Domain Specific Language for Indoor Air Quality Analysis in Museums

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Abstract

Indoor air quality plays a major role in preventive cultural heritage conservation. There are several parameters that have an influence on the degradation process. Some examples are temperature, relative humidity, visible light, UV, radiation, particulate matter and reactive gases. All these parameters are measured and stored for monitoring purposes, but the amount of data is overwhelming for caretakers. The Indoor Air Quality is affected by various influences, such as people that visit the museum, the weather outside, and many more. Various simulation programs exist that will analyze the flow of air inside a building, but the construction of the input needed for those simulation is quite inconvenient. A new method is proposed that will make it more convenient to construct an input for the simulation program EnergyPlus. The results of the simulation could then be used to assign a classification to the Indoor Air Quality, but this is outside the scope of this study.

Keywords: Domain Specific Language, Indoor Air Quality, Museums

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1. Indoor Air Quality in general

The air we breath has a big influence on our health. A lot of attention has been paid to the air quality outdoors, with reducing the emissions of cars and

URL: `www.uantwerpen.be` (University of Antwerp) factories, but the air quality indoors research is booming at the moment. A lot of research has been done investigating the influence of it on the human health. The construction materials used in our homes can have an effect on the air quality, just as combustion of fuels, think about cooking or heating our home, release gasses that infleunce the air quality. All these factors and many more can cause health issues or even endanger us. The World Health Organisation (WHO) has released a report on the dangers of indoor air quality for human health, which can be publicly viewed [1].

1.1. Indoor Air Quality in museums

In the previous section the effect of Indoor Air Quality on humans was discussed, but there is also a lot of research regarding the effects of Indoor Air Quality on our cultural heritage [2]. It has been proven that the Indoor Air Quality does have an effect on cultural heritage, mainly due to the degradation proces of materials. Materials degradade naturally but the quality of the air can speed up this process.

Preservation of cultural heritage objects is better than restoring them. Restorations of cultural heritage objects will never be as good as the original works, since appropriate materials might not be available anymore. Two examples of failed restorations are given in the following paragraphs to illustrate the importance of preservation.

A local teacher was asked in 2018 by the Parrish priest to restore a sculpture of Saint George on a horse, clad in armor while fighting a dragon [3]. The sculpture is located at the church of San Miguel de Estella in Navarre, Spain. However, the restoration did not go well and Saint George now looks like a cartoon from a disney movie, as can be seen in Figure 1.

Figure 1: Sculpture of Saint George before and after restoration.

Another attempted restoration, which happened a year earlier, can be seen at the the church of Santuario de Misericordia in Borja, Spain, where a fresco of Christ by 19th century Spanish artist Elias Garcia Martinez was completely ruined [4]. An elderly woman replaced almost all of Martinezs original brush-strokes, as can be seen in Figure 2.

Figure 2: Martinez's fresco before and after restoration.

The restoration cases provided above are extreme examples of how a restoration could go wrong, however, they show in a visible manner what happens when an object is restored instead of preserved. If the object had been preserved, the initial damage to the object would not have been so severe, and no attempts would have been made to restore the object.

2. Background information

2.1. Metadepth

MetaDepth is a framework for multi-level meta-modelling [5]. The framework is developed by the miso research group from the Universidad Autnoma de Madrid [6]. It supports a dual linguistic/ontological instantiation and permits to build systems with an arbitrary number of meta-levels through deep meta-modelling. The framework implements advanced modelling concepts allowing the specification and evaluation of derived attributes and constraints across multiple meta-levels, linguistic extensions of ontological instance models, transactions, and hosting different constraint and action languages.

2.2. EnergyPlus

EnergyPlus is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption (heating, cooling, ventilation, lighting and plug and process loads) and water use in buildings [7]. The program has a simple interface where an idf file and a weather file can be loaded. After that, the user can start the simulation and view the output of it. A lot of output methods are available and can be found in the EnergyPlus documentation. The user interface of EnergyPlus is very simple. An EnergyPlus input data file (IDF) can be choosen and weather data can be loaded as can be seen in figure 3. After the simulation is performed, the results can be viewed in a folder.

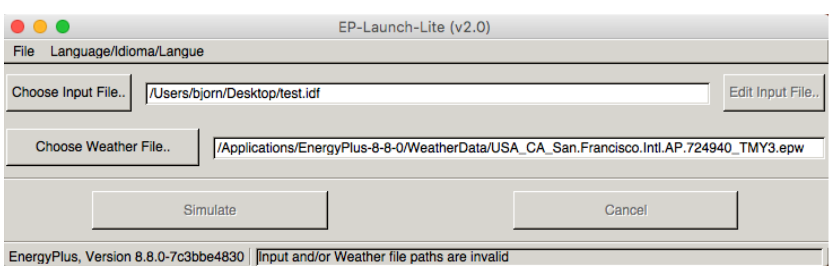

Figure 3: EnergyPlus User Interface

2.2.1. *EnergyPlus input data files file*

The previous paragraph discussed the EnergyPlus simulation program, which uses IDF files to create the environment of a building. The downside of the IDF file, is that it has to be created by hand, since only a helper tool exists that creates objects in the textfile. Since the EnergyPlus program supports a lot of features, it's very hard to create a file without the right knowledge. A modelling language could require less effort and technical knowledge to create a floorplan. An example idf file which was provided by the developers of EnergyPlus to help people get started, but the simple example counted almost 2000 lines.

Heritage guardians have to deal with a lot of data, but they do not know which factors have an influence on the Indoor Air Quality. Using the simulation program EnergyPlus, they could analyze how the building where our cultural heritage resides, could be improved to increase the quality of the air.

For these reasons, two modelling languages are introduced in this thesis. The first one is a lower level modelling language that is a visual representation of the IDF file format. It is capable of visualising the elements needed to construct a building, such as zones, materials, people, schedules and thermostats that are linked with a heating and cooling system. This language makes it more convenient to create and IDF file with less effort and no lines of code to write.

The second language is a higher level modelling language that is created to make it more convenient to create a building plan. The complexity of adding outerwalls and their vertices is eliminated and is handled by the transformation to the lower level modelling language. The positioning of materials such as windows is more convenient and the results are visually displayed, which leads to a faster insight of the building layout.

The simulation of the IDF file can show the influence of the weather outside and internal factors such as people on the air quality. After the simulation is executed, the values can be converted to a judgment (good-mediocre-bad) to show the impact of the factors described above on the indoor air quality.

3. DSL for Indoor Air Quality in Museums

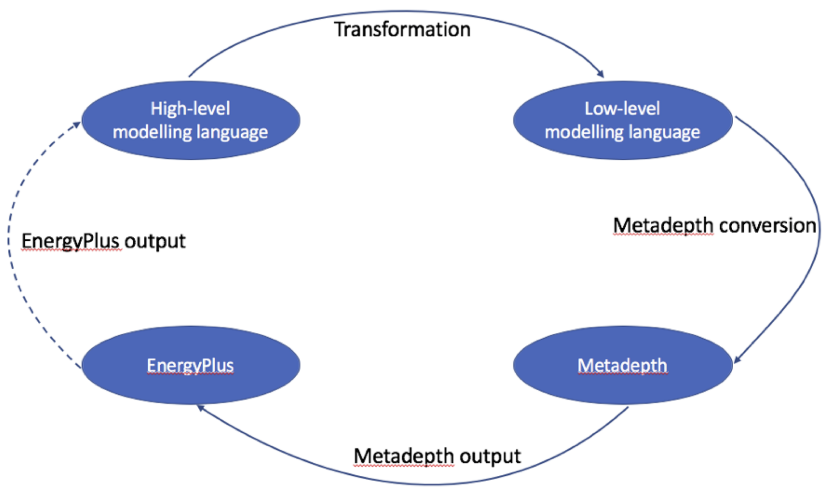

Figure 4: The roadmap of the various transformations.

