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 pollutans from **unavoidable** sources

source avoidance / control / containment are the best control strategies

Do we need performance based approaches?

Do we monitor? ↔ Do we model?

What is the decisive parameter for selecting a modelling approach (CFD ↔ 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)

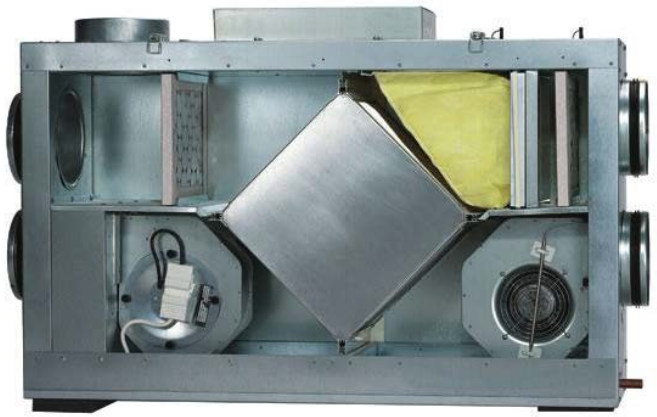
limited sound insulation

<u>BUT</u> (under favourable outdoor conditions)

Optimal air quality at very low (auxiliary) energy use

(Demand-controlled) Mechanical ventilation

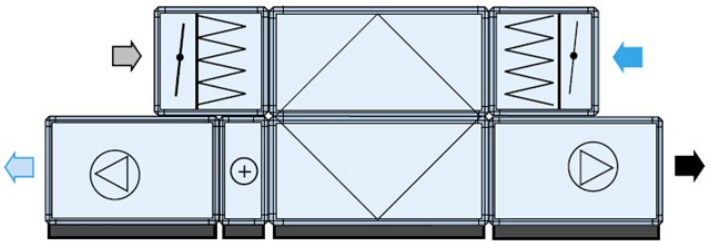
mechanical supply, mechanical exhaust, heat recovery, air filters



reduction of ventilation energy losses

increase of auxiliary energy use of fans

Supply air and exhaust air installation with plate heat exchanger

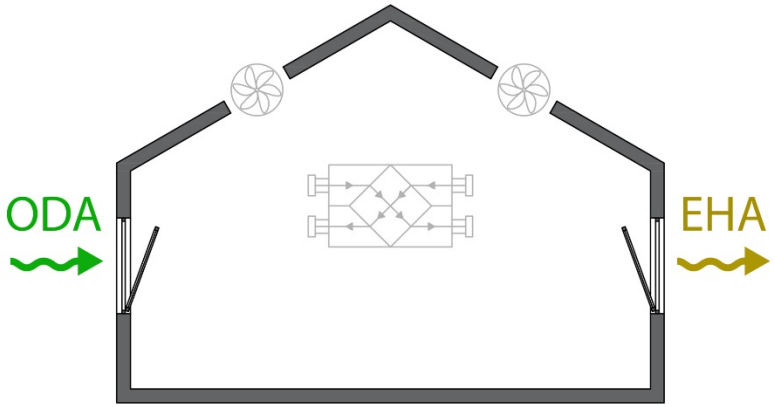


Why hybrid?

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

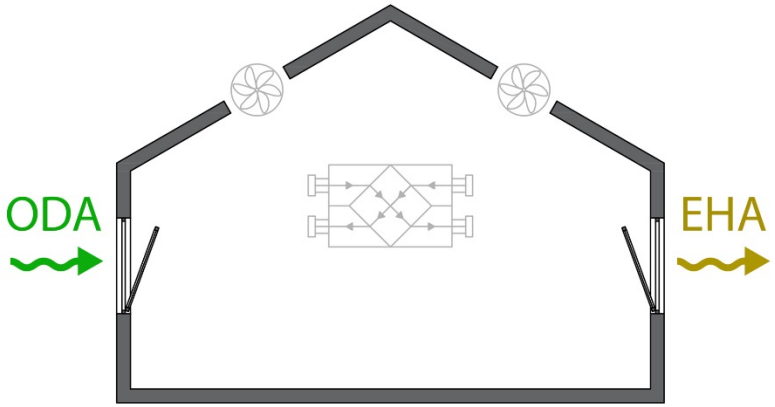
=

To combine IAQ with energy efficiency

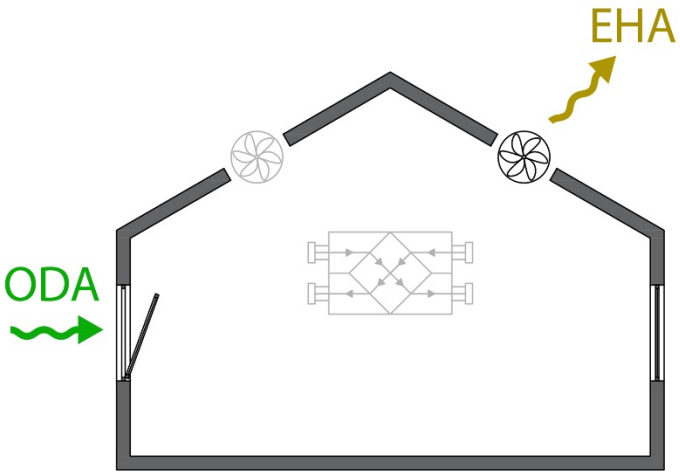


1

hygienic ventilation with natural supply- and outlet-openings

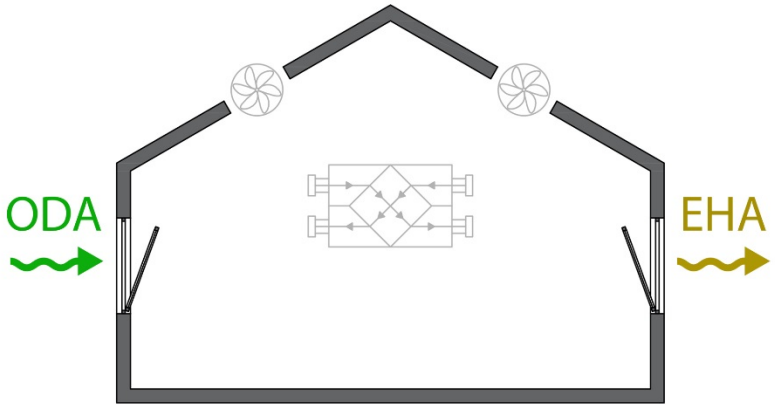


1



2

hygienic ventilation with natural supply and mechanical extraction



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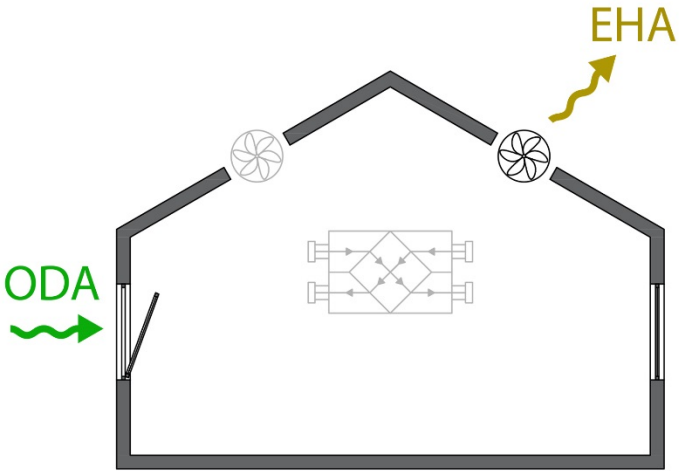

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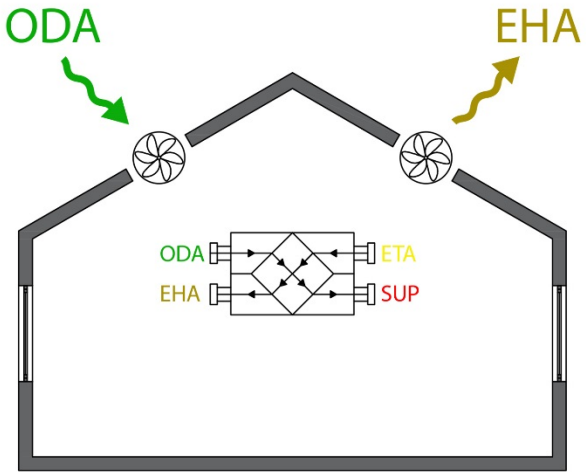
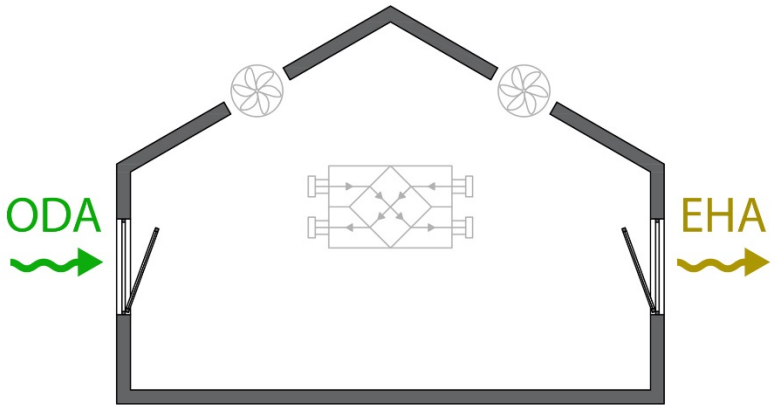
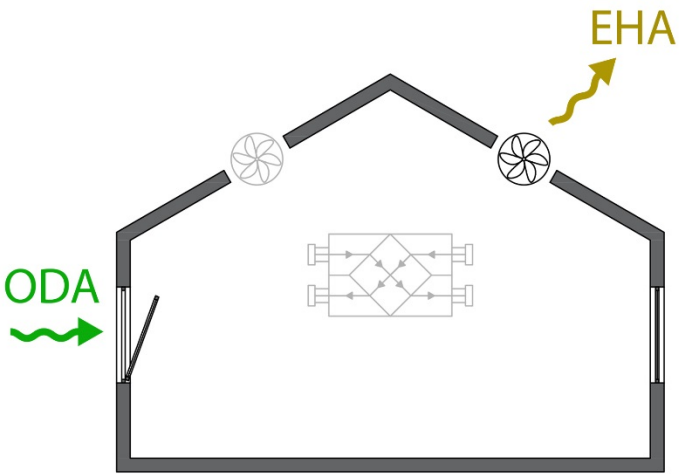


