

EnergyPlus Programming Standard

(to understand and be able to write the code)

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Introduction

EnergyPlus is a building simulation program written in a modular fashion using the Fortran 90 programming language. Most programs have progenitors: EnergyPlus is no exception. It is built upon the DOE-2 and iBLAST building simulation programs. Both of these programs were written in Fortran 77 without any consistent style or structure. Consequently, both programs had become difficult to understand, maintain and extend.

The EnergyPlus Programming Standard is intended to be a coding guideline for EnergyPlus software developers. The rules and standards described in this document are intended to impose a consistent structure and style on all code written for EnergyPlus. This consistency should aid all present and future developers in understanding, maintaining, and adding to EnergyPlus.

All Fortran code will be separated from text and formatted using the following notation to distinguish it from other information:

```
SUBROUTINE ReportZoneConditions      ! EnergyPlus Subroutine
INTEGER ZoneNum
DO ZoneNum=1,MaxNumZones
```

Reference Documents

This document is one of a set of documents for the EnergyPlus developer. It describes the programming standards for EnergyPlus source code and shall be followed by all developers (whether funded directly from the EnergyPlus funding or collaborative developers who submit modules to the team for inclusion). Other documents in the set are:

Guide for Interface Developers: Everything you need to know about EnergyPlus Input and Output (to develop a user-friendly interface)

The Interface Developer's Guide will tell you all the information about using and developing IDD (Input Data Dictionary) statements, Input Data File (IDF) statements, EnergyPlus outputs, and essentials of running EnergyPlus.

Guide for Module Developers: Everything you need to know about developing for EnergyPlus

The Module Developer's Guide will tell you further about useful routines and functions built into the EnergyPlus code that will make getting items from the IDF for your simulation relatively easy. Other parts of the guide tell about utility routines and functions as well as how to create the documents and how to document your example input files.

Engineering Reference: The Reference to EnergyPlus Calculations (in case you want or need to know)

The Engineering documentation gives details of the theory, equations and, occasionally, code snippets behind the EnergyPlus features.

Input-Output Reference: The Encyclopedic Reference to EnergyPlus Input and Output

Extensive details of the inputs used and outputs (reported variables) produced with EnergyPlus.

Output Details and Examples: An In-Depth Guide to EnergyPlus Output and Example Files

Extensive details output files and (future) examples files distributed with EnergyPlus.

Auxiliary Programs: To Increase Your Efficiency at Using EnergyPlus

Guides for the Weather Converter program, Using Ground Heat Transfer in EnergyPlus, HVAC Templates, WinEPDraw, EP-Macro, VCompare, and Transition (Convert old IDFs to later release version IDFs). (*and more*)

Getting Started: Everything You Need to Know about Running EnergyPlus (and a start at building simulation)

A guide to running EnergyPlus and some of the auxiliary programs as well as an introduction to building simulation modeling for those who might be new to the field or new to the precepts of EnergyPlus.

Coding Standard

Fortran 90/95

Because of the power, modular structure, and other strengths as a computational language, we chose Fortran90/95 as the language of choice for EnergyPlus. All of the guidelines presented in this section ("Coding Standard") are based on the use of Fortran for all code in EnergyPlus. The information in this section is not intended to be a complete description of the Fortran programming language but rather a supplement to the ANSI Standard. As we change compilers to later standards such as Fortran 2000/2003, we evolve code as appropriate. For those not familiar with Fortran90, the following books have proved useful to the development team:

- Ellis, T.M.R., Ivor R. Phillips, Thomas M. Lahey, 1994. *Fortran 90 Programming*, New York: Addison-Wesley.
- Redwine, Cooper. 1995. *Upgrading to Fortran 90*. New York: Springer Verlag.
- Chapman, Steven, McGraw Hill, 1998. *Fortran 90/95 for Scientists and Engineers*. New York: McGraw Hill.
- Metcalf, Michael, John Reid, Malcolm Cohen, 2004. *fortran 95/2003 explained*. New York: Oxford University Press.

However, there are many other Fortran 90/95 texts available. A useful book about software design is:

- McConnell, Steve C. 1993. *Code Complete: A Practical Handbook of Software Construction*, Redmond, Washington: Microsoft Press.

Fortran 90 Code

For the EnergyPlus project, three types of code that may coexist in any version of the program:

- Legacy Code
- Reengineered Code
- New Code

While these types of code will coexist in the EnergyPlus source, different expectations on the relative "purity" of the code will be enforced. All legacy code that is included in EnergyPlus must be at least F90 strict. (Note that legacy code included from another source may need permission/granting clauses to be placed in EnergyPlus – see the Module Developer's Guide for more on this). Mildly reengineered code (near legacy) that has not undergone any algorithm changes (only inclusion in a module, renaming of variables, etc.) will be allowed as long as it conforms to the F90 strict test. Reengineered code that has been modified significantly and all new code will be required to conform to the F90/95 pure standard.

All code should be placed in "free-format" as opposed to the fixed format used by F77 and other versions of Fortran. (Legacy code may be converted from fixed to free format using a utility available from team members.) In addition, the following guidelines should be followed for all free-formatted code in EnergyPlus:

- Only ! is valid for indicating comments.
- In-line comments are allowed and encouraged.

Guidelines from Code Complete should be followed for inline comments. Several suggestions are repeated here:

- *Avoid* endline (inline) comments that merely repeat the code.

- *Avoid* endline comments for multiple lines of code. In other words, avoid using a comment at the end of one line that applies to several lines of code.
- Use endline comments to annotate data declarations.
- Use endline comments for maintenance notes (bug fixes, for example).
- Use endline comments to mark ends of blocks.
- Lines must not extend past 130 characters. (Absolute limit is 132 characters!)
- We recommend that you limit most lines to 80 characters for readability. This allows most code to be seen on a standard size screen and be printed without resorting to micro-fonts or landscape mode.
- Column 6 is not associated with a continuation line in free format. To continue one line onto the next line, place an ampersand (&) at the end of the line to be continued.
- The main program should begin with a PROGRAM statement.
- To help visually distinguish between F90 syntax and other code elements such as comments and names, F90 syntax should be in all capital letters while other elements should be mixed case.
- Tab characters are not allowed in any source code file. If the file editor allows tab characters, be certain to set it up so that the tab characters are converted to spaces upon saving the file.
- It is highly recommended that programmers not use generic loop counters such as i, j, k, etc. This simply adds to the complexity of the code. The source code will be much easier to read if programmers use logical names for loop counting such as SurfaceNum, SystemNum, IterationNum, etc.
- Though the F90/95 standard allows for multiple statements on a line, *do not use these*.

```
E.g. a=0; b=0
instead → use:
a=0
b=0
```