A roadmap of the various steps of the Domain Specific Language can be found in Figure 4. The higher-level language is transformed into the lower-level modelling language with the help of transformation rules. The higher-level language is converted into the metadepth format, after which metadepth generates an IDF file. The IDF file can be used as input for EnergyPlus, and the output of the EnergyPlus simulation could be fed back into the higher-level modelling language. This last step is not implemented during this study. The next sections discuss the different steps in more detail.

3.1. Lower-level modelling language

The IDF files are quite long, and a lot of technical knowledge about the subject is needed to create such a file. A modelling language that takes care of these difficulties could require less effort and technical knowledge to create such a file.

The modelling language I created simplifies a lot of things:

- There is no need to define materials themselves, since basic ones are already included.
- Zones can be created, after which walls, a floor, a ceiling and windows can be added. It also supports persons in a zone, and a thermostat indicating that the zone is heated.
- Schedules for people can be created, so their behaviour can be simulated during periods of time and their load during those periods.
- Schedules for heating and cooling can be created as well, with the same tools as the schedules for people.
- The model can be exported to metadepth, and code generation will transform the model into an idf file.

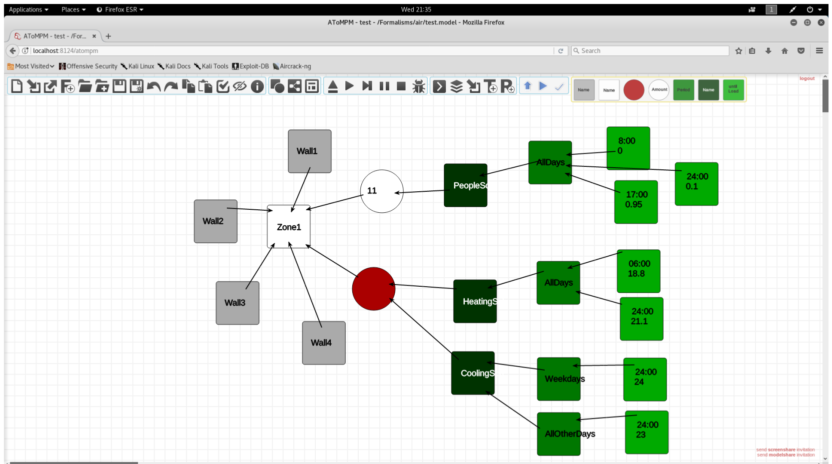

Figure 5: Modelling language example.

An example of the newly created modelling language can be seen in figure 5, where a zone is created with the name Zone1. That zone contains several construction materials depicted with the grey boxes. They are named Wall1, Wall2, Wall3 and Wall4. The materials themselves are predefined so that a window, an inner wall and an outer wall can be used in the language. A zone can also contain a thermostat, which makes the zone heatable or coolable. This is represented with the red circle. The thermostat is connected to a heating and a cooling schedule. When the temperature drops below a value that was set in the heating schedule, the heating process is started. If the temperature raises above a value that was set in the cooling schedule, the cooling process is started. The possibility is added to configure the schedules for periods, such as weekdays, holidays and weekends, and moments in time during those periods. These are depicted in different shades of green in the example. This means that everything can be put into one simulation instead of linking multiple simulations after each other for various inputs.

People can also affect the temperature and relative humidity with their bodies. For this reason people are also included in the simulation. Schedules can be set to simulate their behaviour and the amount of visitors that come during a certain period of the day. Information can also be extracted from the simulation about their thermal comfort, and the influence they have on the environment. EnergyPlus sees these people as internal gains, where lights and other equipment also falls under.

The modelling language makes creating idf files a bit easier, but it still requires a lot of focus to set the right vertices of each material seperately. Therefor, another modelling language is created to make this process easier.

3.1.1. Transformation to the IDF format: code generation

When the lower level modelling language is exported to metadepth, code generation takes place to generate the IDF file. Some general information about the building, the simulation itself and the location are created. The location is set for Chicago, but can be changed in the IDF file if necessary. Changing a generated file brings some risks with it. Since the user has to change information which might not always be clear, the changes might break the file and generate errors. As suggested in the future work chapter, the modelling language can be extended to also include information about the location.

Several constructions are created, such as inner walls, outer walls, ceilings, floors and windows. These are created with the help of predefined materials that are also added to the file. Some standard outputs are defined as well. They determine the output that the simulation has to store. If the output is not necessary, the output can be deleted from the IDF file, or if more output is necessary it can be added to the IDF file.

The other elements of the code are generated with the help of the lower level modelling language. It transforms thermostats, people, zones, materials, and schedules to the IDF format. If a relationship exists it is also transformed, such as the relationship between a zone and the materials that are inside it.

Figure 6: Simulation of the generated code

The code generation of the example in figure 5 can be seen in chapter 6. The code is used as input for EnergyPlus and the simulation is succesful as seen in figure 6. An output folder is created where all the output types defined in the IDF file are stored. An example of the output for the lower level modelling language can be seen in Figure 7 and Figure 8, where the results of one day are displayed in a graph. The occupation by people happens according to the schedule that was drawn in figure 5, as indicated by the blue bars in Figure 7.

The heating and cooling schedules kick in to maintain a constant temperature, as can be seen in Figure 8. When people are present in the building, the cooling has to work harder to maintain a good temperature.