3

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



1



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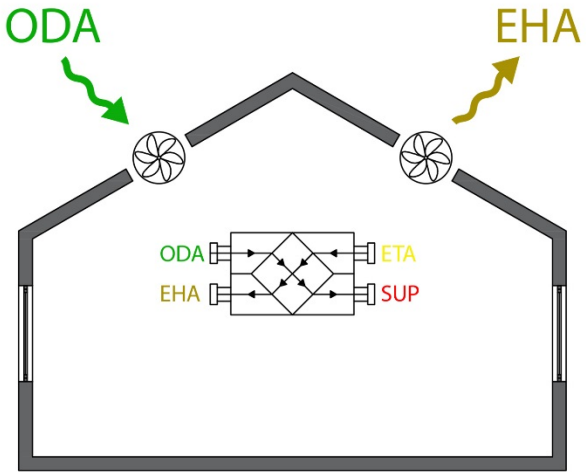
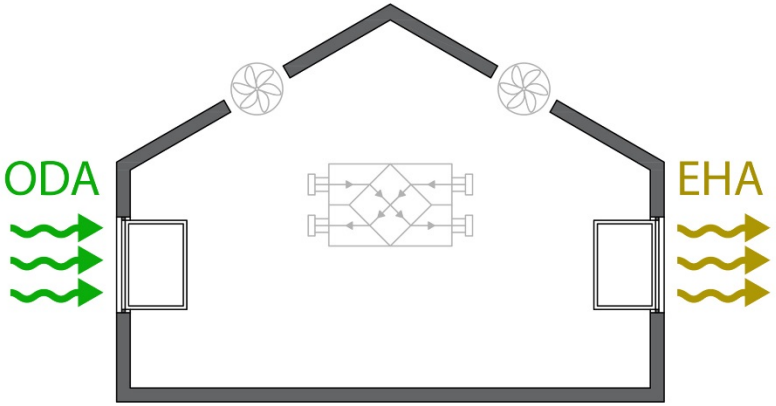


3



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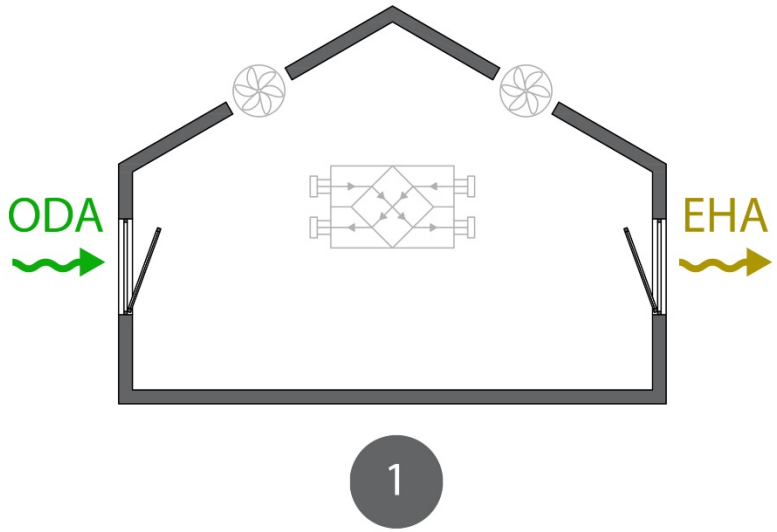
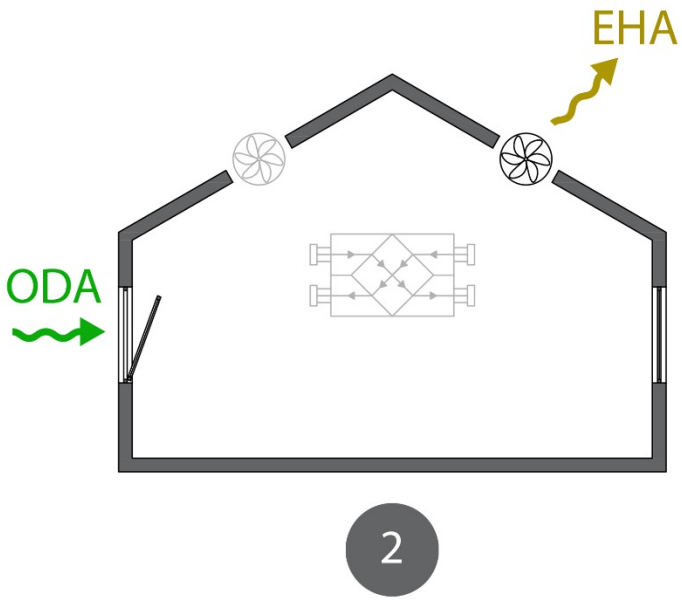
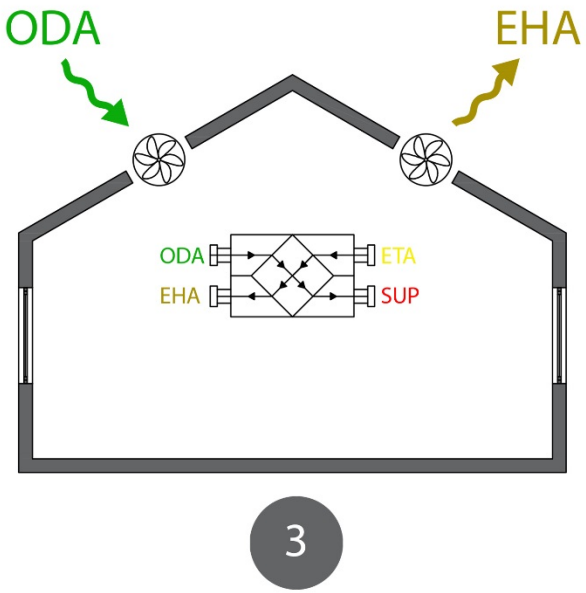
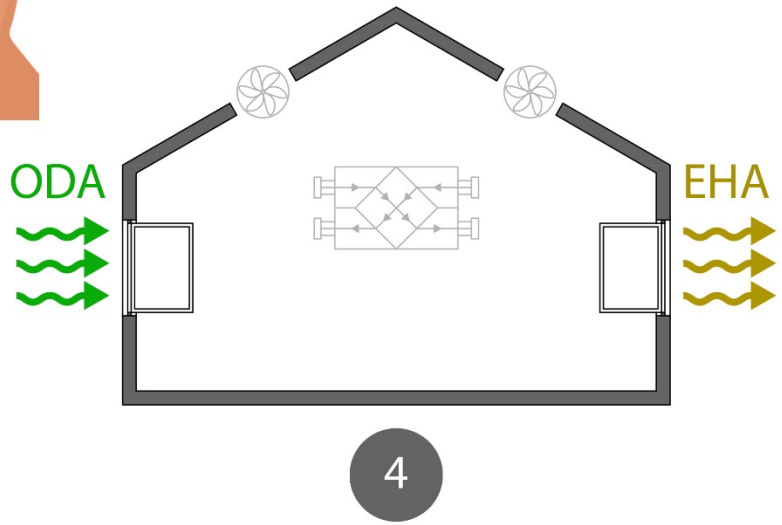

ODA
EHA
1


EHA
ODA
2


Feedback
1 info
2 info
3 info
4 info


ODA
EHA
ODA
ETA
EHA
SUP
3


ODA
EHA
4

To achieve our goal we need

Smart Controls

↓

A test environment that can ‘simultaniously’ 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