- Likewise while F90/F95 allows multiple initialization statements on a line, *do not use these*.

```
E.g. Integer, Save :: Var1=0, Var2=0
Instead use →
Integer, Save :: Var1=0    ! should also have commenting on what var1 is
Integer, Save :: Var2=0    ! Var2 definition
```

- We require that you take advantage of the F95 standard for default initialization of derived type elements. The following example illustrates this. When CompData type is allocated (usually these are arrays), it is automatically filled with the indicated defaults.

```
TYPE CompData
  CHARACTER(len=MaxNameLength) :: TypeOf=' ' ! identifying component type
  CHARACTER(len=MaxNameLength) :: Name=' '   !Component name
  INTEGER                       :: CompNum=0  !component ID number
  CHARACTER(len=MaxNameLength) :: FlowCtrl=' ' !Component flow control
                                           ! (ACTIVE/PASSIVE/BYPASS)
  LOGICAL                       :: ON=.false. !When true, the
                                           ! designated component or operation scheme is available
  CHARACTER(len=MaxNameLength) :: NodeNameIn=' ' !Component inlet node
                                           ! name
  CHARACTER(len=MaxNameLength) :: NodeNameOut=' ' !Component outlet node
                                           ! name
  INTEGER                       :: NodeNumIn=0  !Component inlet node
                                           ! number
  INTEGER                       :: NodeNumOut=0  !Component outlet node
                                           ! number
```

REAL	:: MyLoad=0.0	!Distributed Load
REAL	:: MaxLoad=0.0	!Maximum load
REAL	:: MinLoad=0.0	!Minimum Load
REAL	:: OptLoad=0.0	!Optimal Load
END TYPE CompData		

Other F90 syntax that are either allowed or prohibited in various types of EnergyPlus code are listed below:

- EQUIVALENCE statements are **not** allowed in any code except legacy code. Since EQUIVALENCE is a deprecated feature of F90, as many equivalence statements as possible should be eliminated during the reengineering process. New code should not use EQUIVALENCE statements. If you have code with EQUIVALENCE statements, the EnergyPlus development team will help you transition to newer forms.
- Do not use COMMON blocks and INCLUDE files, instead replace these with module level variables or data only modules (where allowed). Commons and includes will be allowed in legacy and reengineered code until sufficient reengineering has taken place in that section of code to make other methods of variable declarations more appropriate. Commons and include files are **not** allowed in new code except where necessary for interfacing with legacy or mildly reengineered code.
- Legacy code should be gone at this point. One only uses legacy forms to make sure that transition to the F90/F95/F2003 has gone correctly.
- Avoid GOTO statements in both reengineered and new code.
- Do **not** use platform/machine specific features of extensions to F90 in any code.

F90/95 Language Features for Use in EnergyPlus

There are numerous features in F90 that provide advantages to EnergyPlus programmers. The following program elements must be used for all reengineered and new code:

- Modules
- USE statements (allows interaction of modules)

The following F90/95 features should be considered for use with all reengineered and new code in EnergyPlus:

- Derived types
 - Variables in Derived Types must be “initialized” so that when allocated or originally presented, these values will be automatically assumed in the structure.
- Variable intent
- Interface blocks

Fortran 90/95 Compilers

- The EnergyPlus development team uses Windows OS machines for most development. Linux is used for some testing as well as creating the Linux install version. The primary compiler being used is Intel Visual Fortran (IVF), which operates within Microsoft Visual Studio. Other compilers such as Lahey F95 and the open source g-95 is used in portability tests. At times, the results from other compilers is compared to the IVF results. For detailed compiler switches for Intel Fortran, please contact the development team.

It should also be noted that since tab characters are not allowed in EnergyPlus but are valid in SOME COMPILERS that all developers should configure ANY EDITOR to replace tabs with spaces.

Beyond F90/95 Language Features for Use in EnergyPlus

The original programming standard was written before F95 had been adopted. Though we don't yet (2007) have fully compliant compilers for F2000+, we are beginning to use these features. Notably:

- Allocatable structures in Derived Types -- if one has a variable length array that belongs to part of a Derived Type structure, F90 "allowed" these to be pointers. This is not, in general, a stellar idea and since F2003 allows these to be "allocatable", EnergyPlus code should reflect that convention.
- Standard methods of determining command line arguments and defined environment variables. F2003 defines standard routines `GET_COMMAND_ARGUMENT` and `GET_ENVIRONMENT_VARIABLE`.

Naming Conventions

The naming conventions shown in the next several sections apply to all code, whether reengineered or new. Legacy code that is brought over "as is" will not be required to undergo name changes immediately. However, if the code is to remain in EnergyPlus, it should conform to the EnergyPlus standards – naming conventions, readability and language use. If one must retain links to the legacy code, one can change the legacy code to comments with the new statements in succeeding blocks.

In all of the naming conventions listed below, the F90/F95 conventions of 31 character names has been used. In F2003, variable names can be up to 63 characters – some of the EnergyPlus code takes advantage of this. Spaces are not allowed as valid characters in any of the names. Underscores ("_") should be avoided but may be useful in defining "constants" (aka Parameters).

Note that different naming conventions apply to the Data Dictionary and Report Variables – these guidelines are contained in the Module Developer's document.

Subroutine Naming Convention

Subroutine names should be constructed using the verb-predicate rule. Every subroutine models an action on some item. Thus, the subroutine name should reflect this by including both the action and the item upon which the action is taken. The verb should be the first part of the name followed by the predicate. Below are some examples of the verb-predicate notation:

- `CorrectZoneAirTemp`
- `CalcZoneMassBalance`
- `SimAirLoops`
- `ReportFan`

Notice that the first letter of each word is capitalized to make the name easier to read. In general, the use of longer names for subroutine names rather than abbreviations is encouraged because subroutine names will not appear often in the code. However, abbreviations may be used if the subroutine name is readily understandable when abbreviated.

Module and Source Code File Naming Convention

Since modules typically are associated with objects or data groupings, the name selected for a module should refer to the object or data grouping. For example, a module that deals with pumps in the central plant should be called "PlantPumps". Modules which consist of only variable declarations (data-only module, see section on Variable Declarations) should use a "Data" prefix for its name followed by a logical descriptive term or terms. An example of a potential name for a data-only module is "DataGlobals".