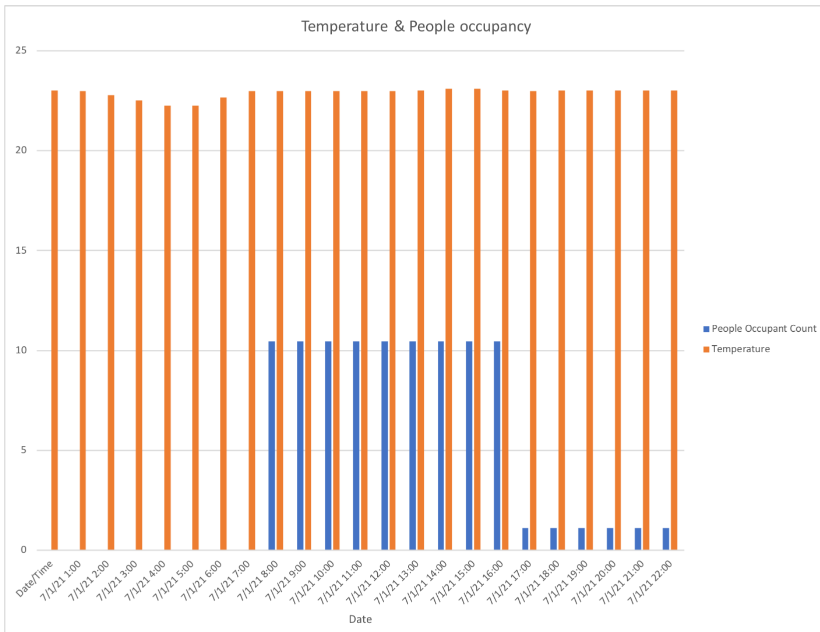

Figure 7: Temperature and people occupancy simulation result for one day

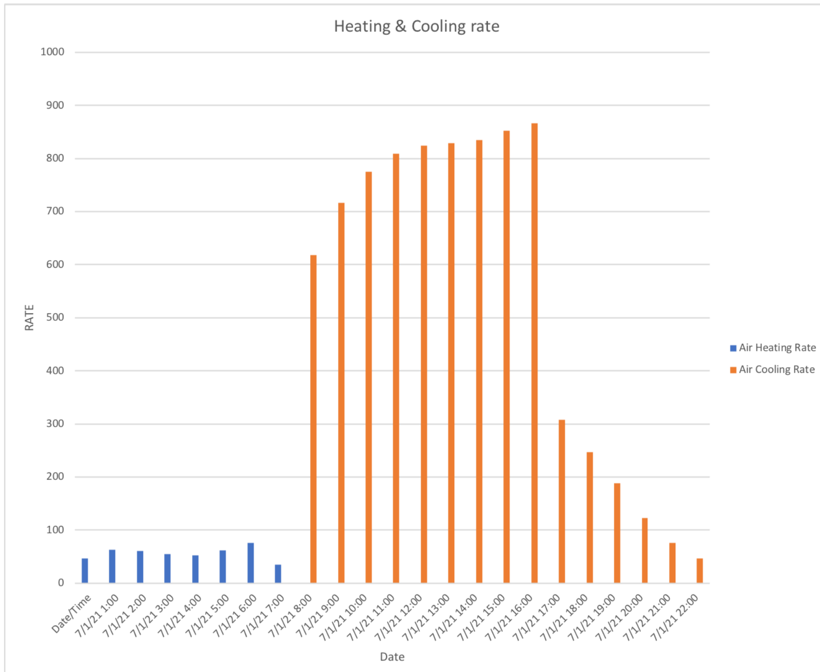

Figure 8: Heating and cooling rate for one day

3.2. Higher level modelling language

A higher level modelling language is created, to make it more convenient to construct a building, without doing all the math yourself. An example of the higher level modelling language in practice can be seen in figure 9. The user can create a floor, where he can add windows, inner walls, thermostats and people. The usage of the schedules remains the same as in the previous modelling language, depicted in different shades of green in the example. The outer walls of the building are created automaticly when the transformation is executed to transform this new language into the previous language.

The concepts of zones and materials are removed from the lower level modelling language. They are replaced with a floor that can be resized, inner walls and windows. A floor can contain a thermostat and people, which adheres to the same concept as in the lower level modelling language. This new language removes the complexity of inserting vertices, adding a floor and a ceiling, and

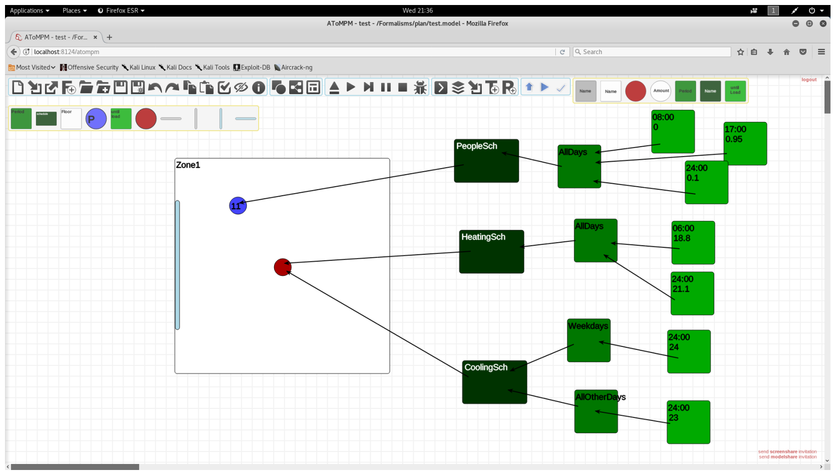

Figure 9: Higher level modelling language example

the materials don't need be inserted by the user. Instead, some materials have been predefined for the user, such as inner walls and windows.

3.2.1. Transformation to the lower level language

In order to use the higher level modelling language for the EnergyPlus program, the language needs to be transformed to the lower level modelling language. Some concepts are the same in both language, and can be transformed in a one-to-one relation, such as temperature, people and the concept of schedules with the periods and time instances.

A window is transformed into a material. The rule for this can be seen in figure 10. A floor is transformed into materials: 4 outer walls, a floor and a ceiling are generated as can be seen in figure 11. The transformation rules stores the connection between the lower level and higher level modelling languages. These connection are removed when all the objects from the higher level modelling language are removed.

After the transformation from the higher level language to the lower level language is completed, code generation can be used to create and IDF file, which can be used as input for the EnergyPlus application.

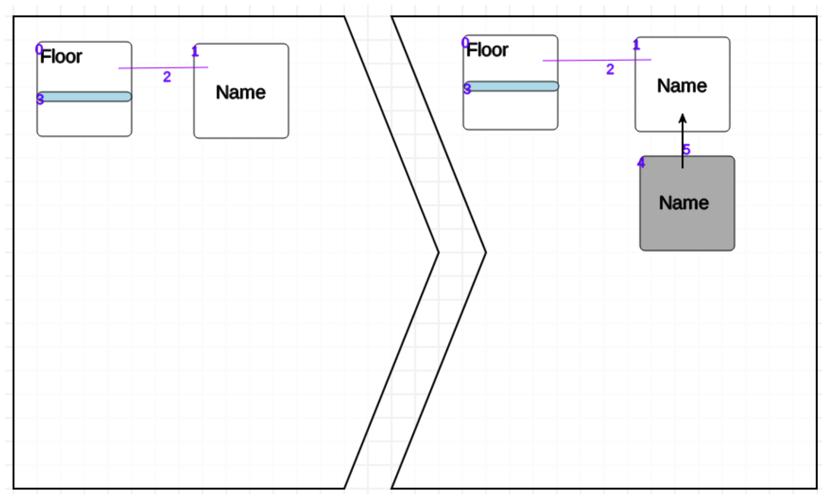

Figure 10: Transformation rule for window from higher level to lower level

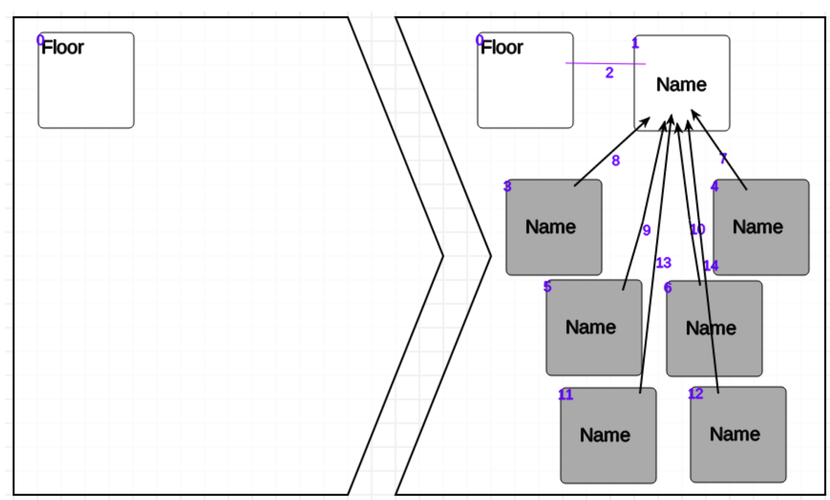

Figure 11: Transformation rule for floor from higher level to lower level

4. Existing tools

4.1. AirSense

AirSense [8] is an Intelligent Home-based Sensing System for Indoor Air Quality Analytics. The entire architecture is shown in figure 12 below.