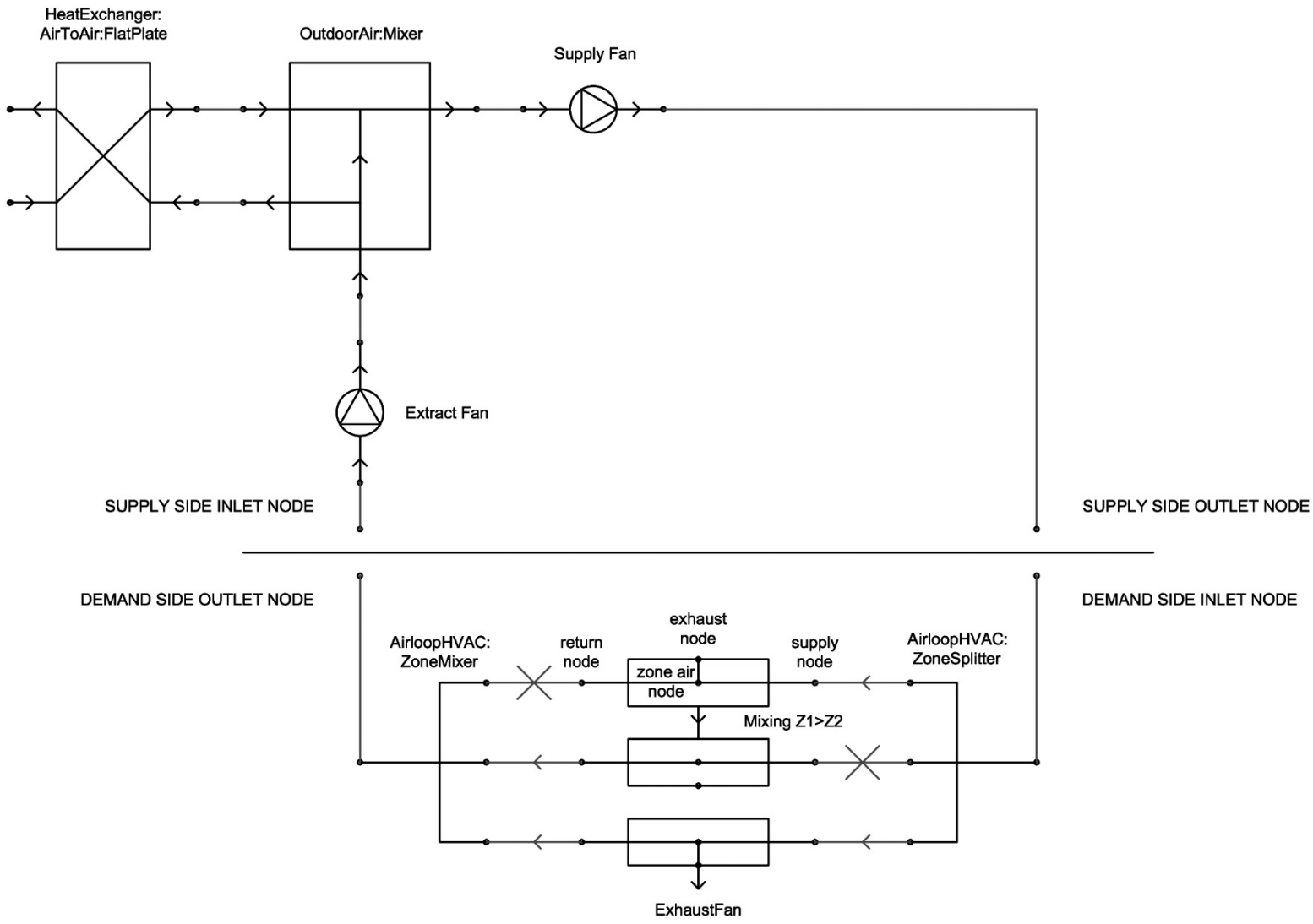
INPUT

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

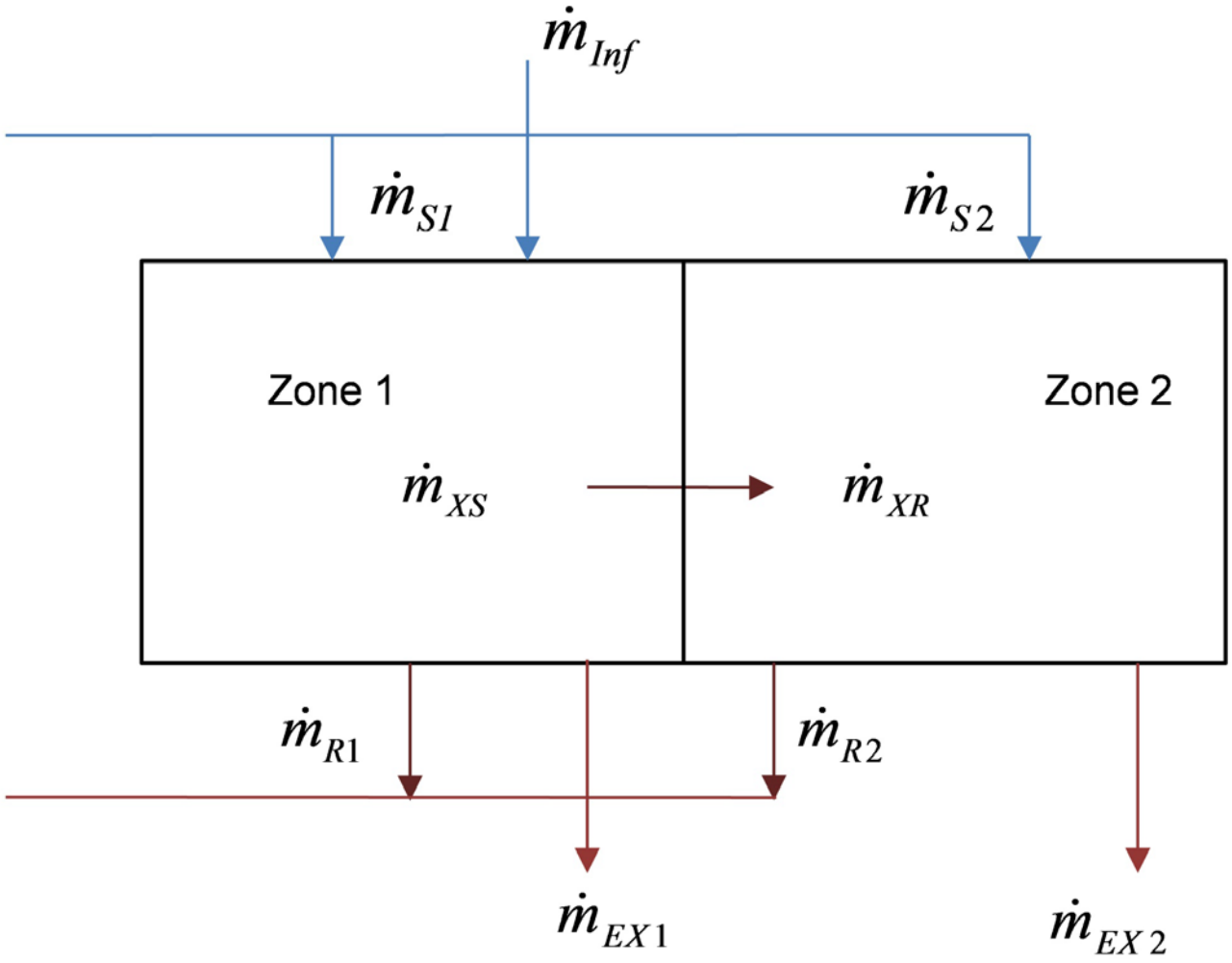
OUTPUT

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



Source: EnergyPlus Engineering Reference Manual

Modelling the HV's Natural and Extract ventilation modes

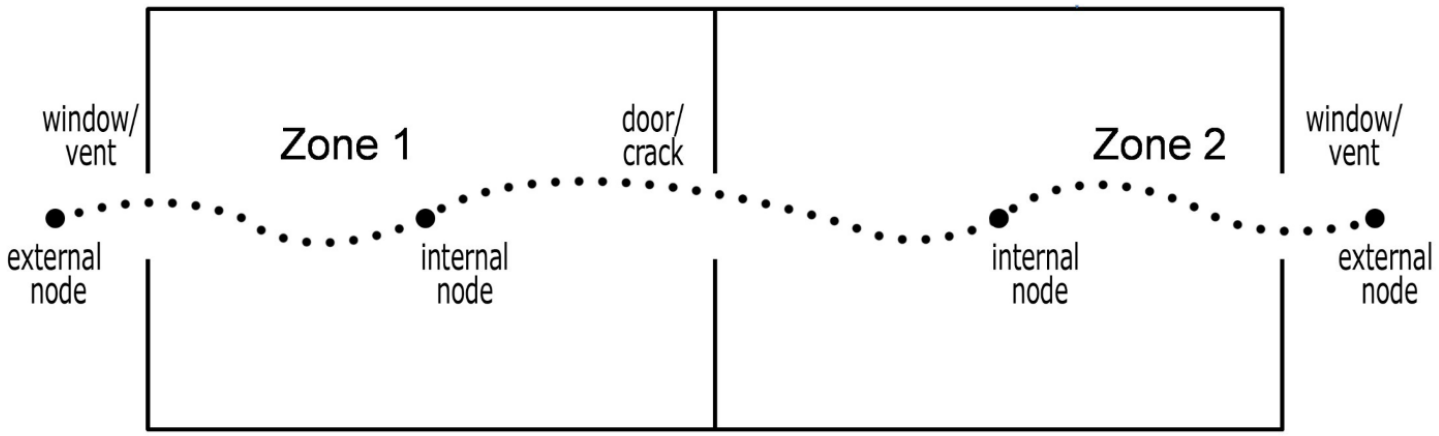
Building = series of zones = nodes, interconnected by flow paths = links

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

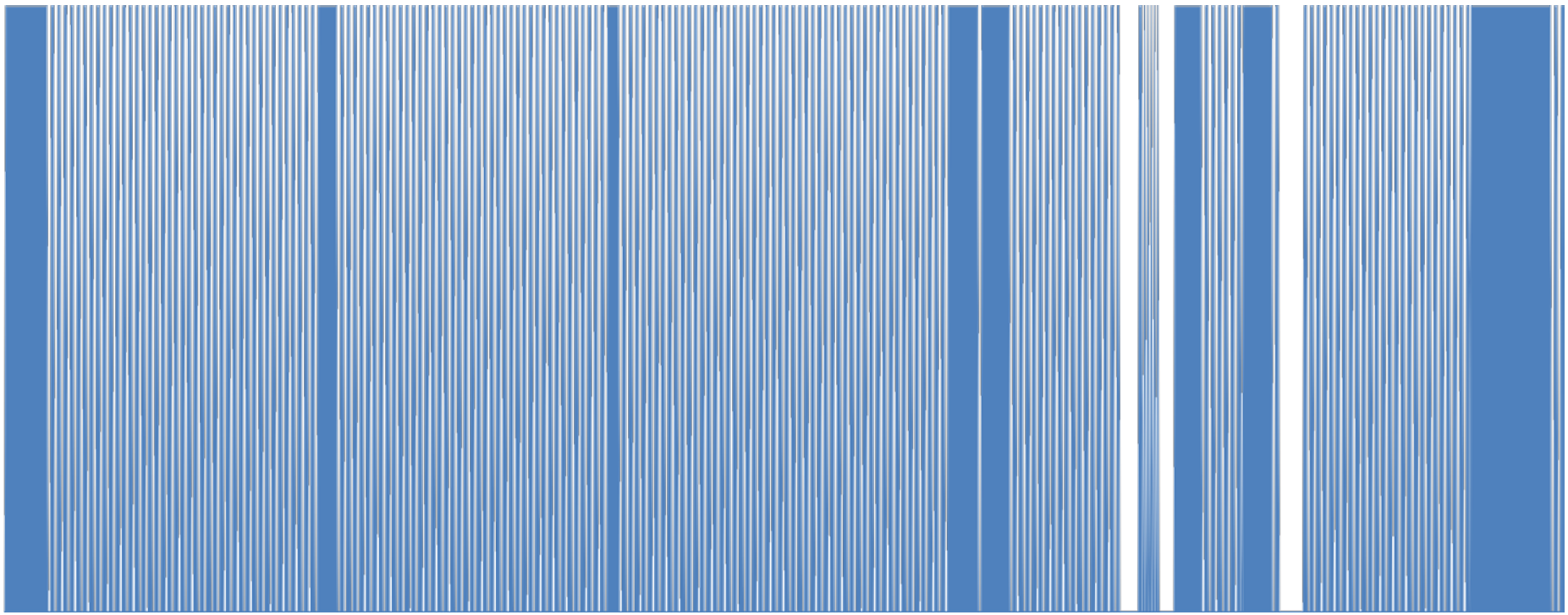
```
END Precalculation of AFN for Zone 1

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

ZONE2
=====================================================================================================
ZonePeopleScheduleName = ZONE2PEOPLESCHEDULE
Zone Floor Area = 9.0000m2
        Call to ManageAirflowNetworkBalance() in CalcHybridVentSysAvailMgr()


BEGIN Precalculation of AFN for Zone 2


ManageAirflowNetworkBalance()

        AirflowNetworkGetInputFlag = 0
```