Since each file containing source code must consist of a single program module, *source code files should use the name of the module as the base name* and a “.f90” as the file extension. Thus, the examples listed in the preceding paragraph would be contained in the files PlantPumps.f90 and DataGlobals.f90. It should be noted that there are some limits on file names on certain machines. Consequently, programmers should omit terms such as “algorithm” or “model” from module names.

Variable Naming Convention

Variable names appear in code much more often than subroutine or module names. As a result, using long variable names can become a burden for the programmer to enter. It also makes the code more difficult to read as program statements may continue over several lines. On the other hand, the use of short, cryptic names makes it difficult to understand the code without extensive documentation.

For variable names, logical abbreviations are thus encouraged. Typically, lengthy words should be shortened to somewhere between three and five characters to make a logical yet concise name for the various program variables. For example, the variable for the humidity ratio of the air entering the cooling coil might be named “InletAirHumRat”. In addition, plurals should not be used (i.e., use Zone instead of Zones, System instead of Systems, etc.) in variable names.

A list of approved abbreviations for use in EnergyPlus programming may be found in Appendix A. In the cases where words are five letters or shorter in length or do not have a logical abbreviation, these should not be abbreviated. As with all of the other items found in this standard, developers should use their judgment in implementing these abbreviations within code. When in doubt, do not use an abbreviation.

It should be noted that an explicit order for items, modifiers, etc. for variable names cannot be defined using the verb-predicate rule for the subroutine names. This, in part, is because variables may include more than one noun (InletAirHumRat) or several modifiers (NumSingleTempHeatCoolControls). We recommend that the variable name gives preference to the most important or higher level elements. As always, the developer should use common sense in applying these guidelines to program code.

Program Variables

Variable Declarations and Usage

One of the guiding philosophies for variable handling in EnergyPlus is that variables are only available and accessible where they are needed. This is one of the benefits of modules, i.e., that information which is not needed by a particular routine can be hidden from it. Limiting the scope of variables also makes the code easier to read, maintain, and test. Another goal of this standard is to minimize the amount of information that must be transferred from one routine to another via a passed variable list and to eliminate the need for commons. In order to ensure that this goal is realized, several restrictions on the availability of variables must be observed.

All EnergyPlus subroutines and functions must declare “IMPLICIT NONE” near the beginning of each routine or function. Consequently, all variables must be declared using valid F90 syntax. In F90, programmer has the ability to define certain variables as either **private** or **public**. This specification has implications on the availability of a particular variable outside of that module.

Real data in EnergyPlus must be a minimum of 64 bit reals (often called double precision). To facilitate this, a Data Only module called “DataPrecisionGlobals.f90” is included and should be USED by each module. The declaration for reals, is then:

```
REAL(r64) :: MyReal
```

And note that comparisons may imply that a single precision is used. For example, .2 is not the same as .2d0. So, a comparison should be:

IF (InputValue > .2d0) ...

Only four methods of variable definition are allowed in EnergyPlus:

- 1) *Subroutine Level Variables*. The first method of defining a variable is at the subroutine level as private. This definition is consistent with the F77 local variable. Subroutine level variables are not available anywhere outside the subroutine in which they are declared. Thus, by definition, any variable declared at the subroutine level is “private”. Local subroutine variables should be the first choice for the method of declaration.
- 2) *Module Level Variables — Private*. An alternative for defining a variable is private at the module level. Variables defined in this way are available to all of the subroutines in the module but to no routines outside the module or other modules. This definition is closely related to the use of common blocks in F77 code except that related data has now been grouped into a particular section of the code. Declaring a variable as private at the module level avoids the need to pass the variable from one subroutine to another within the same module. It should be noted, however, that it is inadvisable to declare loop counters or any other variable that could be declared as a subroutine local variable as module level variables. While it may seem redundant to declare a variable in several subroutines, experience has shown that such an abuse of module level variables is poor programming and will inevitably lead to program bugs.
- 3) *Data Only Module — Public (Superblock)*. In most cases, the prudent selection of module routines will result in the need for only subroutine level and private module-level variables. However, there will be some circumstances involving either legacy code or complex new code where the variables will need to be accessible in several related modules. Such related modules are considered a superblock. Variables that are used in several related modules should be separated and defined in a module that only includes public variable declarations. Defining module level variables as “public” should only be done when variables must be shared in a significant number of modules in a superblock. For example, material properties are used in several parts of the heat balance code that may be broken up into separate modules. Elevating variables to public status in data only modules should be a rare exception to the previous two rules and should be done with caution. Variables declared as public should only be used within modules that are considered part of their superblock (e.g., waste heat should not be used in the heat balance). Note that variables in modules that have subroutines should not be defined as public.
- 4) *Data Only Module — Public (Global)*. As in almost any other significant program, EnergyPlus will have certain variables that will be utilized in many modules. When several superblocks require access to a variable, it must be elevated to “global” status. As a rule, there should be very few global variables, and elevating a variable to global status should only be used as a last resort. Variables which may end up being global variables include: physical and geometric constants such as π , environment information variables (described in a later section) such as time, date, hour, time step, etc., and file unit numbers. When Data Only modules are used, sometimes it is useful or expedient to include some functions that operate with the variables in these blocks – view DataEnvironment for an example. Likewise, some primarily data modules may include the “get” routines for the data as expedient in complex calling structures.

Another issue related to variable declaration addressed by this standard is the **static** vs. dynamic storage of local subroutine variables. Due to the large number of legacy code variables that became part of the EnergyPlus program, it was originally necessary to specify the static storage of variables as a compiler flag. Variables in new and reengineered code should take advantage of dynamic allocation when possible and be explicit about its need to save variable values between subroutine calls. The compiler flag for static “all” is no longer used for the release compiles.

Two features of F90/95 that this standard encourages but does not mandate are intent and derived types. **Intent** allows the programmer to declare how a passed variable will be used within a subroutine: as in input, an output, or both. The use of intent is another issue of the

clarity of variable usage. With the intent of a variable explicitly defined, bugs in the program will show up much earlier in the development process and will be easier to detect and eliminate.

Derived types offer a convenient way to group and, if necessary, pass related variables. They are a method for constructing custom data structures within a program. For example, all of the information about a cooling coil could be defined as derived type. Consult any F90 book on the merit, advantages, and applications of derived types. While derived types can be nested (one derived type becomes part of another, etc.), no derived type used with EnergyPlus may be nested more than three layers deep.

