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# LINKING THE COMIS MULTI-ZONE AIRFLOW MODEL WITH THE ENERGYPLUS BUILDING ENERGY SIMULATION PROGRAM

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## ABSTRACT

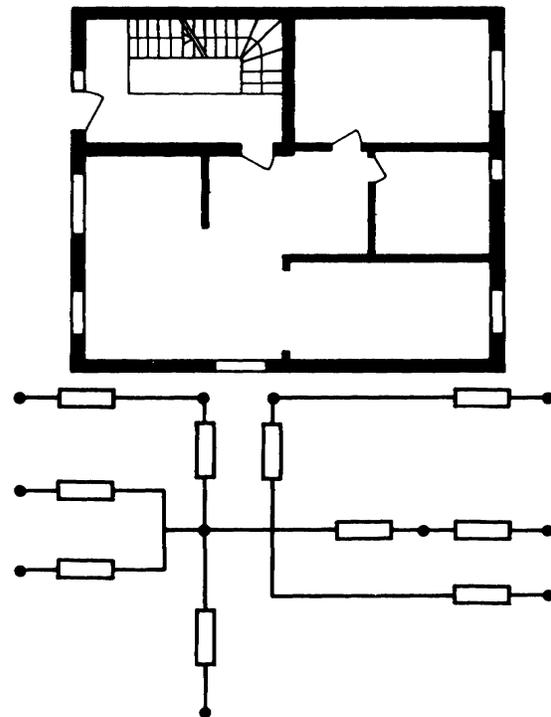
This paper describes an effort to link the COMIS 3.0 multi-zone airflow model with the EnergyPlus building energy simulation program. COMIS 3.0 is a network-based multi-zone airflow model developed by a multinational team in the framework of International Energy Agency's Annex 23 for simulating airflows through the building fabric due to infiltration or natural ventilation, and from zone to zone, as well as the interactions of the HVAC system, ducts, and exhaust hoods and fans. EnergyPlus is a new whole-building energy simulation program being developed for the United States Department of Energy that combines the best features of the DOE-2 and IBLAST programs. The EnergyPlus program is modular in structure, and uses the heat balance technique to simulate building thermal loads. The EnergyPlus program calls COMIS from the Air Heat Balance Manager module and passes to COMIS the ambient weather conditions and zone air temperatures from the previous time step. COMIS uses these as boundary conditions to calculate the airflows, which are used by EnergyPlus in the subsequent heat balance simulation. The paper will describe how this linkage was implemented and discuss issues such as convergence, time steps, program run time, and alternate solution methods.

## INTRODUCTION

In the last ten years, significant advances have been made in the development of airflow models that can simulate interzone airflows and pollution transport in both single- and multi-zone buildings (Feustel 1998, Walton 1994). COMIS 3.0 is one such program that was developed in the framework of International Energy Agency (IEA) Annex 23, starting in 1990 and officially finishing in 1997.

Multi-zone airflow models such as COMIS represent a major improvement over previous single-zone infiltration models, permitting the modeling of

airflows within a building as well as through the building fabric from the outside. The airflows are modeled using a network of air-mass flow paths, with joints representing the zones of a building, and connections between joints representing airflow paths. The paths include the flow resistances caused by open or closed doors and windows as well as air leakage through walls (see Figure 1) (Feustel 1999).



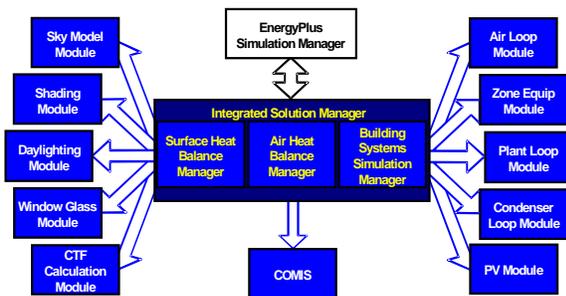
**Figure 1.** Floor plan of a simple building and its representation in a two-dimensional nodal network (fr. Feustel 1990)