Zone1 Precalculation

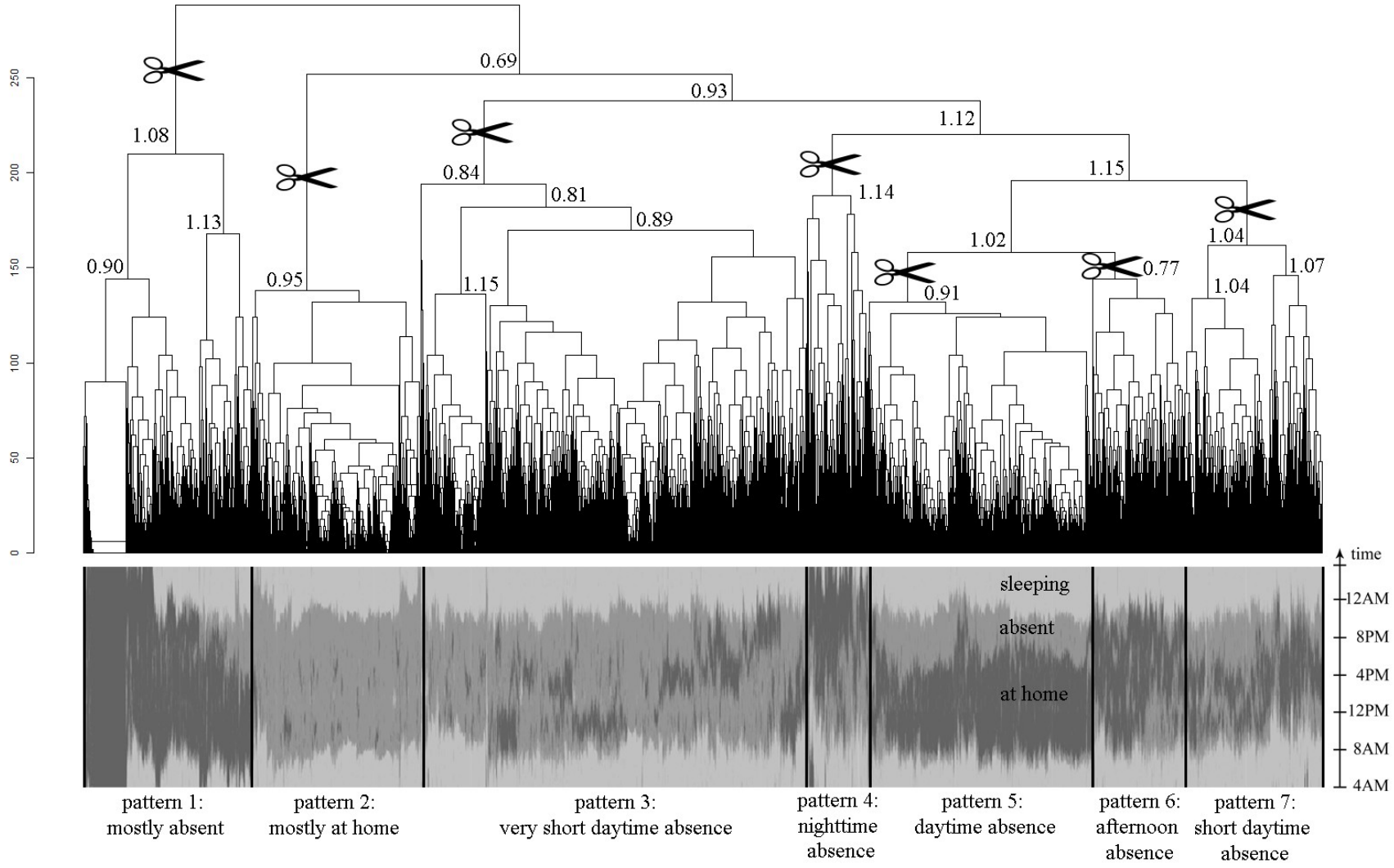
Zone1 Precalculation Result = Multizone = use AFN = Natural or Extract ventilation

Start Zone2 Precalculation

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



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)