One feature of F77 that will be eliminated during the process of reengineering the legacy code is the use of **common blocks** (and the include files which contain them). While common blocks are allowed in legacy code, their use in reengineered and new code will be limited to any temporary scaffolding that is needed to mesh between the old data system and the improved structure as outlined in this document. Even with that, they should only be used until the developer is comfortable that the new/revised structure is performing as the old and then the common blocks should be removed. Ideally, this will happen prior to being included in a version of official EnergyPlus code.

Units in EnergyPlus

Since the scope of EnergyPlus is limited to building energy analysis and does not include pre- or post-processing interfaces, EnergyPlus will expect information in a single unit system (SI). Thus, interface developers will be required to convert user inputs from those preferred by architects and engineers into the standard metric units of EnergyPlus. Thus, EnergyPlus does perform any unit conversions and will not have any unit conversion routines. Standard internal as well as program input and output units are as follows:

Table 1. **Standard Units for EnergyPlus.**

Variable Type	Units
Area	m ²
Conductivity	W/m-K
Density	kg/m ³
Energy	J
Enthalpy	J/kg
Heat Content (Fuels)	J/kg
Length	m
Mass Flow	kg/s
Mass	kg
Power	W
Pressure	Pa
R-Value	m ² -K/W
Specific Heat	J/kg-K
Speed	m/s
Temperature	C
Delta Temperature	C
U-Value	W/ m ² -K
Volume	m ³
Volume Flow	m ³ /s

Unless otherwise noted in program comments or in the output file description, all units must conform to the above list.

Variable Initializations

Consistency in variable initialization has been a concern in most of the legacy code. The problem existed because the methods of initialization were used interchangeably for different types of initialization. Consequently, attempts to do parametric runs were limited to separate program launches rather than control of parametric cases within the program.

Several types of initializations might occur in a program:

- 1) Variable is set to some value and never changes throughout the rest of the program. These variables should be defined as a parameter when they are declared regardless of whether the variable is a subroutine variable, a module level variable, or a data-only module variable.
- 2) Variable is set to some value defined by the user and never changes during the run. These variables should be set in the "Get" routines based on the values read in from the user input file.
- 3) Variable is set to some initial value and then gets updated one or more times during the run. In F90, the developer has the opportunity to initialize a variable as part of its declaration statement. This method is preferred over the data statement because a data statement must be placed somewhere in the code, i.e. in a routine. Code that is much easier to read will result if these variables are initialized at declaration.
- 4) Variable is set periodically during the simulation or would need to be reset during subsequent cases of a parametric run. These variables must be reset within defined initialization subroutines as described in the initialization information provided in the next section, Module Structure and Interaction.
- 5) Variable is used within a subroutine – IVF compiler does not "pre-initialize" values nor hold those values from one call of the subroutine to the next. Within the scope of the subroutine, one must always initialize this variable. IF the value is to hold from one call of the subroutine to the next, it should be designated as a SAVE variable in the declaration.

Notice that block data statements must not be used for any of the initializations -- they are only allowed deprecated features in legacy code. Using the definitions and methods described above, there is no longer any need for the confusing block data statements.

Allocation/Deallocation Variable Arrays

A really nice feature of F90 and beyond is the dynamic allocation of arrays. This feature allows EnergyPlus to accept virtually any number of zones, surfaces, etc. without imposing limitations on the user.

However, if you decide to allocate/deallocate with every subroutine call, you are wasting time – allocation and deallocation consumes time. This will not show up with many of our simple test files but will become painfully obvious to the large simulation with many "widgets" to allocate.

- Allocate during initial phases of the simulation (GetInput, Initialize) for module level variables
- For routine variable arrays, allocate to the maximum once (by using "one time" flags).

Unused Variables

Unused variables are usually be flagged by compilers. While some unused variables might be intended for later/future developments, these should be commented out until such time as they are needed.

Module Structure and Interaction

Module Usage in EnergyPlus

The module is the building block of the EnergyPlus program code. Modules are used to bring together either related algorithms or related data. In EnergyPlus, modules are used for grouping both data and algorithms because in many cases they are linked together. The EnergyPlus Module Structure has four important goals:

- to promote uniformity of program code
- to simplify the process of adding additional modules to the code
- to enhance the testing capability of various program elements
- to replace the extremely confusing data structure with a more understandable, segmented data structure as defined in the previous section.

Modules are most consistently organized when a map of the various modules and their interaction form an inverted tree or pyramid shape. EnergyPlus uses a modified form of this tree structure in that one main driver module accesses the heat balance module. In turn, the heat balance module interacts with the main system module through the heat balance-system “interface”. In a like manner, the major blocks of the HVAC code also interact through defined “interfaces”. Each of these main program elements access routines and data contained in other related modules.

The transformation of the code from a distributed program environment into discrete modules requires careful planning. The next several sections outline the potential elements of each module. This information should serve as a guide to constructing a module either from new or legacy code. Again, programmers should remember to take both data structure and algorithmic considerations into account when constructing a module for EnergyPlus.

Driver Subroutines

Driver routines are subroutines contained within a module that are called from subroutines in other modules. Access to the module and its data elements are only allowed through the driver routines. These routines would be the only PUBLIC routines in the module (with the possible exception of some of the input routines) since they are accessed from outside of the module. All other routines in this module are accessed from these main driver routines.

The main driver subroutines may contain any programming necessary to model the component or element on a macroscopic level. Other details of the algorithm should be contained in one of the subroutine types described below. Therefore, the driver routines will in most cases be a list of subroutine calls and possibly some control logic. For convenience, the programmer may specify a sub-driver routine for each of the main subroutine sections described below to minimize the number of calls that appear in the main driver routine.

Environment Flags

One set of variables that are candidates for elevation to “GLOBAL” status is the environment flags. The environment flags serve to keep track of time during the simulation. There are environment variables for hour, time step, sub-time step, day, etc. In addition, there are flags which are set to tell whether the current moment in the simulation is the beginning of a particular time frame (time step, hour, day, etc.) or at the end of the time frame. This information is extremely important to the driver subroutine that controls the simulation of the component module.

Based on the values of the environment flags, the driver will decide what types of initializations are required, whether input data must be read, the record keeping that must be done, and if reporting is necessary. In other words, the environment variables help the driver control all of the actions taken on the local and module variables except actual changes required by the model algorithms.

User Data Interface Subroutines (Get routines)

Most, if not all, modules require some input from the user such as design values, locations, schedules, etc. Consequently, these modules must have subroutines that interface with the user data. These routines are called from the driver routine(s) of this module or possibly from an input reading driver routine. It is also conceivable that this section might include some standard file operations such as “new”, “open”, “save”, “save as”, etc. that would relate to the external storage of input data for this module. In short, these routines are responsible only for transferring information from the user-input file to the particular variables.