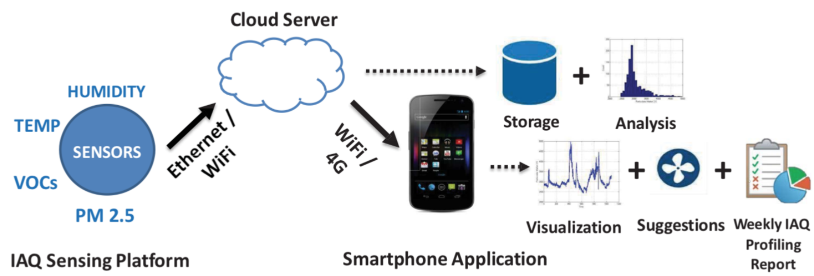

Figure 12: AirSense system architecture

Other monitoring techniques focus on Indoor Air Quality measurements and visualization, but the lack of information about the pollution sources as well as the intensity of the pollution causes ignorance of the polluted air at their homes. AirSense is able to automatically detect pollution, identify the source of the polution and estimate personal exposure to that pollution. It also provides actionable suggestion to help people improve the Indoor Air Quality.

The AirSense system architecture is composed of several components. The first one is an Indoor Air Quality sensing platform that has several sensors build in to detect parameters in the air, such as temperature, humidity, particulate matter, volatile organic compound, and more if desired. The data is collected every 5 seconds and is send to a cloud server.

The cloud server does the processing of the data and stores the results in a database and some graphs are created.

The smartphone application allows the user to view the information and get suggestions as to what parameter needs to be changed to improve the Indoor Air Quality.

The AirSense approach is directed at the Indoor Air Quality and its effects on the human health. The EnergyPlus simulation takes people, weather, and other things into considertation to determine the air flow inside a building, after which preventive steps to maintain a solid air quality can be simulated first, and performed in the real world if the simulation proves that the air quality remains stable despite other effects in the environment.

4.2. IAQX

IAQX [9] is an indoor air quality simulation software package that complements and supplements existing indoor air quality simulation programs. IAQX helps users analyze the impact of pollutant sources and sinks, ventilation, and air cleaners. It performs conventional indoor air quality simulations to calculate the pollutant concentration and/or personal exposure as a function of time. It can also estimate adequate ventilation rates based on user-provided air quality criteria. This is a unique feature useful for product stewardship and risk management.

IAQX consists of a general-purpose simulation program and a series of standalone, special-purpose programs. The general-purpose program performs multizone, multipollutant simulations and allows gas-phase chemical reactions. The four special-purpose programs contain more complex mass transfer models than the general-purpose programs, including:

- Models for predicting volatile organic compound (VOC) emissions from solvent-based indoor coating materials based on product formulation
- Models for indoor solvent spills
- A model for VOC emissions from diffusion-controlled homogeneous slabs such as new carpet backing
- A model for indoor particulate matter

The IAQX has an old user interface and the program is only available for windows. There are a lot of options to configure, but it takes some time to figure all of those out. IAQX can also analyse airflows between different zones, but it's outdated and doesn't support as much features as EnergyPlus does.

5. Conclusion

The introduction of the lower level modelling language simplifies the complexity of creating an IDF file by hand. The visual representation gives a structure, and the necessary fields are asked. However, creating a floorplan using these icons can still be tricky. Therefor, the higher level modelling language was introduced. The visual representation looks more like a floorplan of a building and is easier to use, since the vertices of each construction material do not have to be calculated by heritage guardians themselves.

Both languages are restricted by the construction materials they can use. The code generation takes care of some predefined construction materials, but it is not possible to use other construction materials or change the properties of the predefined construction materials.

In the higher level language it's only possible to create a single floor in a rectangular shape, but the lower level language supports the creation of several zones.

The higher level modelling language example contains 18 elements, which are converted into 23 elements in the lower level modelling language. The code generation generates 692 lines of code for those 23 elements.

As mentioned in the roapmap (see Figure 4), the step that converts the EnergyPlus output to input for the higher-level modelling language is not done during this study. That final step could be used to analyze the indoor air quality and assign a classification of good-average-bad, so the heritage guardians know with a single glance how the environment is affecting our cultural heritage.

5.1. Future work

Despite all the added functionality, the modelling languages do not cover all the features of EnergyPlus, since it is such a huge collection. The most basic features for analysing the flow of air in a building is covered by the modelling language. Adding more features can be seen as future work. Some ideas are mentioned below:

- A single floor can be created by the higher level modelling language, but EnergyPlus supports multiple zones.
- Other heating/cooling options exist in EnergyPlus, which can be added to both modelling languages.
- Materials are predefined in the codegeneration, but they could be made part of the modelling languages themselves.
- Constructions are also predefined with the materials. This can also be made part of the modelling language
- Every floor is surrounded by outer walls while performing the transformation between the two modelling languages, even if they are next to each other, but this can probably be improved.
- Simulation information such as the runperiod can be made part of the modelling language.
- Location information can be made part of the modelling language.
- Building information can be made part of the modelling language.
- Results of the simulation can be linked back to the higher level modelling language.

