	0,00927	0,64485	0	0,0919	0,42085	4,51559	0	0	1,02943	0,61601	0,0392	0,022	0,32264	0,16811	0,16811	0,16811	
16	07/03 10:10:	2,6833333	305	0,29781	0,34311	0	2,54621	0,10716	0,0477	0,9845	0,129	0,38048	0,0001	0,21346	0,17714	2,86509	0,00888	0	0,79172	0,47939	0,0892	0,019	0,3059	0,265	0,265	0,265	
17	07/03 10:20:	2,7666667	310	0,44193	0,22225	0	3,65412	0,24308	0,00192	1,10987	0,089	0,45967	0	0,31194	0,10268	3,30169	0,0101	0	0,84371	0,17809	0,41049	0	0,10168	0,67419	0,67419	0,67419	
18	07/03 10:30:	2,85	315	0,90146	0,00254	0	4,36354	0,39868	0	0,99331	0,14369	0,45709	0,00002	0,59986	0,00002	3,27316	0,00004	0,11379	0,21068	0,14688	0,40686	0	0,35842	0,82604	0,82604		
19	07/03 10:40:	2,9333333	320	1,43367	0,00001	0	4,98179	0,54936	0	0,83073	0,26323	0,42135	0,00002	0,89964	0,00001	3,04732	0,0201	0,31394	0,10595	0	1,65205	0	0,91107	1,08451	1,08451		
20	07/03 10:50:	3,0166667	325	1,49438	0,00011	0	4,15053	0,54104	0,00006	0,68789	0,35942	0,29039	0,0527	0,92847	0,0001	2,44678	0,27175	0,61999	0,00001	0	1,82648	0	1,2109	1,22421	1,22421		
21	07/03 11:00:	3,1	330	1,70286	0,00011	0	4,0748	0,59795	0,00006	0,68839	0,59527	0,22039	0,12555	1,05565	0,0001	2,36581	0,59876	0,92476	0	0	2,14745	0	1,25907	1,36294	1,36294		
22	07/03 11:10:	3,1	276,6666667	0,17214	0,80353	0,0636	1,92433	0,0948	0,1074	1,34202	0,14869	0,57384	0,0105	0,14164	0,42538	4,08266	0,0728	0	2,33855	1,60731	0	0	0,40852	0,18519	0,18519		
23	07/03 11:20:	3,1	223,3333333	3,46829	0	5,28017	0	1,15177	0	0	3,3018	0	1,106	2,09396	0	0	6,73568	0	2,18	1,61288	0	0,95861	0,0195	0,82114	0,82114		
24	07/03 11:30:	3,1	170	3,95425	0	7,14088	0	1,30455	0	0	7,21513	0	2,38556	2,38059	0	0	15,0214	2,23787	0	0,00602	0,88835	1,10742	0	0,31587	0,31587		
25	07/03 11:40:	3,1	116,6666667	0	4,13653	7,52689	0	0	1,39062	0,00505	2,25062	0	0,75236	0	2,48944	0,0893	4,45761	0	1,60703	3,18189	0	1,72022	0,00764	0,00345	1,60703		
26	07/03 11:50:	3,1	63,33333333	0	6,31584	0	7,19607	0	2,06107	4,6789	0	1,6533	0	0	3,78956	10,46279	0	3,2817	0	0	3,10158	0	1,02437	0	1,50158		
27	07/03 12:00:	3,1	10	0,033	1,92033	0	9,7793	0,00524	0,47744	1,16825	0,13132	0,64272	0,0296	0,0271	1,11102	0,11704	0,13692	4,68986	0	0	5,81087	0	2,1706	1,21836	1,21836		
28	07/03 12:10:	3,1833333	10	0,0272	1,97302	0	10,04321	0,00408	0,48986	1,20538	0,12532	0,66187	0,0265	0,0229	1,14161	4,21776	0,12602	4,81378	0	0	5,96563	0	2,2292	1,25168	1,25168		
29	07/03 12:20:	3,2666667	10	0,0257	2,02339	0	10,29893	0,00356	0,50232	1,24343	0,1252	0,68031	0,0257	0,0222	1,17123	4,31946	0,12425	4,85339	0	0	6,29604	0,00641	1,60645	1,08823	1,08823		
30	07/03 12:30:	3,35	10	0,0236	2,07309	0	10,55232	0,00335	0,51467	1,27831	0,12506	0,6986	0,0248	0,0213	1,2003	4,42135	0,12238	4,61612	0,00394	0	5,45159	0	0,00019	0,26566	0,26566		
31	07/03 12:40:	3,4333333	10	0,0212	2,12515	0	10,80948	0,00294	0,52697	1,31449	0,12275	0,71756	0,0235	0,019	1,22988	4,52276	0,1165	2,78051	0,012	0	2,76867	0	0,00018	0,0001	0,0001		
32	07/03 12:50:	3,5166667	10	0,0215	2,17457	0	11,0595	0,00298	0,53903	1,3514	0,12518	0,73552	0,024	0,0193	1,25881	4,62584	0,11903	0,00035	0	0	0,00042	0	0,00022	0,00009	0,00009		
33	07/03 13:00:	3,6	10	0,0189	2,22561	0	11,31706	0,00214	0,55142	1,38662	0,12253	0,75416	0,0223	0,0178	1,28922	4,72636	0,1115	0,00036	0	0	0,00044	0	0,00022	0,00009	0,00009		
34	07/03 13:10:	3,6	68,33333333	0	7,33083	0	7,33772	0	2,39445	5,08652	0	1,80748	0	0	4,40055	11,38504	0	0,00019	0	0	0,00018	0	0,00008	0	0,00008		
35	07/03 13:20:	3,6	126,6666667	0	4,07501	10,1154	0	0	1,39992	0	3,59677	0	1,23897	0	2,45892	0,0135	7,53537	0,00002	0	0,00019	0	0,00019	0	0	0,00019		
36	07/03 13:30:	3,6	185	5,85981	0	8,2253	0	1,94345	0	0	8,3008	0	2,74828	3,53008	0	0	17,26869	0,00005	0	0,00008	0	0,00011	0	0,00013	0,00013		
37	07/03 13:40:	3,6	282,3333333	4,41944	0	9,24947	0	1,4944	0	0	4,0137	0	1,20068	2,67138	0	0	8,04591	0	0,00044	0,00027	0	0,00016	0	0,00006	0,00006		