Initialization Subroutine(s)

All routines that perform any required manipulations on the user data to obtain simulation ready information are considered initialization subroutines. The routines in this section may include several routines that are called from the driver subroutines within this module based on the value of the global environment (status) flags. For example, at the beginning of the simulation, one subroutine may be called to set up information that will be valid throughout the simulation such as processing of coil design data into a simulation-ready format. There may also be monthly, daily, hour, and time step level initializations that must be performed. Each of these levels could have a separate subroutine in this section dedicated to such initializations. Generally, though, it is preferred that all initializations be performed in one “Init” routine.

Calculation Routines and Utility Subroutines and Functions

This section includes any calculations that are required to simulate the element represented by this module. Thus, most of the details of the algorithm will be contained in this section. There should be one “Calc” routine and as many utility routines as are needed. Generally, no data movement will take place in the calculation section of the module.

Update Routine(s)

This section normally consists of one routine that performs any data transfer or movement that is needed within EnergyPlus, after the actual calculation in the module has taken place.

Reporting Subroutine(s)

Usually there is one reporting routine for each module. This routine will do any calculation that is needed strictly for output or reporting purposes and will contain the calls to the EnergyPlus reporting routines.

USE Statements in EnergyPlus

Once the various modules have been constructed, the “blocks” of the “pyramid” must be assembled using the F90 “USE” statements. The USE statement allows access from one module to another. For example, in EnergyPlus, since the ManageSimulation subroutine calls the ManageHeatBalance subroutine, it must have access to the HeatBalanceModule. Thus, the ManageSimulation subroutine or the SimulationManager module must have a USE HeatBalanceModule statement in it to allow this access. The USE statement also allows access to the data-only modules.

One question that arises through the implementation of USE statements is: “Where does the USE statement belong—at the module level or the subroutine level?” At this point, a definite rule has not been established to answer this question. However, the following guidelines seem reasonable and appropriate to the goals of this programming standard:

- USE statements that are required for access to a subroutine that is in another module probably belong at the subroutine level. In the example above, if the call to ManageHeatBalance is the only access to HeatBalanceModule from within the SimulationManager module, then the USE statement should probably reside at the subroutine level (in subroutine ManageSimulation in this case).

- If there are numerous calls from various subroutines in one module to another module, then the programmer may wish to elevate the USE statement to the module level for the sake of convenience. The number of calls threshold is left to the discretion of the programmer.
- Due to the definition of “global” data (i.e., global data should be available everywhere), any USE statements which are included for access to the global data (DataGlobals) must be placed at the module level.
- USE statements for access to “super-block” data-only modules can be placed at either the subroutine or the module level though it is recommended that these USE statements reside at the module level. If data is only used in a single subroutine, the programmer may need to consider passing the data as subroutine arguments.

Example of the EnergyPlus Module Structure

The code listed in the Module Developer's Guide is intended to give the reader a good example of how to implement the module described in the previous sections.

Generic Subroutines and Functions

There is a good possibility that the EnergyPlus code may contain some “generic” mathematical functions or procedures that are used by several, disparate sections of the program. Rather than repeat this code in each module that it is required, it might be appropriate to construct a generic subroutine/function module. Then, subroutines that need that function can use this generic module. Some examples of processes that might be included in a generic procedure module include array-zeroing subroutines, special functions not included in the F90 standard, etc. Developers should note that F90 does include a variety of matrix manipulation intrinsic functions. These standard functions should be used unless there are special conditions that require more specific programming. Subroutines or functions that are only called from a single module should be included in the utilities section of that module. Finally, subroutines or functions added to this generic process module should be written in the most general terms so that any routine which must call into this module will be able to do this without the assistance of extra programming or the definition of a new routine.

Several routines, such as “GetNumObject” or other “Get” routines as well as Psychrometric functions have already been defined for the EnergyPlus Developer. To find out more about these, refer to the Module Developer's Guide.

Programming Style

Some of the issues related to programming style have already been discussed in the *Fortran 90/95 Code* section above and will not be repeated here. In order to complete the discussion of style within program code, it is necessary to step back and review the goals of the project. Members of the project team determined that two of the most important features for the EnergyPlus code were maintainability and understandability. The key to achieving these characteristics is to use uniform, simple code for as much programming as possible. Algorithm tasks should be well defined and documented.

The next section contains a code template that is to be used with all EnergyPlus modules. This template will help promote uniformity between various sections of the EnergyPlus code.

Code Template

```
MODULE <module_name>

    ! Module containing the routines dealing with the <module_name>

    ! MODULE INFORMATION:
    !     AUTHOR      <author>
    !     DATE WRITTEN <date_written>
```

```

!      MODIFIED      na
!      RE-ENGINEERED na

! PURPOSE OF THIS MODULE:
! <description>

! METHODOLOGY EMPLOYED:
! <description>

! REFERENCES:
! na

! OTHER NOTES:
! na

! USE STATEMENTS:
! <use statements for data only modules>
USE DataGlobals, ONLY: ShowWarningError, ShowSevereError, ShowFatalError, &
    MaxNameLength, ...

! <use statements for access to subroutines in other modules>

IMPLICIT NONE ! Enforce explicit typing of all variables

PRIVATE ! Everything private unless explicitly made public

! MODULE PARAMETER DEFINITIONS:
! na

! DERIVED TYPE DEFINITIONS:
! na

! MODULE VARIABLE DECLARATIONS:
! na

! SUBROUTINE SPECIFICATIONS FOR MODULE:
! Driver/Manager Routines
PUBLIC  Sim<module_name>

! Get Input routines for module
PRIVATE Get<module_name>

! Initialization routines for module
PRIVATE Init<module_name>

! Algorithms/Calculation routines for the module
PRIVATE Calc<module_name>

! Update routines to check convergence and update nodes
PRIVATE Update<module_name>

! Reporting routines for module
PRIVATE Report<module_name>

! Utility routines for module
! these would be public such as:
! PUBLIC  Get<module>InletNode
! PUBLIC  Get<module>OutletNode

CONTAINS

SUBROUTINE Sim<module_name>

! SUBROUTINE INFORMATION:
!      AUTHOR      <author>
!      DATE WRITTEN <date_written>
!      MODIFIED     na
!      RE-ENGINEERED na

! PURPOSE OF THIS SUBROUTINE:
! <description>