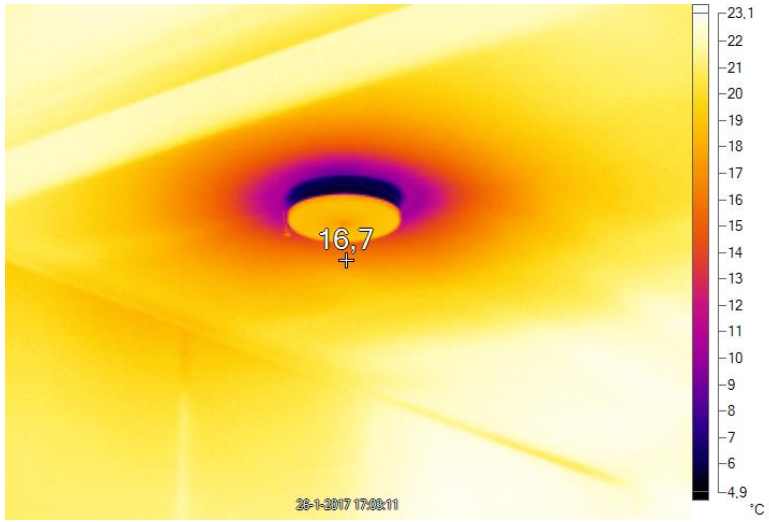
2 adults, 2 small children

Countryside

Balanced ventilation system with crossflow heat recovery

Monitoring

Monitoring

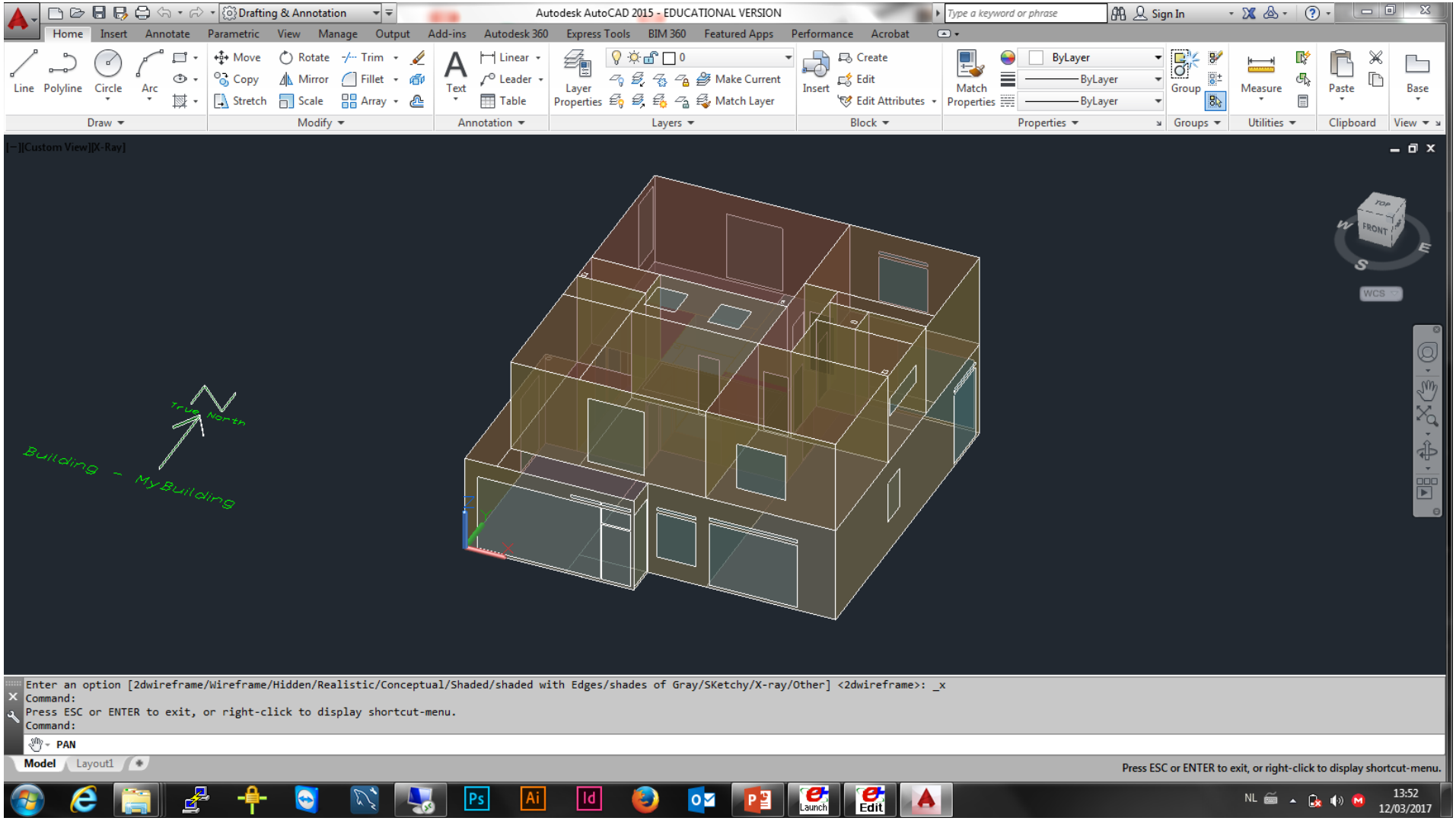


Monitoring

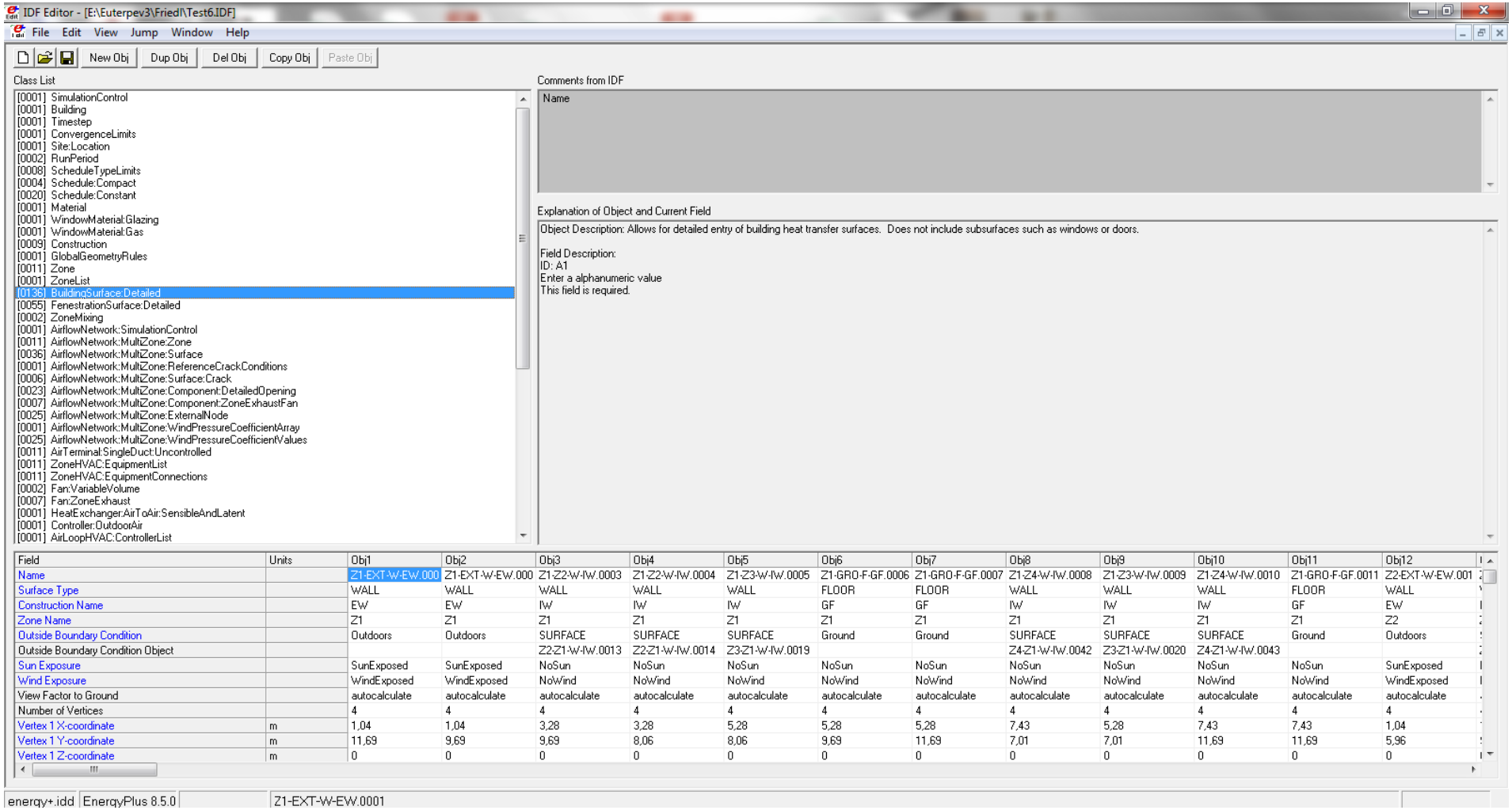
Monitoring

Monitoring

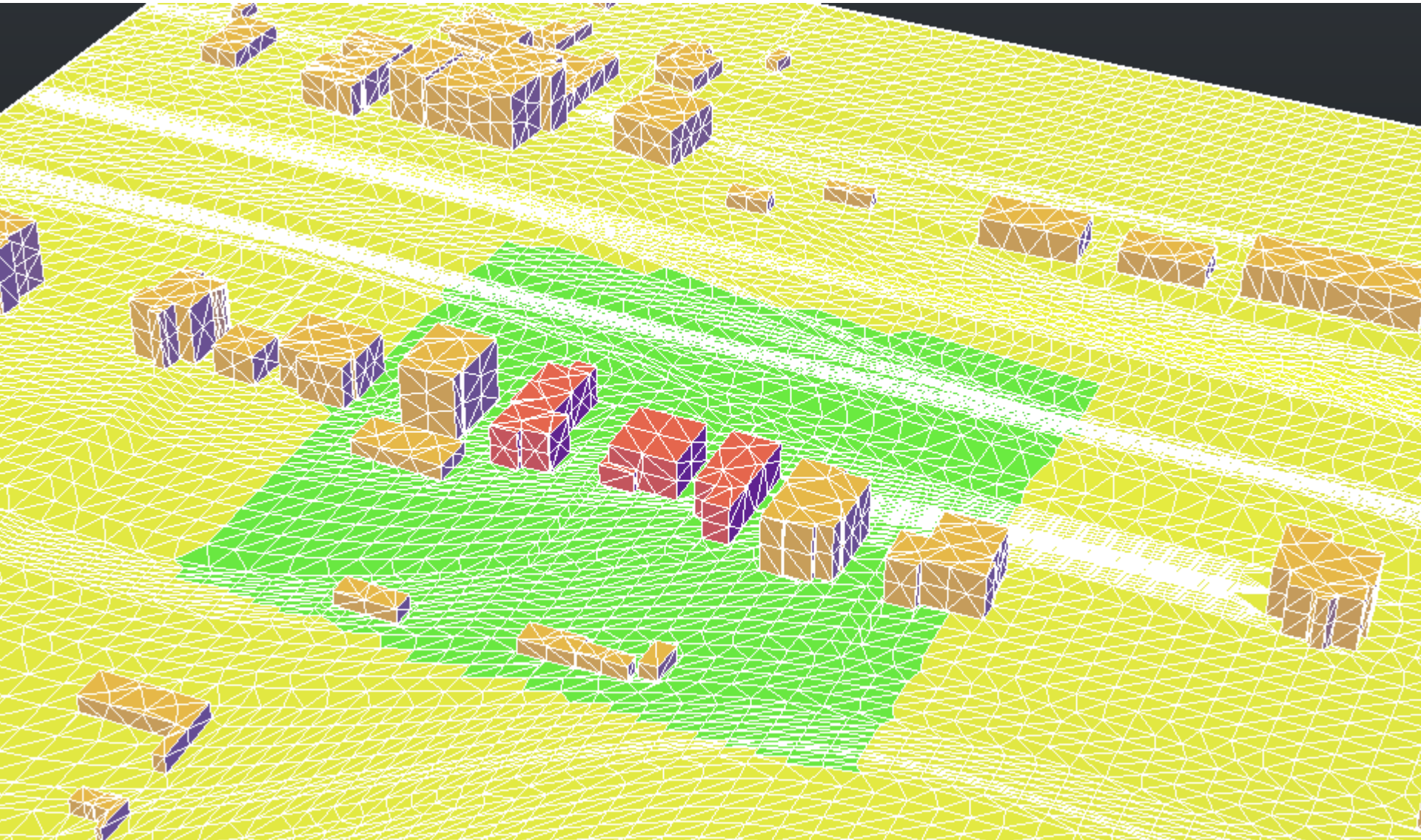
Generating EnergyPlus .idf input from CAD data