6. Appendix: Code generation result

```
! Code generated by AtomPm
  Version ,8.8;
Building ,
        GenerationByAtomPm ,        !- Name
        0.0 ,                       !- North Axis {deg}
        Country ,                   !- Terrain
        0.04 ,                      !- Loads Convergence Tolerance Value
        0.4 ,                       !- Temperature Convergence Tolerance
         Value {deltaC}
        FullInteriorAndExterior ,   !- Solar Distribution
        ,                           !- Maximum Number of Warmup Days
        6;                          !- Minimum Number of Warmup Days

!-   ===========  ALL OBJECTS IN CLASS: TIMESTEP IN HOUR ===========

  Timestep ,4;

!-   ===========  ALL OBJECTS IN CLASS: INSIDE CONVECTION ALGORITHM
   ===========

  SurfaceConvectionAlgorithm:Inside ,TARP;

!-   ===========  ALL OBJECTS IN CLASS: OUTSIDE CONVECTION ALGORITHM
   ===========

  SurfaceConvectionAlgorithm:Outside ,TARP;

!-   ===========  ALL OBJECTS IN CLASS: SOLUTION ALGORITHM ===========
```

```
  HeatBalanceAlgorithm,ConductionTransferFunction;

!-   =========== ALL OBJECTS IN CLASS: RUN CONTROL ===========

  SimulationControl,
    Yes,                          !- Do Zone Sizing Calculation
    Yes,                          !- Do System Sizing Calculation
    No,                          !- Do Plant Sizing Calculation
    Yes,                         !- Run Simulation for Sizing Periods
    No;                          !- Run Simulation for Weather File Run
        Periods

  RunPeriod,
    ,                            !- Name
    1,                           !- Begin Month
    1,                           !- Begin Day of Month
    12,                          !- End Month
    31,                          !- End Day of Month
    UseWeatherFile,              !- Day of Week for Start Day
    Yes,                         !- Use Weather File Holidays and Special
        Days
    Yes,                         !- Use Weather File Daylight Saving Period
    No,                          !- Apply Weekend Holiday Rule
    Yes,                         !- Use Weather File Rain Indicators
    Yes,                         !- Use Weather File Snow Indicators
    1;                           !- Number of Times Runperiod to be Repeated
!-   =========== ALL OBJECTS IN CLASS: LOCATION ===========

  Site:Location,
    CHICAGO_IL_USA TMY2-94846,   !- Name
```

```
    41.78000,                 !- Latitude {deg}
    -87.75000,                !- Longitude {deg}
    -6.000000,                !- Time Zone {hr}
    190.0000;                 !- Elevation {m}

!-   ===========  ALL OBJECTS IN CLASS: DESIGNDAY ===========
! CHICAGO_IL_USA Cooling (DB=>MWB) .4%, MaxDB=  32.80 MWB=  23.60

  SizingPeriod:DesignDay,
    CHICAGO_IL_USA Cooling .4% Conditions DB=>MWB,  !- Name
    7,                        !- Month
    21,                       !- Day of Month
    SummerDesignDay,          !- Day Type
    32.80000,                 !- Maximum Dry-Bulb Temperature {C}
    10.90000,                 !- Daily Dry-Bulb Temperature Range {deltaC}
    ,                         !- Dry-Bulb Temperature Range Modifier Type
    ,                         !- Dry-Bulb Temperature Range Modifier Day
       Schedule Name
    Wetbulb,                  !- Humidity Condition Type
    23.60000,                 !- Wetbulb or DewPoint at Maximum Dry-Bulb {
       C}
    ,                         !- Humidity Condition Day Schedule Name
    ,                         !- Humidity Ratio at Maximum Dry-Bulb {
       kgWater/kgDryAir}
    ,                         !- Enthalpy at Maximum Dry-Bulb {J/kg}
    ,                         !- Daily Wet-Bulb Temperature Range {deltaC}
    99063.21,                 !- Barometric Pressure {Pa}
    0.0,                      !- Wind Speed {m/s}
    0.0,                      !- Wind Direction {deg}
    No,                       !- Rain Indicator
```

```
    No,                      !- Snow Indicator
    No,                      !- Daylight Saving Time Indicator
    ASHRAEClearSky,          !- Solar Model Indicator
    ,                        !- Beam Solar Day Schedule Name
    ,                        !- Diffuse Solar Day Schedule Name
    ,                        !- ASHRAE Clear Sky Optical Depth for Beam Irradiance (taub) {dimensionless}
    ,                        !- ASHRAE Clear Sky Optical Depth for Diffuse Irradiance (taud) {dimensionless}
    1.000000;                !- Sky Clearness

! CHICAGO_IL_USA Heating 99.6%, MaxDB= -21.20 Wind Speed=   4.60 Wind Dir= 270.00

  SizingPeriod:DesignDay,
    CHICAGO_IL_USA Heating 99.6% Conditions,  !- Name
    1,                       !- Month
    21,                      !- Day of Month
    WinterDesignDay,         !- Day Type
    -21.20000,               !- Maximum Dry-Bulb Temperature {C}
    0.0,                     !- Daily Dry-Bulb Temperature Range {deltaC}
    ,                        !- Dry-Bulb Temperature Range Modifier Type
    ,                        !- Dry-Bulb Temperature Range Modifier Day Schedule Name
    Wetbulb,                 !- Humidity Condition Type
    -21.20000,               !- Wetbulb or DewPoint at Maximum Dry-Bulb {C}
    ,                        !- Humidity Condition Day Schedule Name
    ,                        !- Humidity Ratio at Maximum Dry-Bulb {kgWater/kgDryAir}
```

```
    ,                          !- Enthalpy at Maximum Dry-Bulb {J/kg}
    ,                          !- Daily Wet-Bulb Temperature Range {deltaC}
    99063.21,                  !- Barometric Pressure {Pa}
    4.600000,                  !- Wind Speed {m/s}
    270.0000,                  !- Wind Direction {deg}
    No,                        !- Rain Indicator
    No,                        !- Snow Indicator
    No,                        !- Daylight Saving Time Indicator
    ASHRAEClearSky,            !- Solar Model Indicator
    ,                          !- Beam Solar Day Schedule Name
    ,                          !- Diffuse Solar Day Schedule Name
    ,                          !- ASHRAE Clear Sky Optical Depth for Beam
      Irradiance (taub) {dimensionless}
    ,                          !- ASHRAE Clear Sky Optical Depth for
      Diffuse Irradiance (taud) {dimensionless}
    0.0;                       !- Sky Clearness

!-   ===========  ALL OBJECTS IN CLASS: GROUNDTEMPERATURES ===========

  Site:GroundTemperature:BuildingSurface
     ,18.3,18.2,18.3,18.4,20.1,22.0,22.3,22.5,22.5,20.7,18.9,18.5;

  Sizing:Parameters,
    1.2,                       !- Heating Sizing Factor
    1.2;                       !- Cooling Sizing Factor

  HVACTemplate:System:Unitary,
    Zone1 Unitary,        !- Name
    Constant,                !- System Availability Schedule Name
    Zone1,           !- Control Zone or Thermostat Location Name
```

```
autosize,                    !- Supply Fan Maximum Flow Rate {m3/s}
HVACTemplate:System:UnitaryZone1 UnitaryContinuousFanSchedule,  !-
    Supply Fan Operating Mode Schedule Name
0.7,                         !- Supply Fan Total Efficiency
600,                         !- Supply Fan Delta Pressure {Pa}
0.9,                         !- Supply Fan Motor Efficiency
1,                           !- Supply Fan Motor in Air Stream Fraction
SingleSpeedDX,               !- Cooling Coil Type
,                            !- Cooling Coil Availability Schedule Name
,                            !- Cooling Design Supply Air Temperature {C}
autosize,                    !- Cooling Coil Gross Rated Total Capacity {
    W}
autosize,                    !- Cooling Coil Gross Rated Sensible Heat
    Ratio
3,                           !- Cooling Coil Gross Rated COP {W/W}
Gas,                         !- Heating Coil Type
,                            !- Heating Coil Availability Schedule Name
,                            !- Heating Design Supply Air Temperature {C}
autosize,                    !- Heating Coil Capacity {W}
0.8,                         !- Gas Heating Coil Efficiency