```

```

        ! METHODOLOGY EMPLOYED:
        ! <description>

        ! REFERENCES:
        ! na

        ! USE STATEMENTS:
        ! na

IMPLICIT NONE ! Enforce explicit typing of all variables in this routine

        ! SUBROUTINE ARGUMENT DEFINITIONS:
        ! na

        ! SUBROUTINE PARAMETER DEFINITIONS:
        ! na

        ! INTERFACE BLOCK SPECIFICATIONS:
        ! na

        ! DERIVED TYPE DEFINITIONS:
        ! na

        ! SUBROUTINE LOCAL VARIABLE DECLARATIONS:
LOGICAL,SAVE      :: GetInputFlag = .true.  ! First time, input is "gotten"

IF (GetInputFlag) THEN
    CALL Get<module_name>Input
    GetInputFlag=.false.
ENDIF

<... insert any necessary code here>

CALL Init<module_name>(Args)

CALL Calc<module_name>(Args)

CALL Update<module_name>(Args)

CALL Report<module_name>(Args)

RETURN

END SUBROUTINE Sim<module_name>

SUBROUTINE Get<module_name>Input

        ! SUBROUTINE INFORMATION:
        !       AUTHOR      <author>
        !       DATE WRITTEN <date_written>
        !       MODIFIED     na
        !       RE-ENGINEERED na

        ! PURPOSE OF THIS SUBROUTINE:
        ! <description>

        ! METHODOLOGY EMPLOYED:
        ! <description>

        ! REFERENCES:
        ! na

        ! USE STATEMENTS:
USE InputProcessor, ONLY: GetNumObjectsFound, GetObjectItem ! might also use FindItemInList

IMPLICIT NONE ! Enforce explicit typing of all variables in this routine

        ! SUBROUTINE ARGUMENT DEFINITIONS:
        ! na

```

```

        ! SUBROUTINE PARAMETER DEFINITIONS:
        ! na

        ! INTERFACE BLOCK SPECIFICATIONS:
        ! na

        ! DERIVED TYPE DEFINITIONS:
        ! na

        ! SUBROUTINE LOCAL VARIABLE DECLARATIONS:
        INTEGER                                :: Item      ! Item to be "gotten"
        CHARACTER(len=MaxNameLength), &
            DIMENSION(x) :: Alphas  ! Alpha items for object
        REAL, DIMENSION(y)                   :: Numbers ! Numeric items for object
        INTEGER                                :: NumAlphas ! Number of Alphas for each GetObjectItem call
        INTEGER                                :: NumNumbers ! Number of Numbers for each GetObjectItem call
        INTEGER                                :: IOStatus  ! Used in GetObjectItem
        LOGICAL                                :: ErrorsFound=.false. ! Set to true if errors in input, fatal
at end of routine

<NumItems>=GetNumObjectsFound('object for <module_name>')
DO Item=1,<NumItems>
    CALL GetObjectItem('object for <module_name>', Item, Alphas, NumAlphas, Numbers, NumNumbers, &
        IOStatus)
    <process, noting errors>
ENDDO

<SetupOutputVariables here...>

IF (ErrorsFound) THEN
    CALL ShowFatalError('Get<module_name>Input: Errors found in input')
ENDIF

RETURN

END SUBROUTINE Get<module_name>Input

SUBROUTINE Init<module_name>

    ! SUBROUTINE INFORMATION:
    !     AUTHOR          <author>
    !     DATE WRITTEN    <date_written>
    !     MODIFIED        na
    !     RE-ENGINEERED   na

    ! PURPOSE OF THIS SUBROUTINE:
    ! <description>

    ! METHODOLOGY EMPLOYED:
    ! <description>

    ! REFERENCES:
    ! na

    ! USE STATEMENTS:
    ! na

    IMPLICIT NONE      ! Enforce explicit typing of all variables in this routine

    ! SUBROUTINE ARGUMENT DEFINITIONS:
    ! na

    ! SUBROUTINE PARAMETER DEFINITIONS:
    ! na

    ! INTERFACE BLOCK SPECIFICATIONS
    ! na

    ! DERIVED TYPE DEFINITIONS
    ! na

```

```

        ! SUBROUTINE LOCAL VARIABLE DECLARATIONS:
        ! na

    RETURN

END SUBROUTINE Init<module_name>

SUBROUTINE Size<module_name>

    ! SUBROUTINE INFORMATION:
    !     AUTHOR          <author>
    !     DATE WRITTEN    <date_written>
    !     MODIFIED        na
    !     RE-ENGINEERED   na

    ! PURPOSE OF THIS SUBROUTINE:
    ! <description>

    ! METHODOLOGY EMPLOYED:
    ! <description>

    ! REFERENCES:
    ! na

    ! USE STATEMENTS:
    ! na

    IMPLICIT NONE      ! Enforce explicit typing of all variables in this routine

    ! SUBROUTINE ARGUMENT DEFINITIONS:
    ! na

    ! SUBROUTINE PARAMETER DEFINITIONS:
    ! na

    ! INTERFACE BLOCK SPECIFICATIONS
    ! na

    ! DERIVED TYPE DEFINITIONS
    ! na

    ! SUBROUTINE LOCAL VARIABLE DECLARATIONS:
    ! na

    RETURN

END SUBROUTINE Size<module_name>

SUBROUTINE Calc<module_name>

    ! SUBROUTINE INFORMATION:
    !     AUTHOR          <author>
    !     DATE WRITTEN    <date_written>
    !     MODIFIED        na
    !     RE-ENGINEERED   na

    ! PURPOSE OF THIS SUBROUTINE:
    ! <description>

    ! METHODOLOGY EMPLOYED:
    ! <description>

    ! REFERENCES:
    ! na

    ! USE STATEMENTS:
    ! na

    IMPLICIT NONE ! Enforce explicit typing of all variables in this routine

    ! SUBROUTINE ARGUMENT DEFINITIONS:

```

```
! na

! SUBROUTINE PARAMETER DEFINITIONS:
! na

! INTERFACE BLOCK SPECIFICATIONS:
! na

! DERIVED TYPE DEFINITIONS:
! na

! SUBROUTINE LOCAL VARIABLE DECLARATIONS:
! na

RETURN

END SUBROUTINE Calc<module_name>

SUBROUTINE Update<module_name>

! SUBROUTINE INFORMATION:
!   AUTHOR      <author>
!   DATE WRITTEN <date_written>
!   MODIFIED    na
!   RE-ENGINEERED na

! PURPOSE OF THIS SUBROUTINE:
! <description>

! METHODOLOGY EMPLOYED:
! <description>

! REFERENCES:
! na

! USE STATEMENTS:
! na

IMPLICIT NONE ! Enforce explicit typing of all variables in this routine

! SUBROUTINE ARGUMENT DEFINITIONS:
! na

! SUBROUTINE PARAMETER DEFINITIONS:
! na

! INTERFACE BLOCK SPECIFICATIONS:
! na

! DERIVED TYPE DEFINITIONS:
! na

! SUBROUTINE LOCAL VARIABLE DECLARATIONS:
! na

RETURN

END SUBROUTINE Update<module_name>

SUBROUTINE Report<module_name>

! SUBROUTINE INFORMATION:
!   AUTHOR      <author>
!   DATE WRITTEN <date_written>
!   MODIFIED    na
!   RE-ENGINEERED na

! PURPOSE OF THIS SUBROUTINE:
! <description>

! METHODOLOGY EMPLOYED:
```

```

! <description>

! REFERENCES:
! na

! USE STATEMENTS:
! na

IMPLICIT NONE ! Enforce explicit typing of all variables in this routine

! SUBROUTINE ARGUMENT DEFINITIONS:
! na

! SUBROUTINE PARAMETER DEFINITIONS:
! na

! INTERFACE BLOCK SPECIFICATIONS:
! na

! DERIVED TYPE DEFINITIONS:
! na

! SUBROUTINE LOCAL VARIABLE DECLARATIONS:
! na

! <this routine is typically needed only for those cases where you must transform the internal
data to a reportable form>

RETURN

END SUBROUTINE Report<module_name>

!===== Utility/Other routines for module.
! Insert as appropriate

! Insert Standard Copyright Notice here.

END MODULE <module_name>

```

Notes on the EnergyPlus Code Template

Programmers should copy the above text into an empty file, changing names and filling in comments and code as appropriate. Comments in the template that are enclosed in {{double braces}} should be replaced with actual comments specific to the module or subroutine. Comments that are enclosed in <<double hinges>> should be replaced with program code. Other comments should be left in the file as they are. Note that some of the comments appear in all capital letters while others appear in mixed case. These all capitalized comments are special “header” comments. Developer comments should be in sentence case rather than all upper case. All comments (including in-line comments) should begin in the 11th column or later to help set them off visually from the code. In-line comments should leave at least one blank character between the end of the syntax and the comment marker. Furthermore, it should be noted that the indentation of program code did not begin until the subroutine level had been reached. Finally, functions may be added in a similar manner as the subroutines.

Good Coding Practices

Though we hope that the interfaces to EnergyPlus will produce correct input files, this may not be the case. Therefore, you should program defensively when accepted incorrect data will cause your routines to go “belly-up”. For example, the “ShowFatalError” routine is called in the code example (Ref: Module Developer’s Guide) when the “SimulateFanComponents” is passed a fan name that it cannot find in the list of fans. Ideally, this kind of error-checking should be accomplished during the “Get” routines for the module. Nevertheless, having this detection somewhere (anywhere) will save countless hours of debugging an incorrect input file.

Code Readability vs. Speed of Execution

Programmers throughout time have had to deal with speed of code execution and it's an ongoing concern. However, compilers are pretty smart these days and, often, can produce speedier code for the hardware platform than the programmer can when he or she uses "speed up" tips. The EnergyPlus development team would rather the code be more "readable" to all than to try to outwit the compilers for every platform. First and foremost, the code is the true document of what EnergyPlus does – other documents will try to explain algorithms and such but must really take a back seat to the code itself.

However, many people may read the code – as developers, we should try to make it as readable at first glance as possible. For a true example from the code and a general indication of preferred style, take the case of the zone temperature update equation. In the engineering document, the form is recognizable and usual:

$$T_z^t = \frac{\sum_{i=1}^{N_{dl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} h_i A_i T_{si} + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p T_{zi} + \dot{m}_{inf} C_p T_{\infty} + \dot{m}_{sys} C_p T_{supply} - \left(\frac{C_z}{\delta t} \right) \left(-3T_z^{t-\delta t} + \frac{3}{2}T_z^{t-2\delta t} - \frac{1}{3}T_z^{t-3\delta t} \right)}{\left(\frac{11}{6} \right) \frac{C_z}{\delta t} + \sum_{i=1}^{N_{surfaces}} h_i A + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p + \dot{m}_{inf} C_p + \dot{m}_{sys} C_p}$$

And, this equation appears in the code (ZoneTempPredictorCorrector Module), as:

```
ZT(ZoneNum)= (CoefSumhat + CoefAirrat*(3.0d0*ZTM1(ZoneNum) - (3.0d0/2.0d0)*ZTM2(ZoneNum) &
+ (1.0d0/3.0d0)* ZTM3(ZoneNum))) &
/ ((11.0d0/6.0d0)*CoefAirrat+CoefSumha)
```

somewhat abbreviated here due to lack of page width but still recognizable from the original.

A better version would actually be:

```
ZT(ZoneNum)= (CoefSumhat - CoefAirrat*(-3.0d0*ZTM1(ZoneNum) + (3.0d0/2.0d0)*ZTM2(ZoneNum) &
- (1.0d0/3.0d0)* ZTM3(ZoneNum))) &
/ ((11.0d0/6.0d0)*CoefAirrat+CoefSumha)
```

whereas the natural tendency of programming would lead to the less readable:

```
ZT(ZoneNum)= (CoefSumhat + CoefAirrat*(3.0d0*ZTM1(ZoneNum) &
- 1.5d0*ZTM2(ZoneNum) + .333333d0* ZTM3(ZoneNum))) &
/ (1.83333d0*CoefAirrat+CoefSumha)
```

The final version is a correct translation (more or less) from the Engineering/usual representation but much harder to look at in code and realize what is being represented. Also, due to all double precision being used, .333333d0 may not be the best representation that the machine can make for 1/3.

This discussion also appears in the Module Developer's Guide.

Code Documentation

In addition to a uniform programming style, proper code documentation will enhance the understandability and maintainability of EnergyPlus. Code documentation includes the comments within the source code as well as written documents. Neither documentation type is intended to be a program tutorial or textbook in building energy analysis physics. Code developers should assume that readers of the documentation will be familiar with standard engineering terminology and have a basic understanding of the processes involved. In cases where extremely complex algorithms are involved, developers should provide as many detailed comments as possible but refer the reader to an appropriate text or article. It should be noted that program code will not be considered complete until the proper documentation for that section of the program is complete.