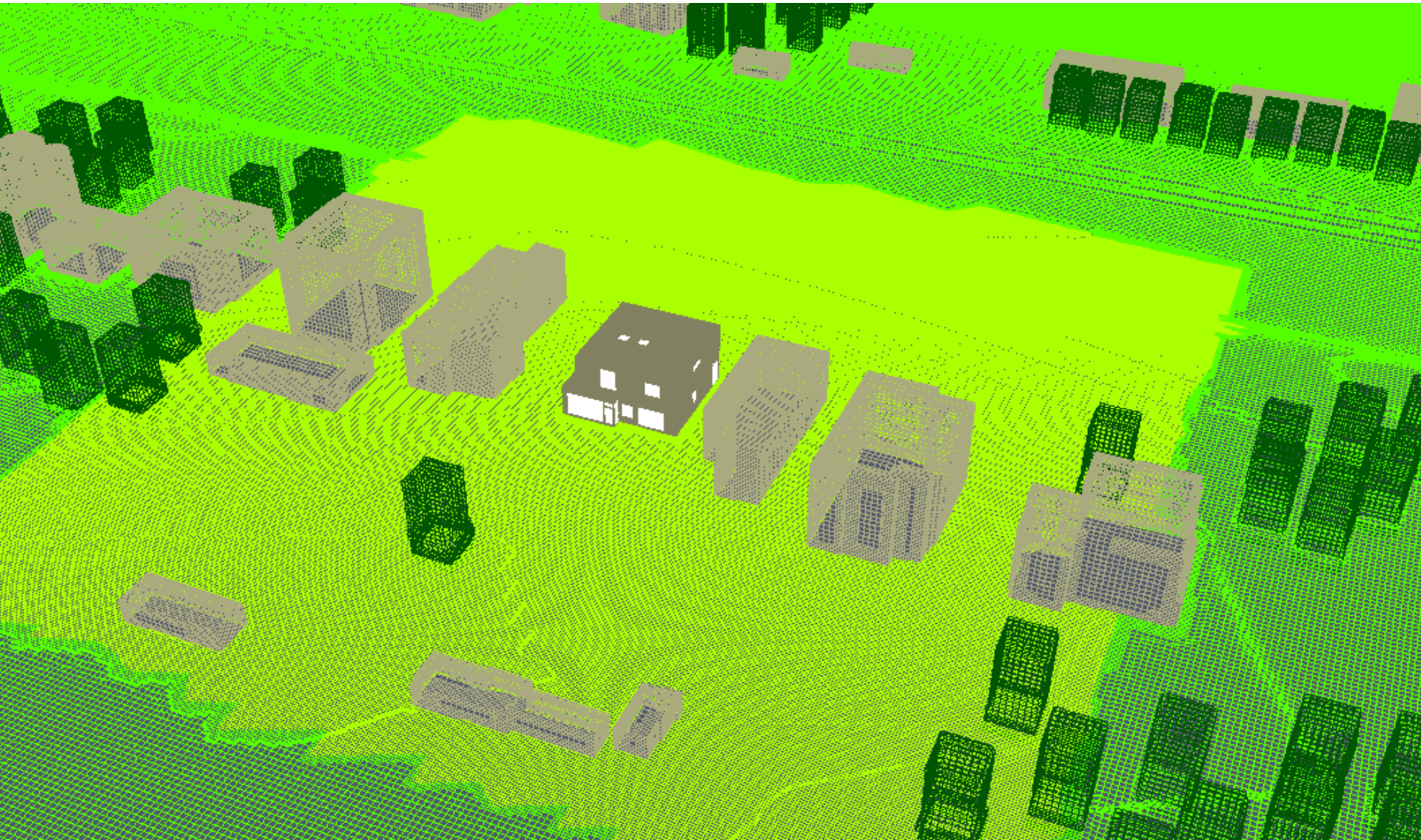
Generating EnergyPlus .idf input from CAD data