,                            !- Gas Heating Coil Parasitic Electric Load
    {W}
autosize,                    !- Maximum Outdoor Air Flow Rate {m3/s}
autosize,                    !- Minimum Outdoor Air Flow Rate {m3/s}
Constant,           !- Minimum Outdoor Air Schedule Name
NoEconomizer,                !- Economizer Type
NoLockout,                   !- Economizer Lockout
,                            !- Economizer Upper Temperature Limit {C}
,                            !- Economizer Lower Temperature Limit {C}
,                            !- Economizer Upper Enthalpy Limit {J/kg}
```

```
  ,                              !- Economizer Maximum Limit Dewpoint
      Temperature {C}
  ,                              !- Supply Plenum Name
  ,                              !- Return Plenum Name
  BlowThrough,                   !- Supply Fan Placement
  StayOff,                       !- Night Cycle Control
  ,                              !- Night Cycle Control Zone Name
  None,                          !- Heat Recovery Type
  0.7,                           !- Sensible Heat Recovery Effectiveness
  0.65,                          !- Latent Heat Recovery Effectiveness
  ,                              !- Dehumidification Control Type
  ,                              !- Dehumidification Setpoint {percent}
  ,                              !- Humidifier Type
  ,                              !- Humidifier Availability Schedule Name
  ,                              !- Humidifier Rated Capacity {m3/s}
  ,                              !- Humidifier Rated Electric Power {W}
  ,                              !- Humidifier Control Zone Name
  ,                              !- Humidifier Setpoint {percent}
  ,                              !- Return Fan
  ,                              !- Return Fan Total Efficiency
  ,                              !- Return Fan Delta Pressure {Pa}
  ,                              !- Return Fan Motor Efficiency
  ;                              !- Return Fan Motor in Air Stream Fraction

Schedule:Constant,HVACTemplate:System:UnitaryZone1
    UnitaryContinuousFanSchedule,Any Number,1;

HVACTemplate:Thermostat,
  Therm1,             !- Name
  HeatingSch,!- Heating Setpoint Schedule Name
```

```
  ,                          !- Constant Heating Setpoint {C}
  CoolingSch,!- Cooling Setpoint Schedule Name
  ;                          !- Constant Cooling Setpoint {C}

HVACTemplate:Zone:Unitary,
  Zone1,           !- Zone Name
  Zone1 Unitary,       !- Template Unitary System Name
  Therm1,          !- Template Thermostat Name
  autosize,                  !- Supply Air Maximum Flow Rate {m3/s}
  ,                          !- Zone Heating Sizing Factor
  ,                          !- Zone Cooling Sizing Factor
  Flow/Person,               !- Outdoor Air Method
  0.00944,                   !- Outdoor Air Flow Rate per Person {m3/s}
  0.0,                       !- Outdoor Air Flow Rate per Zone Floor Area
      {m3/s-m2}
  0.0,                       !- Outdoor Air Flow Rate per Zone {m3/s}
  ,                          !- Supply Plenum Name
  ,                          !- Return Plenum Name
  None,                      !- Baseboard Heating Type
  ,                          !- Baseboard Heating Availability Schedule
     Name
  autosize,                  !- Baseboard Heating Capacity {W}
  SystemSupplyAirTemperature,  !- Zone Cooling Design Supply Air
     Temperature Input Method
  ,                          !- Zone Cooling Design Supply Air
     Temperature {C}
  ,                          !- Zone Cooling Design Supply Air
     Temperature Difference {deltaC}
  SystemSupplyAirTemperature,  !- Zone Heating Design Supply Air
     Temperature Input Method
```

```
    ,                           !- Zone Heating Design Supply Air
        Temperature {C}
    ;                           !- Zone Heating Design Supply Air
        Temperature Difference {deltaC}

!-   ===========  ALL OBJECTS IN CLASS: MATERIAL:REGULAR ===========
  Material,
    WD10,                       !- Name
    MediumSmooth,               !- Roughness
    0.667,                      !- Thickness {m}
    0.115,                      !- Conductivity {W/m-K}
    513,                        !- Density {kg/m3}
    1381,                       !- Specific Heat {J/kg-K}
    0.9,                        !- Thermal Absorptance
    0.78,                       !- Solar Absorptance
    0.78;                       !- Visible Absorptance

  Material,
    RG01,                       !- Name
    Rough,                      !- Roughness
    1.2700000E-02,              !- Thickness {m}
    1.442000,                   !- Conductivity {W/m-K}
    881.0000,                   !- Density {kg/m3}
    1674.000,                   !- Specific Heat {J/kg-K}
    0.9000000,                  !- Thermal Absorptance
    0.6500000,                  !- Solar Absorptance
    0.6500000;                  !- Visible Absorptance

  Material,
    BR01,                       !- Name
```

```
    VeryRough,                   !- Roughness
    9.4999997E-03,               !- Thickness {m}
    0.1620000,                   !- Conductivity {W/m-K}
    1121.000,                    !- Density {kg/m3}
    1464.000,                    !- Specific Heat {J/kg-K}
    0.9000000,                   !- Thermal Absorptance
    0.7000000,                   !- Solar Absorptance
    0.7000000;                   !- Visible Absorptance

  Material,
    IN46,                        !- Name
    VeryRough,                   !- Roughness
    7.6200001E-02,               !- Thickness {m}
    2.3000000E-02,               !- Conductivity {W/m-K}
    24.00000,                    !- Density {kg/m3}
    1590.000,                    !- Specific Heat {J/kg-K}
    0.9000000,                   !- Thermal Absorptance
    0.5000000,                   !- Solar Absorptance
    0.5000000;                   !- Visible Absorptance

  Material,
    WD01,                        !- Name
    MediumSmooth,                !- Roughness
    1.9099999E-02,               !- Thickness {m}
    0.1150000,                   !- Conductivity {W/m-K}
    513.0000,                    !- Density {kg/m3}
    1381.000,                    !- Specific Heat {J/kg-K}
    0.9000000,                   !- Thermal Absorptance
    0.7800000,                   !- Solar Absorptance
    0.7800000;                   !- Visible Absorptance
```

```
Material,
  PW03,                    !- Name
  MediumSmooth,            !- Roughness
  1.2700000E-02,           !- Thickness {m}
  0.1150000,               !- Conductivity {W/m-K}
  545.0000,                !- Density {kg/m3}
  1213.000,                !- Specific Heat {J/kg-K}
  0.9000000,               !- Thermal Absorptance
  0.7800000,               !- Solar Absorptance
  0.7800000;               !- Visible Absorptance

Material,
  IN02,                    !- Name
  Rough,                   !- Roughness
  9.0099998E-02,           !- Thickness {m}
  4.3000001E-02,           !- Conductivity {W/m-K}
  10.00000,                !- Density {kg/m3}
  837.0000,                !- Specific Heat {J/kg-K}
  0.9000000,               !- Thermal Absorptance
  0.7500000,               !- Solar Absorptance
  0.7500000;               !- Visible Absorptance

Material,
  GP01,                    !- Name
  MediumSmooth,            !- Roughness
  1.2700000E-02,           !- Thickness {m}
  0.1600000,               !- Conductivity {W/m-K}
  801.0000,                !- Density {kg/m3}
  837.0000,                !- Specific Heat {J/kg-K}
```

```
    0.9000000,                    !- Thermal Absorptance
    0.7500000,                    !- Solar Absorptance
    0.7500000;                    !- Visible Absorptance

  Material,
    GP02,                         !- Name
    MediumSmooth,                 !- Roughness
    1.5900001E-02,                !- Thickness {m}
    0.1600000,                    !- Conductivity {W/m-K}
    801.0000,                     !- Density {kg/m3}