The boundary conditions for pressure distribution in the building can be described by grid points outside the building, or outside zones. The inputs needed for COMIS are the flow coefficients ( $C_s$ ) and exponents for cracks and closed windows and doors, the height

and width of opened windows and doors, the physical dimensions of the building zones and their linkages to each other and the outside, the pressure coefficients ( $C_p$ ) on the exterior facades, and the ambient air temperature, wind speed and direction, humidity, and barometric pressure. Although COMIS calculates the impact of temperature on airflows, e.g., stack-driven ventilation, it does not simulate the thermal conditions of the spaces but requires zone temperatures as input parameters.

To take full advantage of its capabilities to model airflows, COMIS should be linked with a building thermal program that can model the thermal conditions within a building and pass to COMIS the indoor zone temperatures. COMIS in turn can improve the thermal modeling by returning to the thermal program the calculated airflows from the outside and zone to zone. In this paper, we describe the linkage of COMIS to EnergyPlus, a new building energy simulation program currently being developed jointly by the University of Illinois Building Systems Laboratory and Lawrence Berkeley National Laboratory with support from the U.S. Department of Energy (USDOE).

Starting in 1995, USDOE has been supporting the development of EnergyPlus with the goal of combining the best features and capabilities of the two major existing public-domain simulation programs, IBLAST and DOE-2. The general features of this new program has been described in other papers (Pedersen et al. 1997, Crawley et al. 1999). A separate paper at this conference summarizes the simulation methodology and improved calculations used in EnergyPlus (Strand et al. 1999). In addition to improved simulation algorithms, an equally important objective in the design of EnergyPlus is to maintain maximum modularity and clarity in the computer code to permit easy extensibility through the use of modules. For example, the linkage to the COMIS multi-zone airflow model occurs entirely in the Air Heat Balance Manager module (see Figure 2).



**Figure 2.** Heat Balance Modules in EnergyPlus

## APPROACH

There are four possible approaches to couple an airflow model with a thermal simulation model. The first is sequential coupling, where the thermal model is run and the output history of zone temperatures used as inputs to the airflow model. The second approach is “ping-pong coupling”, where the outputs from the thermal model are passed to the airflow model at each time step, which in turn returns its outputs to the thermal model for use in the subsequent time-step. The third approach is an elaboration of the previous one, where iterative calculations are done between the two models until some criteria of convergence is achieved. The fourth approach is to actually couple the algorithms of both models and simultaneously solve the expanded matrix.

The first approach is the simplest but of questionable accuracy due to the lack of any feedback between the two models. This problem is partially addressed in the second approach, where the feedback is lagged by one time step. The feedback is improved in the third approach, but our experience with iterative solutions is that they’re cumbersome, slow, and susceptible to stability problems. The fourth method, while ideal from a theoretical point of view, would require a tremendous amount of work and likely produce complex matrices beyond the capabilities of current mathematical solvers. In essence, this would require embedding the COMIS solver into the basic heat balance solution of EnergyPlus.

The working approach chosen in this project is the second one of a single “ping-pong” between the EnergyPlus thermal and the COMIS airflow models. Such an implementation fits well into the modular structure of EnergyPlus, in which the link to COMIS occurs entirely within the Air Heat Balance Manager module. Since EnergyPlus permits user-defined simulation time steps, the issues of feedback and convergence can be addressed by selecting an appropriate time step for a particular problem. The effect of different time steps on the solution results for a sample 3-zone problem are discussed later in this paper.

In principle, the EnergyPlus-COMIS link is achieved by converting COMIS to a subroutine that is called within the Air Heat Balance Manager module in EnergyPlus. Meanwhile, the Air Heat Balance Manager module has to prepare and pass to COMIS input information on the building, window operations, weather conditions and zone air temperatures from the previous time step. COMIS uses these to calculate airflows from the outside

through infiltration and ventilation, and inter-zone airflows, that are returned to the Air Heat Balance Manager module to be used in the subsequent heat balance simulation in EnergyPlus.