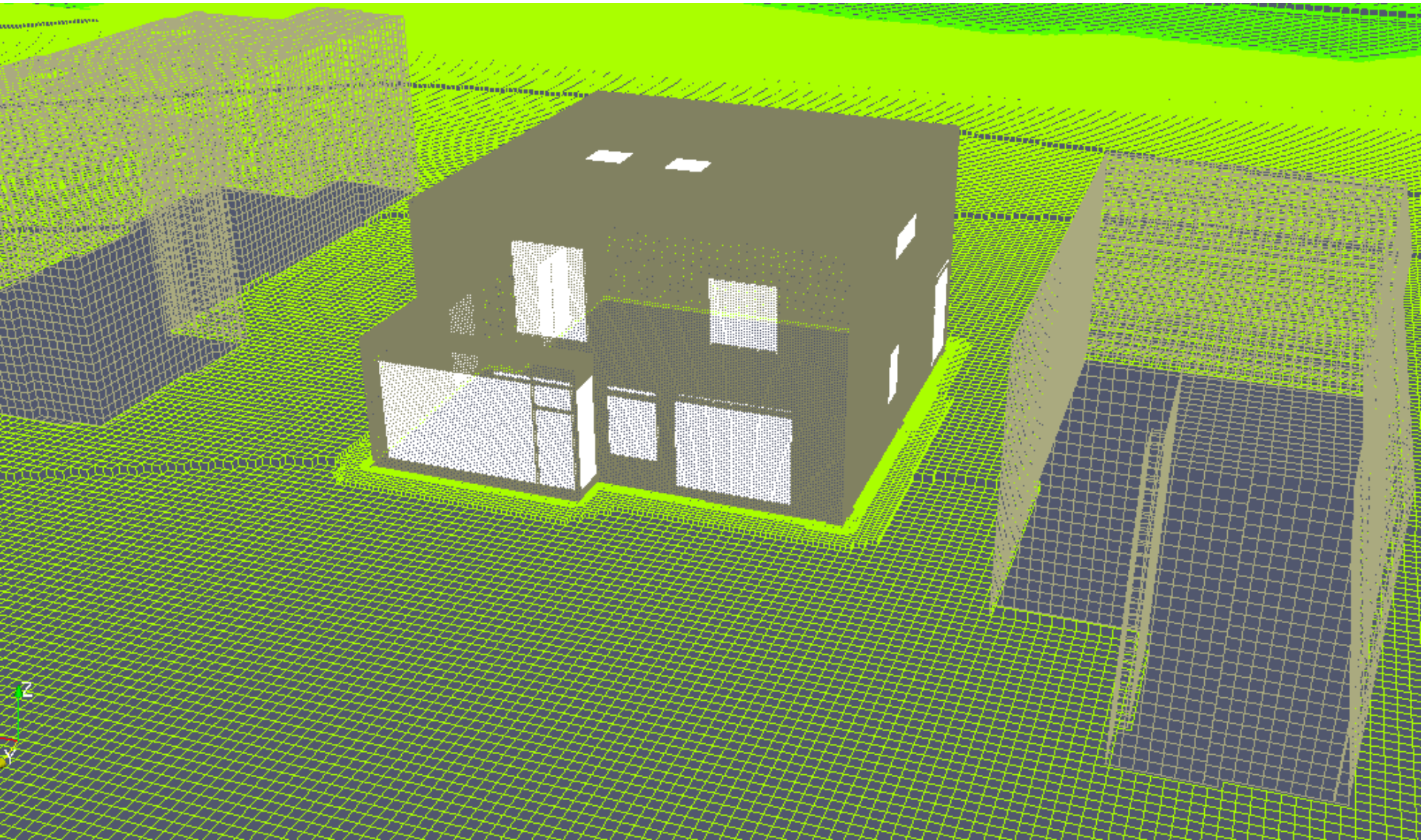
Cp values – OpenFoam CFD



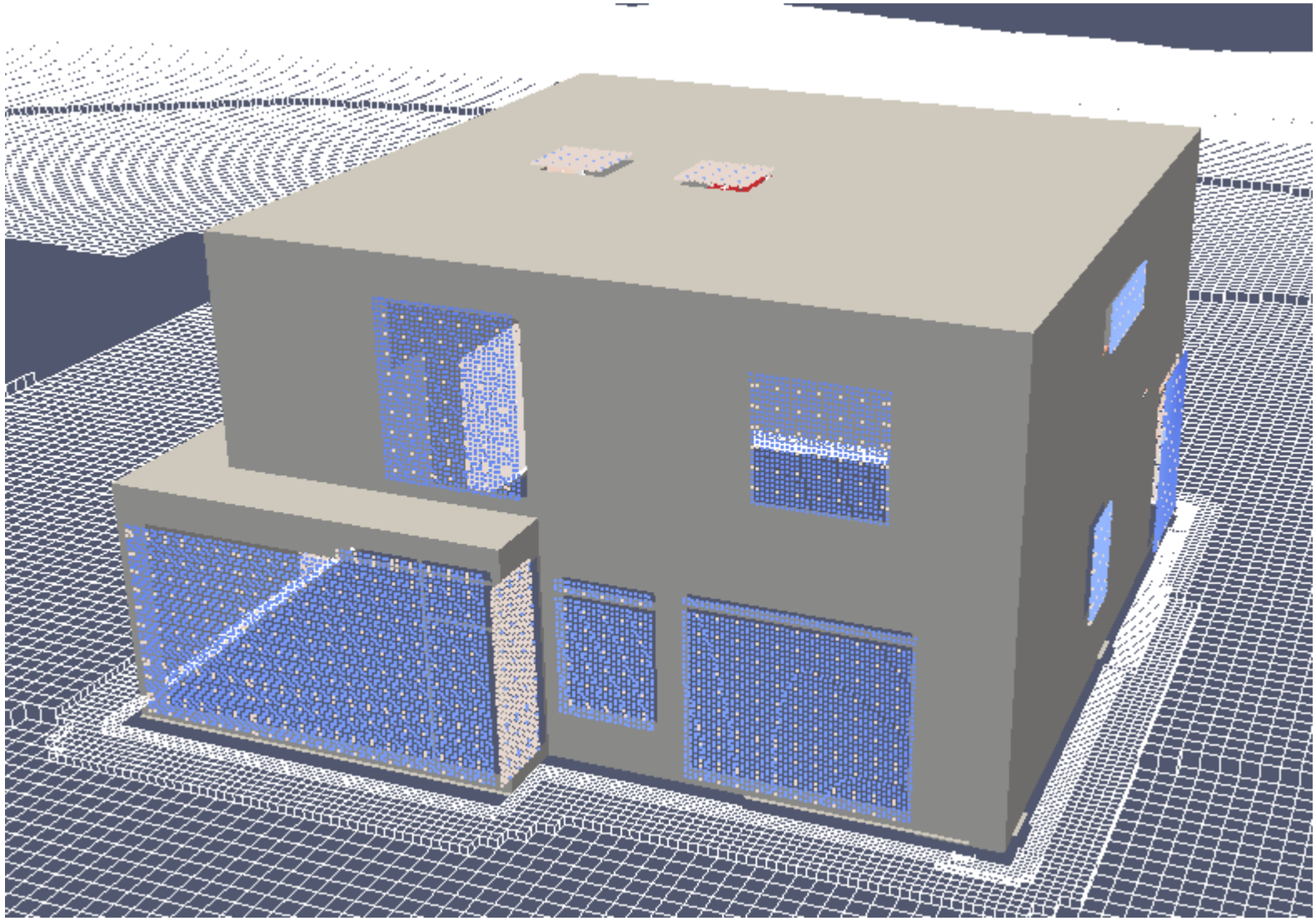
Cp values – OpenFoam CFD



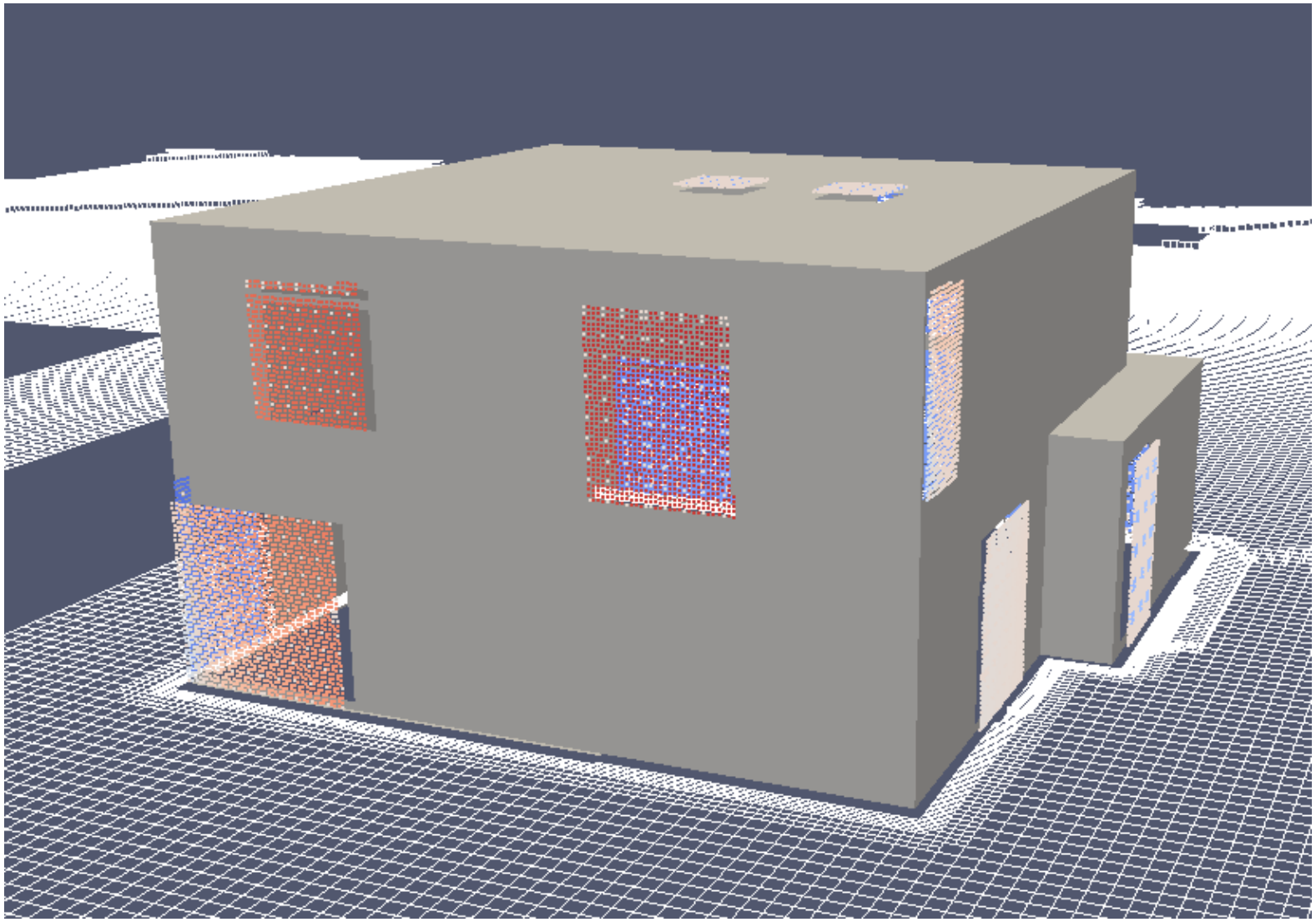
Cp values – OpenFoam CFD



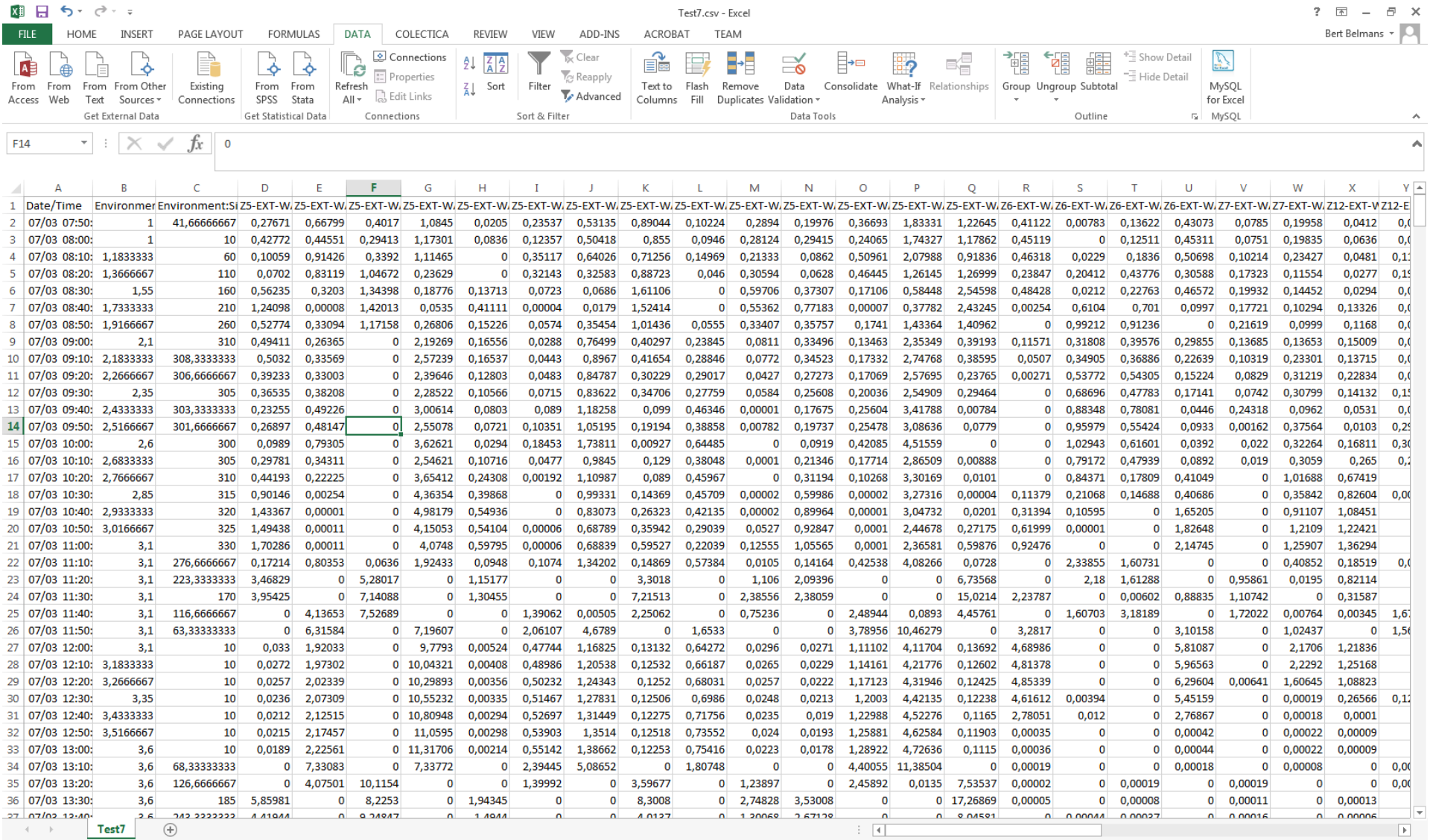
Cp values – OpenFoam CFD



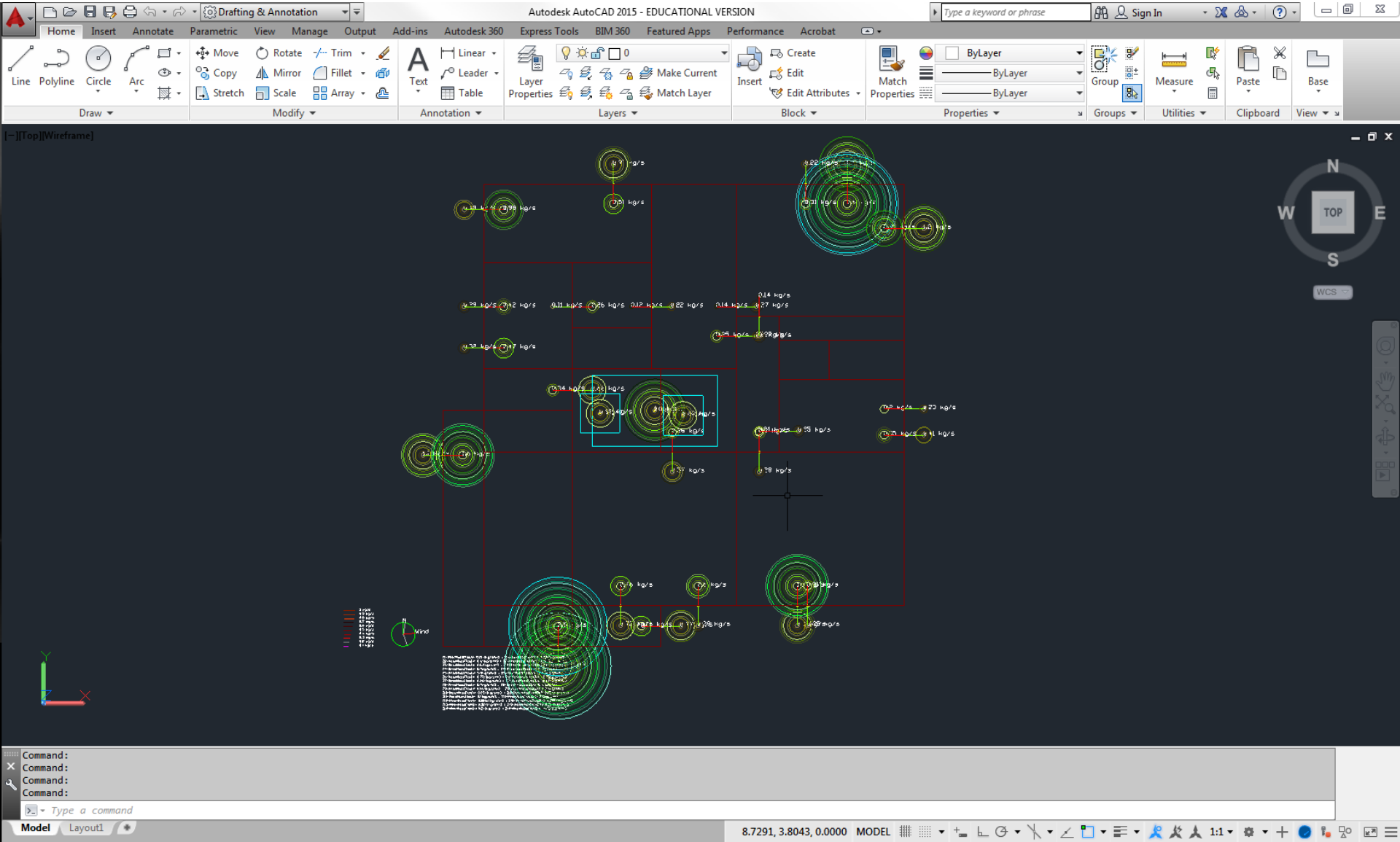
Cp values – OpenFoam CFD



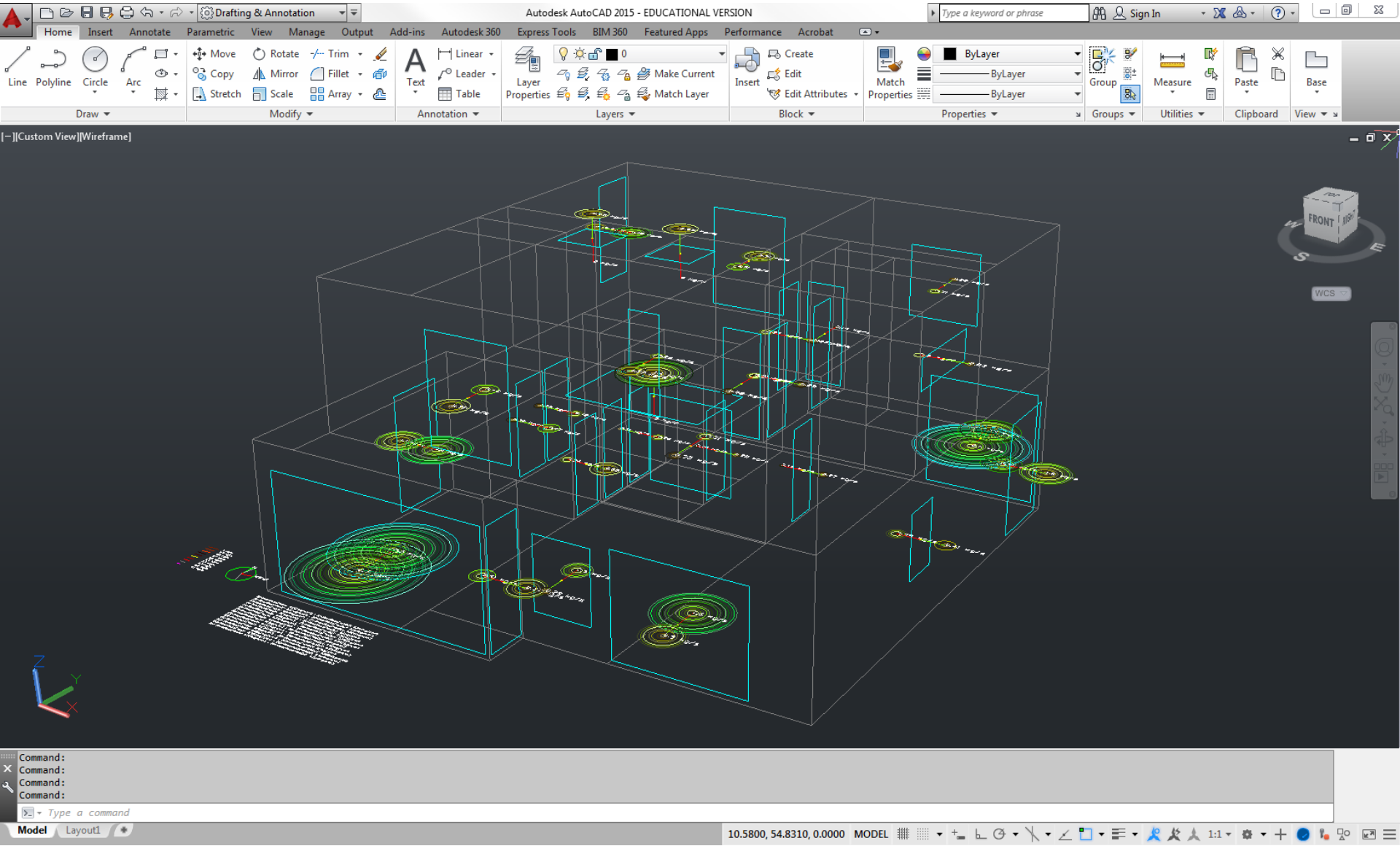