    837.0000,                     !- Specific Heat {J/kg-K}
    0.9000000,                    !- Thermal Absorptance
    0.7500000,                    !- Solar Absorptance
    0.7500000;                    !- Visible Absorptance

  Material,
    CC03,                         !- Name
    MediumRough,                  !- Roughness
    0.1016000,                    !- Thickness {m}
    1.310000,                     !- Conductivity {W/m-K}
    2243.000,                     !- Density {kg/m3}
    837.0000,                     !- Specific Heat {J/kg-K}
    0.9000000,                    !- Thermal Absorptance
    0.6500000,                    !- Solar Absorptance
    0.6500000;                    !- Visible Absorptance

  Material:NoMass,
    CP01,                         !- Name
    Rough,                        !- Roughness
    0.3670000,                    !- Thermal Resistance {m2-K/W}
```

```
  0.9000000,                   !- Thermal Absorptance
  0.7500000,                   !- Solar Absorptance
  0.7500000;                   !- Visible Absorptance

Material:NoMass,
  MAT-SB-U,                    !- Name
  Rough,                       !- Roughness
  0.117406666,                 !- Thermal Resistance {m2-K/W}
  0.65,                        !- Thermal Absorptance
  0.65,                        !- Solar Absorptance
  0.65;                        !- Visible Absorptance

Material:NoMass,
  MAT-CLNG-1,                  !- Name
  Rough,                       !- Roughness
  0.652259290,                 !- Thermal Resistance {m2-K/W}
  0.65,                        !- Thermal Absorptance
  0.65,                        !- Solar Absorptance
  0.65;                        !- Visible Absorptance

Material:NoMass,
  MAT-FLOOR-1,                 !- Name
  Rough,                       !- Roughness
  3.522199631,                 !- Thermal Resistance {m2-K/W}
  0.65,                        !- Thermal Absorptance
  0.65,                        !- Solar Absorptance
  0.65;                        !- Visible Absorptance

Material:AirGap,
  AL21,                        !- Name
```

```
    0.1570000;                  !- Thermal Resistance {m2-K/W}

  Material:AirGap,
    AL23,                       !- Name
    0.1530000;                  !- Thermal Resistance {m2-K/W}

!-   ===========  ALL OBJECTS IN CLASS: WINDOWMATERIAL ===========

  WindowMaterial:Glazing,
    CLEAR 3MM,                  !- Name
    SpectralAverage,            !- Optical Data Type
    ,                           !- Window Glass Spectral Data Set Name
    0.003,                      !- Thickness {m}
    0.837,                      !- Solar Transmittance at Normal Incidence
    0.075,                      !- Front Side Solar Reflectance at Normal
       Incidence
    0.075,                      !- Back Side Solar Reflectance at Normal
       Incidence
    0.898,                      !- Visible Transmittance at Normal Incidence
    0.081,                      !- Front Side Visible Reflectance at Normal
       Incidence
    0.081,                      !- Back Side Visible Reflectance at Normal
       Incidence
    0.0,                        !- Infrared Transmittance at Normal
       Incidence
    0.84,                       !- Front Side Infrared Hemispherical
       Emissivity
    0.84,                       !- Back Side Infrared Hemispherical
       Emissivity
    0.9;                        !- Conductivity {W/m-K}
```

```
WindowMaterial:Glazing,
  GREY 3MM,                   !- Name
  SpectralAverage,            !- Optical Data Type
  ,                           !- Window Glass Spectral Data Set Name
  0.003,                      !- Thickness {m}
  0.626,                      !- Solar Transmittance at Normal Incidence
  0.061,                      !- Front Side Solar Reflectance at Normal
      Incidence
  0.061,                      !- Back Side Solar Reflectance at Normal
      Incidence
  0.611,                      !- Visible Transmittance at Normal Incidence
  0.061,                      !- Front Side Visible Reflectance at Normal
      Incidence
  0.061,                      !- Back Side Visible Reflectance at Normal
      Incidence
  0.0,                        !- Infrared Transmittance at Normal
      Incidence
  0.84,                       !- Front Side Infrared Hemispherical
      Emissivity
  0.84,                       !- Back Side Infrared Hemispherical
      Emissivity
  0.9;                        !- Conductivity {W/m-K}

WindowMaterial:Glazing,
  CLEAR 6MM,                  !- Name
  SpectralAverage,            !- Optical Data Type
  ,                           !- Window Glass Spectral Data Set Name
  0.006,                      !- Thickness {m}
  0.775,                      !- Solar Transmittance at Normal Incidence
```

```
  0.071,                  !- Front Side Solar Reflectance at Normal
      Incidence
  0.071,                  !- Back Side Solar Reflectance at Normal
      Incidence
  0.881,                  !- Visible Transmittance at Normal Incidence
  0.080,                  !- Front Side Visible Reflectance at Normal
      Incidence
  0.080,                  !- Back Side Visible Reflectance at Normal
      Incidence
  0.0,                    !- Infrared Transmittance at Normal
      Incidence
  0.84,                   !- Front Side Infrared Hemispherical
      Emissivity
  0.84,                   !- Back Side Infrared Hemispherical
      Emissivity
  0.9;                    !- Conductivity {W/m-K}

WindowMaterial:Glazing,
  LoE CLEAR 6MM,          !- Name
  SpectralAverage,        !- Optical Data Type
  ,                       !- Window Glass Spectral Data Set Name
  0.006,                  !- Thickness {m}
  0.600,                  !- Solar Transmittance at Normal Incidence
  0.170,                  !- Front Side Solar Reflectance at Normal
      Incidence
  0.220,                  !- Back Side Solar Reflectance at Normal
      Incidence
  0.840,                  !- Visible Transmittance at Normal Incidence
  0.055,                  !- Front Side Visible Reflectance at Normal
      Incidence
```

```
    0.078,                    !- Back Side Visible Reflectance at Normal
       Incidence
    0.0,                      !- Infrared Transmittance at Normal
       Incidence
    0.84,                     !- Front Side Infrared Hemispherical
       Emissivity
    0.10,                     !- Back Side Infrared Hemispherical
       Emissivity
    0.9;                      !- Conductivity {W/m-K}

  WindowMaterial:Gas,
    AIR 6MM,                  !- Name
    Air,                      !- Gas Type
    0.0063;                   !- Thickness {m}

  WindowMaterial:Gas,
    AIR 13MM,                 !- Name
    Air,                      !- Gas Type
    0.0127;                   !- Thickness {m}

  WindowMaterial:Gas,
    ARGON 13MM,               !- Name
    Argon,                    !- Gas Type
    0.0127;                   !- Thickness {m}

!-   ===========  ALL OBJECTS IN CLASS: CONSTRUCTION ===========

  Construction,
    ROOF-1,                   !- Name
    RG01,                     !- Outside Layer
```

```
  BR01,                    !- Layer 2
  IN46,                    !- Layer 3
  WD01;                    !- Layer 4

Construction,
  WALL-1,                  !- Name
  WD01,                    !- Outside Layer
  PW03,                    !- Layer 2
  IN02,                    !- Layer 3
  GP01;                    !- Layer 4

Construction,
  CLNG-1,                  !- Name
  MAT-CLNG-1;              !- Outside Layer

Construction,
  FLOOR-SLAB-1,            !- Name
  CC03;                    !- Outside Layer

Construction,
  INT-WALL-1,              !- Name
  GP02,                    !- Outside Layer
  AL21,                    !- Layer 2
  GP02;                    !- Layer 3

Construction,
  Double LoE Clear Argon,  !- Name
  LoE CLEAR 6MM,           !- Outside Layer
  ARGON 13MM,              !- Layer 2
  CLEAR 6MM;               !- Layer 3
```