Although there are several enhanced versions of COMIS with graphical interfaces, in this application we have used the basic 3.0 version of the program written in Fortran-77 with text-based inputs and outputs. The input file (DEFAULT.CIF) can be either totally self-contained with all input information necessary for a COMIS calculation, as in a steady-state calculation with static conditions, or can refer to user-defined external files with time-varying data in the case of a dynamic simulation. For example, a COMIS simulation for a three-zone building can read from four files for the outdoor air conditions, and the indoor conditions (temperature, humidity, and pressure) in each of the three zones. The data in the output file (DEFAULT.COF) are specified in the input and can include building and zone-level temperatures, airflows, pressures, and pollution concentrations.

The implementation of the EnergyPlus/COMIS link will proceed in three stages related to data transfer efficiency, not the underlying computation. For the initial “proof-of-concept”, we made the minimum changes necessary for the two programs to interact with each other. We wrote a COMIS DEFAULT.CIF file that was consistent with a corresponding EnergyPlus test input file, and modified the Air Heat Balance Manager module in EnergyPlus so that it would write the time-varying input parameters (ambient and zone air conditions) to small ASCII files just prior to calling COMIS. After the COMIS run, the modified Air Heat Balance Manager would read the airflow rates from the COMIS output file (DEFAULT.COF) and incorporate them into the air heat balance solution. This rudimentary link is very inefficient from computational point of view, since it makes COMIS read the same input over and over again. However, the link performs the correct calculation and allows us to study and fine-tune the link before expending the effort to make a more efficient data transfer mechanism. The linkage details described in this paper refer to this initial “proof-of-concept” implementation.

Once this preliminary linkage has been shown to work satisfactorily, we will first use the standard EnergyPlus input procedure to generate the DEFAULT.CIF input file, which then becomes an internal file to the program. Then, we will modify the COMIS program to eliminate its input/output procedure and allow it to exchange data directly with

EnergyPlus rather than through external files. This work is expected to be done by September 1999.

### COMIS INPUTS

To simulate multi-zone airflow, COMIS requires the following inputs at the minimum:

Crack airflow element Flow coefficient (Cs) Flow exponent (n)
Window or door airflow element Flow coefficient for closed windows (Cs) Flow exponent (n) Type of large vertical opening Width Height Schedule for window/door opening and closing
Zone Reference Height Volume Temperature* Humidity*
Link Element name Zone from-to Height from-to
Facade Element Element number Relative horizontal position Relative vertical position
Pressure Coefficient (Cp) Facade element number Cp value by wind direction
Meteorological Data Temperature * Humidity * Wind speed * Wind direction * Barometric pressure *