Visualizing airflow output in 3D – Design tool

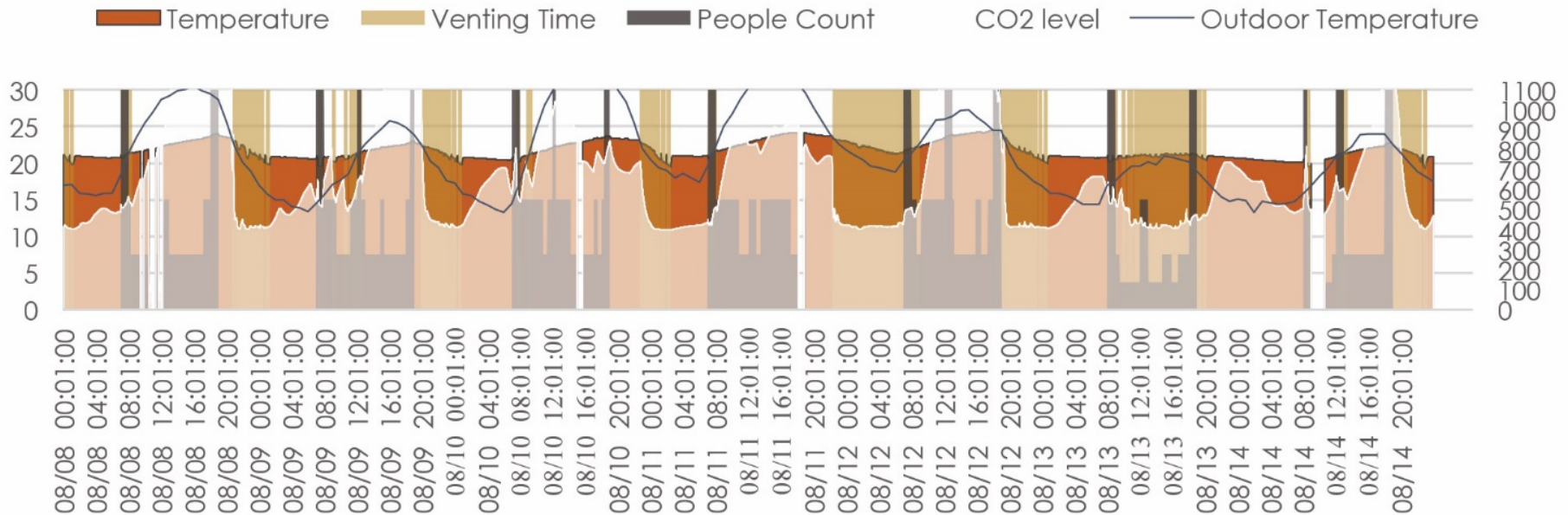


Visualizing airflow output in 3D – Design tool



Simulation output – user influence

Scenario 0 - 801 - August Week 2



Graph 28: Indoor air quality graph of zone 801 for Scenario 0 in the 1st week of July (Final Test)

(Master thesis R. Demeulenaere 2016)

Conclusion: Is ventilation the answer to indoor air quality control in buildings? *Do we need performance based approaches?*

Ventilation should dilute and remove pollutants from
unavoidable sources



source avoidance / control / containment are the
best control strategies

Do we need performance based approaches?

If we do, we should not forget which task the ventilation system was designed for!

ranking (IAQ performance) = differentiating between outside environment classes (noise, pollution, altitude...)

What about the influence of the user on IAQ system performance?

All models are wrong. The practical question is how wrong do they have to be to not be useful.

(George E. P. Box — *Empirical Model-Building and Response Surfaces*, 1987)



ir. arch. Bert Belmans

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bbelmans@vub.be (next week)