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

  Zone,
    Zone1,                   !- Name
    0,                       !- Direction of Relative North {deg}
    0,                       !- X Origin {m}
    0,                       !- Y Origin {m}
    0,                       !- Z Origin {m}
    1,                       !- Type
    1,                       !- Multiplier
    2.7,                     !- Ceiling Height {m}
    24.3;                    !- Volume {m3}

!-   ===========  ALL OBJECTS IN CLASS: SURFACEGEOMETRY ===========

  GlobalGeometryRules,
    UpperLeftCorner,         !- Starting Vertex Position
    Counterclockwise,        !- Vertex Entry Direction
    WorldCoordinateSystem;   !- Coordinate System

!-   ===========  ALL OBJECTS IN CLASS: SURFACE ===========
  BuildingSurface:Detailed,
    Wall1,                   !- Name
    Wall,                    !- Surface Type
    WALL-1,                  !- Construction Name
    Zone1,                   !- Zone Name
    Outdoors,                !- Outside Boundary Condition
    ,                        !- Outside Boundary Condition Object
    SunExposed,              !- Sun Exposure
```

```
  WindExposed,                  !- Wind Exposure
  0.50000,                      !- View Factor to Ground
  4,                            !- Number of Vertices
  0,0,0,   !- X,Y,Z ==> Vertex 1 {m}
  3,0,0,   !- X,Y,Z ==> Vertex 2 {m}
  3,0,2.7,   !- X,Y,Z ==> Vertex 3 {m}
  0,0,2.7;   !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  Wall2,                          !- Name
  Wall,                         !- Surface Type
  WALL-1,                          !- Construction Name
  Zone1,            !- Zone Name
  Outdoors,                     !- Outside Boundary Condition
  ,                             !- Outside Boundary Condition Object
  SunExposed,                   !- Sun Exposure
  WindExposed,                  !- Wind Exposure
  0.50000,                      !- View Factor to Ground
  4,                            !- Number of Vertices
  3,0,0,   !- X,Y,Z ==> Vertex 1 {m}
  3,3,0,   !- X,Y,Z ==> Vertex 2 {m}
  3,3,2.7,   !- X,Y,Z ==> Vertex 3 {m}
  3,0,2.7;   !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  Wall3,                          !- Name
  Wall,                         !- Surface Type
  WALL-1,                          !- Construction Name
  Zone1,            !- Zone Name
  Outdoors,                     !- Outside Boundary Condition
```

```
  ,                          !- Outside Boundary Condition Object
  SunExposed,                !- Sun Exposure
  WindExposed,               !- Wind Exposure
  0.50000,                   !- View Factor to Ground
  4,                         !- Number of Vertices
  3,3,0,  !- X,Y,Z ==> Vertex 1 {m}
  0,3,0,  !- X,Y,Z ==> Vertex 2 {m}
  0,3,2.7,  !- X,Y,Z ==> Vertex 3 {m}
  3,3,2.7;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  Wall4,                      !- Name
  Wall,                      !- Surface Type
  WALL-1,                      !- Construction Name
  Zone1,             !- Zone Name
  Outdoors,                  !- Outside Boundary Condition
  ,                          !- Outside Boundary Condition Object
  SunExposed,                !- Sun Exposure
  WindExposed,               !- Wind Exposure
  0.50000,                   !- View Factor to Ground
  4,                         !- Number of Vertices
  0,3,0,  !- X,Y,Z ==> Vertex 1 {m}
  0,0,0,  !- X,Y,Z ==> Vertex 2 {m}
  0,0,2.7,  !- X,Y,Z ==> Vertex 3 {m}
  0,3,2.7;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  Floor,                      !- Name
  Floor,                     !- Surface Type
  FLOOR-SLAB-1,              !- Construction Name
```

```
  Zone1,          !- Zone Name
  Ground,                    !- Outside Boundary Condition
  ,                          !- Outside Boundary Condition Object
  NoSun,                     !- Sun Exposure
  NoWind,                    !- Wind Exposure
  0.0,                       !- View Factor to Ground
  4,                         !- Number of Vertices
  0,0,0,  !- X,Y,Z ==> Vertex 1 {m}
  3,0,0,  !- X,Y,Z ==> Vertex 2 {m}
  3,3,0,  !- X,Y,Z ==> Vertex 3 {m}
  0,3,0;  !- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed,
  Roof,                      !- Name
  Ceiling,                   !- Surface Type
  CLNG-1,                    !- Construction Name
  Zone1,          !- Zone Name
  Outdoors,                   !- Outside Boundary Condition
  ,                     !- Outside Boundary Condition Object
  NoSun,                     !- Sun Exposure
  NoWind,                    !- Wind Exposure
  0.0,                       !- View Factor to Ground
  4,                         !- Number of Vertices
  0,0,2.7,  !- X,Y,Z ==> Vertex 1 {m}
  3,0,2.7,  !- X,Y,Z ==> Vertex 2 {m}
  3,3,2.7,  !- X,Y,Z ==> Vertex 3 {m}
  0,3,2.7;  !- X,Y,Z ==> Vertex 4 {m}

ScheduleTypeLimits,
  Any Number;                !- Name
```

```
ScheduleTypeLimits,
  Fraction,              !- Name
  0.0,                   !- Lower Limit Value
  1.0,                   !- Upper Limit Value
  Continuous;            !- Numeric Type

ScheduleTypeLimits,
  Temperature,           !- Name
  -60,                   !- Lower Limit Value
  200,                   !- Upper Limit Value
  Continuous;            !- Numeric Type

ScheduleTypeLimits,
  On/Off,                !- Name
  0,                     !- Lower Limit Value
  1,                     !- Upper Limit Value
  Discrete;              !- Numeric Type

Schedule:Compact,
  Constant,              !- Name
  on/off,                !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
  For: AllDays,          !- Field 2
  Until: 24:00,1.0;      !- Field 3

Schedule:Compact,
  ActSchd,               !- Name
  Any Number,            !- Schedule Type Limits Name
  Through: 12/31,        !- Field 1
```

```
  For: AllDays,              !- Field 2
  Until: 24:00,117.239997864; !- Field 3

Schedule:Compact,
  CoolingSch,        !- Name
  Temperature,               !- Schedule Type Limits Name
  Through: 12/31,            !- Field 1
  For: Weekdays, !- Field
  Until: 24:00,24.0,          !- Field
  For: AllOtherDays, !- Field
  Until: 24:00,23.0;          !- Field

Schedule:Compact,
  HeatingSch,        !- Name
  Temperature,               !- Schedule Type Limits Name
  Through: 12/31,            !- Field 1
  For: AllDays, !- Field
  Until: 06:00,18.8,          !- Field
  Until: 24:00,21.1;          !- Field

Schedule:Compact,
  PeopleSch,        !- Name
  Fraction,                  !- Schedule Type Limits Name
  Through: 12/31,            !- Field 1
  For: AllDays, !- Field
  Until: 08:00,0.0,          !- Field
  Until: 17:00,0.95,          !- Field
  Until: 24:00,0.1;          !- Field

People,
```

```
  People1,!- Name
  Zone1,           !- Zone or ZoneList Name
  PeopleSch,        !- Number of People Schedule Name
  People,                  !- Number of People Calculation Method
  11,                      !- Number of People
  ,                        !- People per Zone Floor Area {person/m2}
  ,                        !- Zone Floor Area per Person {m2/person}
  0.3,                     !- Fraction Radiant
  ,                        !- Sensible Heat Fraction
  ActSchd;                 !- Activity Level Schedule Name

Output:Variable,*,Unitary System Fan Part Load Ratio,Hourly;

Output:Variable,*,Cooling Coil Runtime Fraction,Hourly;

Output:Variable,*,Heating Coil Runtime Fraction,Hourly;

Output:Variable,*,Zone Air Temperature,Hourly;

Output:Variable,*,Zone Air System Sensible Cooling Rate,Hourly;

Output:Variable,*,Zone Air System Sensible Heating Rate,Hourly;

Output:Variable,*,Zone People Occupant Count,Hourly;

Output:Surfaces:Drawing,dxf;

OutputControl:Table:Style,
  HTML;                    !- Column Separator
```

```
Output:Table:SummaryReports,
  ABUPS;                         !- Report 1 Name
```

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