In the initial implementation, the time-invariant inputs (those without asterisks) are written manually to a DEFAULT.CIF file. Figure 3 shows a test DEFAULT.CIF file for the 3-zone building. In the Stage Two implementation, the DEFAULT.CIF file will be generated automatically by the Air Heat Balance Manager. Most of the inputs related to building geometry can be extracted from the existing EnergyPlus building descriptions. Others, such as the flow coefficients and exponents, can be added to the Input Data Dictionary (IDD) of EnergyPlus in a straightforward manner. The most complicated inputs are the Pressure Coefficients (Cp) that need to be entered for each façade element by different wind directions. COMIS 3.0 has a routine that calculates

```

&-CIF 1
3ZOSTTEST.CIF
&-PR-IDENTification 2
  Test 3-zone file modified to conform to EnergyPlus
  test file with 3 zones of equal size (3.048 x 6.096 x 6.096),
  with a window in the first zone.
&-PR-OUTPut options 3
VENTilation
NO HEATflow
NO POLLutant
PZ-S 1
PZ-P 1
# WP (Wind Pressure) is now PE (Pressure External)
#PE-S 1,2,3,4
#PE-P 1,2,3,4
PE-S 1
PE-P 1
STARTtime 1999jan01_00:00
STOPTime 1999jan01_00:00
&-PR-CONTROL parameters 4 --- OPTIONAL DATASECTION ---
  1. 1.E-06 1.E-05 0. 1 1.E-12
  0 0 5 50
&-NET-AIR flow components
# Allowed prefixes are: *CR *FA *DS *DF *F1 *F2 *F3 *F4 *WI *TD
# fan duct-fitting window(openable)
# keep the KEYWORDS &-CR,...,&-TD in this part &-NET-AIR
&-CR CRACK
*CR-1
0.0057 0.6666 0.
*CR-2
0.0108 0.6666 0.
*CR-3
0.0065 0.6666 0.
&-WI WINDOW
*WI-1
0.002 0.57 1 5.0 2.0 0.0
0.0 0.6 0.0 1.0 0.0
1.0 0.6 1.0 1.0 0.0
0
&-SCH-TEMPerature schedule 00 --- OPTIONAL DATASECTION ---
F:T1 Zone1T.Dat
&-SCH-TEMPerature schedule 00 --- OPTIONAL DATASECTION ---
F:T2 Zone2T.Dat
&-SCH-TEMPerature schedule 00 --- OPTIONAL DATASECTION ---
F:T3 Zone3T.Dat
&-NET-ZONes 18
  1 zone1 20. 0. 113.27 0. T1
  2 zone2 20. 0. 113.27 0. T2
  3 zone3 20. 0. 113.27 0. T3
&-NET-EXTERNAL node data 21 --- OPTIONAL DATASECTION ---
  1 1 0.
&-NET-LINKs 22
  1 CR-1 3 -1 0 0 1.0 1
  2 CR-2 1 3 0 0 1.0 1
  3 CR-2 1 2 0 0 1.0 1
  4 CR-3 2 -1 0 0. 1.0 1
  5 CR-3 1 -1 0 0 1.0 1
  6 WI-1 1 -1 0 0 1.0 1
&-CP-VALUes 33 --- OPTIONAL DATASECTION ---
  AIVC_6.2.4
  * 0.
  1 1.
&-SCH-METeo data 36 --- OPTIONAL DATASECTION ---
F:Weath.Dat COMIS

```

Figure 3. Sample DEFAULT.CIF input file for test 3-zone building

Pressure Coefficients, but it is limited to block-shaped buildings in certain prescribed urban environments. We will probably include this routine only as an optional input method in the EnergyPlus/COMIS link.

The time-varying inputs marked with asterisks are read from external files that are updated by the Air Heat Balance Manager before each call to COMIS. These appear in Figure 3 as WEATH.DAT, ZONE1T.DAT, ZONE2T.DAT, ZONE3T.DAT, ZONE1H.DAT, ZONE2H.DAT, and ZONE3H.DAT. Each file contains a single line with the current, i.e., previous time-step's, temperature and/or humidity ratio.

### ENERGYPLUS AIR HEAT BALANCE MANAGER

The EnergyPlus program is being developed jointly by the Building System Laboratory at the University of Illinois Champaign/Urbana, the Construction Engineering Research Laboratory, and the Simulation Research Group at Lawrence Berkeley National Laboratory, with support provided by the U.S. Department of Energy. The strategic plan for the program was developed in 1996, and actual software development began in mid-1997. By early 1999, an alpha version of the program has been completed that can simulate a multi-zone building and a limited number of HVAC system types. The air heat balance portion of the program was essentially completed in mid-1998.