Visualizing airflow output in 3D



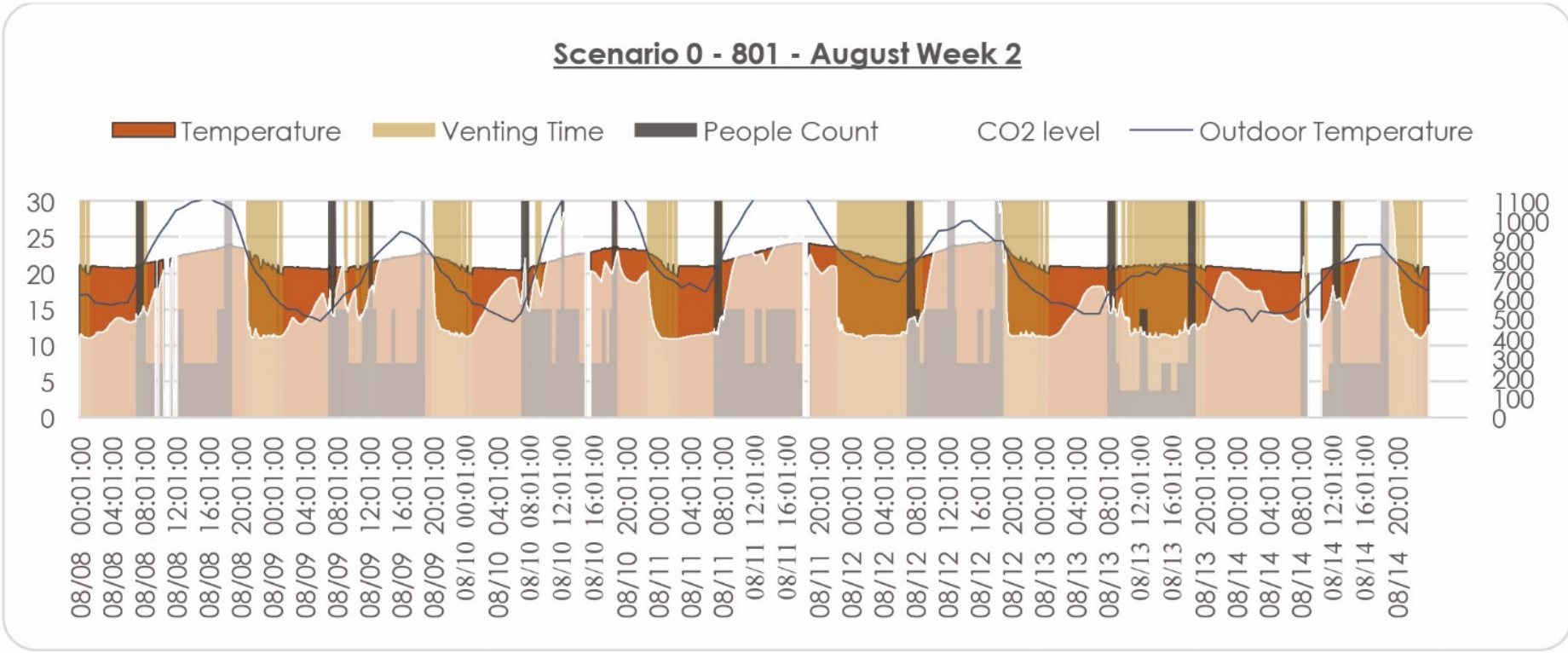
Visualizing airflow output in 3D – Design tool



Visualizing airflow output in 3D – Design tool



Simulation output – user influence



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 pollutans 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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