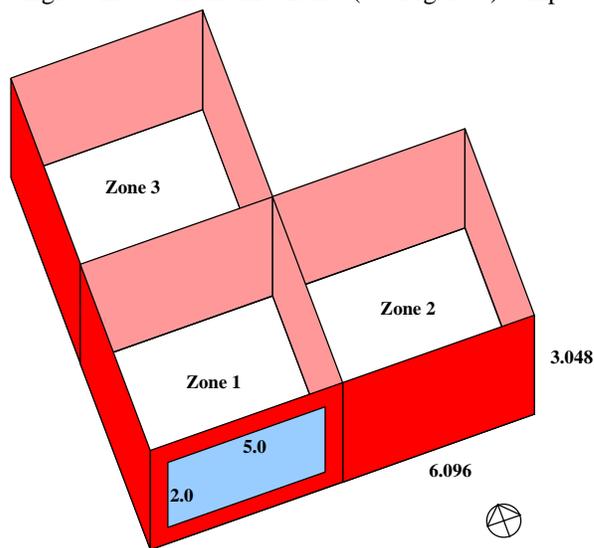
EnergyPlus is written in Fortran 90 using an object-oriented structure that makes extensive use of modules. The link to COMIS occurs in the Air Heat Balance Manager, a module that forms part of the Integrated Solution Manager linking together various modules of the program (see Figure 2). The function of the Air Heat Balance Manager, as implied by its name, is to keep track of the heat balance of the zone air including convection from the inside surfaces and internal sources, HVAC system air, exhaust air, and airflow due to infiltration and ventilation. The original version of the Air Heat Balance Manager has legacy code from the IBLAST program that includes a simple infiltration model based on temperature difference and wind speed, and scheduled mixing and cross-mixing between thermal zones.

For the COMIS link, the nomenclature of infiltration and cross-mixing are left unchanged, but the airflow rates are obtained by a call to COMIS. In the initial "proof-of-concept" implementation, a pre-processor

has been added to the Air Heat Balance Manager that reads the existing, i.e., previous time step's, zone air temperatures, current outdoor conditions, and writes them to small temporary files. After COMIS is called, the modified Air Heat Balance Manager parses the DEFAULT.COF file and uses the computed heat flows in the subsequent infiltration and cross-mixing calculations.

### TEST RUN

The test run used to investigate the initial implement is a simple one-story building with three zones and a single window in the first zone (see Figure 4). Input



**Figure 4.** Test 3-zone building modeled in EnergyPlus/COMIS

files were developed for both EnergyPlus and COMIS following the procedure just described. The DEFAULT.CIF file is shown in Figure 3.

Simulations were done using Chicago weather data for two 10-day periods, one in the winter (January 1 - 10) and the other in the summer (July 1 - 10), under two conditions : (1) window closed at all hours, i.e., with only infiltration, and (2) window opened for one hour during the middle of the day. The final draft of this paper will show how the results differ as a function of the calculation time step, and the computational time of the EnergyPlus heat balance solution, i.e., floating temperature calculation with no HVAC system, with and without the COMIS link. Based on these results, the authors will present their observations on the performance of the single "ping-pong" link, the needed time step size for different building conditions, recommended changes in the linkage solutions, and the usability of the proposed

EnergyPlus/COMIS link for general engineering applications.

## REFERENCES

Crawley, D., L. Lawrie, C. Pedersen, R. Liesen, D. Fisher, R. Strand, R. Taylor, F. Winkelmann, F. Buhl, E. Erdem, and J. Huang 1999. "EnergyPlus: A New-Generation Building Energy Simulation Program", Building Simulation '99, The International Building Performance Simulation Association, Kyoto.

Feustel, H. 1998. "COMIS - An International Multizone Airflow and Contaminant Transport Model", LBNL-42182, Lawrence Berkeley National Laboratory, Berkeley CA.

Pedersen, C., D. Fisher, R. Liesen, R. Strand, R. Taylor, F. Buhl, F. Winkelmann, L. Lawrie, and D. Crawley. 1997. "Energybase : the Merger of BLAST and DOE-2", Building Simulation '97, The International Building Performance Simulation Association, Prague.

Strand, R., C. Pedersen, D. Fisher, R. Liesen, R. Taylor, F. Winkelmann, F. Buhl, J. Huang, D. Crawley, and L. Lawrie 1999. "Enhancing and Extending the Capabilities of the Building Heat Balance Simulation Technique", Building Simulation '99, The International Building Performance Simulation Association, Kyoto.

Walton, G.N. 1989. "AIRNET - A Computer Program for Building Airflow Network Modeling", U.S. Department of Commerce, National Institute of Standards and Technology, Gaithersburg MD.