Source Code Comments

Source code comments include the information sections contained in the code template in the previous section as well as any additional in-line comments. Again, the object is not to

document obvious lines of code but to assist the reader in understanding the code. For example, an in-line comment for an assignment statement probably should not repeat the equation being described because in most cases it will be obvious what is being calculated due to the use of longer variable names. If there are several similarly named variables in an equation, it may be necessary to explain the differences between them. In most cases, if the equation is unique to a particular method, then a citation to one of the references should be given (e.g., Conduction of Heat in Solids, Carslaw and Jaeger. 1946. p. 123, Equation 2.1.5). If a particular algorithm with distinct steps or milestones is used, the addition of such information to the code using in-line comments can be very effective. Do-loops and If-then constructs should have comments that enhance the description of the loop or decision being made.

Engineering Documentation

The written documentation for each module must include user documentation, interface developer documentation (if appropriate), and engineering or technical documentation. The user documentation must incorporate basic facts about how the model is used in the program and some information on the limits of its application within the program. This information should be tailored to someone who will use the program as a “black box”. These users are not concerned with the calculation procedures used by EnergyPlus but are concerned with how to get reasonable results out of the program. The interface developer documentation must provide a detailed description of what input is necessary for the model. Generally, this can be in the form of comments in the Data Dictionary (IDD) file. The module developer must ensure that important information such as input units are part of this documentation section. Finally, the technical documentation should include more detailed information on the processes being programmed. This information must be similar to the documentation found in the program code and be written with other code developers in mind. As with the in-source documentation, avoid lengthy discussion of minute details that are already discussed in reference documents. However, information important to the calculation procedure or any numerical techniques that are used must be highlighted.

External Libraries

Although the most of EnergyPlus is implemented in Fortran90 and compiled as one large executable program, shared libraries are also used. As of version 7.2, the program includes statically linked libraries for SQLite and Delight and dynamically linked libraries for BCVTB, and FMU/FMI. Then, whatever is required by the compiler version to be included. This section discusses what is required when adding new external libraries.

Although external libraries are allowed when necessary, developers should be aware that there are disadvantages to using them. EnergyPlus is a cross-platform application and it is the developers responsibility to provide a library that is also cross-platform. The core EnergyPlus team is small and currently can only maintain the core Fortran.

Requirements and Responsibilities

Any new library must meet the following requirements:

1. The library source code must be provided and stored in the main source code repository.
2. The library source code must be compatible with EnergyPlus's authorship requirements and license options **including its open-source version**.
3. The library source code must be written in a high-level programming language that is fully compiled and portable on all three major platforms, Windows, Mac, and Linux.
4. There must be two version of the fortran source code that calls the library, one a stub and one that actually calls the library. The stub will be used by developers who do not want to build with a dependency on your library.
5. When binding with C-based languages, the fortran code must use ISO standard for variable type declarations (use intrinsic ISO_C_Binding).
6. When binding with FORTRAN languages, the variable declarations should use EnergyPlus practice (see DataPrecisionGlobals.f90).

The developer adding a new library must assume the following responsibilities:

1. The developer must demonstrate that the library compiles on all platforms including: 1. Windows 32 bit, 2. Windows 64 bit, 3. Mac 32 bit, 4. Mac 64 bit, 5. Linux 32 bit and Linux 64 bit. Often when the source code is originally developed on only one platform, it needs to be modified to work correctly on all the other platforms.
2. The developer must submit modified CMAKE build system files that demonstrate the library compiles and links on all platforms. See below for more information on the cross-platform build system.
3. The developer must show that example files that exercise the library run on all platforms and produce the same results.
4. For each subsequent release of EnergyPlus, that includes the feature, the developer must assist the team with testing the installation packages.

Build System

The EnergyPlus internal development team uses two types of build systems. Most developers who are not involved in release packages and external libraries use a simple project setup for their particular integrated development environment and Fortran compiler. However, the main build system for external libraries is based on CMAKE (Cross Platform Make) <http://www.cmake.org/>.

Access to the separate repository where the CMAKE files and stored library code will be made available to those developers involved with external library development. Currently (as

of version 7.2) this repository uses SVN and internal development members will need to request access through their supervisors/EnergyPlus project POCs (Points of Contact).

Software Development Procedures

The EnergyPlus software development philosophy is to proceed incrementally, always maintaining a working version of EnergyPlus. Large, dramatic development steps that break the code are not encouraged. This philosophy grew out of the fact that a large portion of EnergyPlus – the heat balance section – is based upon legacy code from iBLAST. This code, in common with most of the code in DOE-2 and BLAST, is written in Fortran 77 and tends to be disorganized and difficult to understand. Rather than rewrite this code in one step it was decided to begin with the legacy code and transform it gradually into modular, structured Fortran 90 code. This procedure allowed the working of the code to be verified at each stage of transformation and allowed other development to proceed in parallel. This method of gradually transforming legacy code into modern, structured code was dubbed “evolutionary reengineering”; a more detailed description is in Appendix C.

The experience with evolutionary reengineering led to the EnergyPlus development philosophy: proceed in modest development steps; maintain working code; test frequently and always test at the end of each development step. A more detailed description of the software development steps is provided below.

EnergyPlus development: step by step

Understanding the general philosophy of EnergyPlus development is important, but it does not guarantee that the code produced by the developer will meet the goals of the project. In order to increase the probability of success, individual developers in conjunction with other team members should use the following detailed software development plan. The intention of this section is not to impose bureaucracy on the developer but to provide methods for handling difficult situations and resolving issues related to other sections of the code.

It may not be necessary or possible to follow all of these steps for each coding task in EnergyPlus. However, developers should consider these steps to help guide them through development of new features to the program. The following scenario may work best in an academic environment though a similar approach may work for others.

- 1) *Problem/Enhancement Definition.* A new feature to be added to EnergyPlus is identified. This can be done formally during a meeting during the discussion of programming topics or it can be done informally when a problem is recognized in a portion of the EnergyPlus code. (Note – there is a template that should be used to document potential new features.)
- 2) *Team Assembly.* Once the project has been defined, primary responsibility for completion of the task must be assigned to one member of the development team. In addition, the primary developer will assemble a team of two other developers to provide project support. One of these should be a developer who has projects that may be interrelated. For example, a coil project should include a central plant expert as an assistant. The other assistant can be selected from any of the remaining development personnel. The assisting team will provide support for the primary developer and will be responsible for checking that all of the software development procedures have been followed.
- 3) *Planning Stage.* The primary developer will make a preliminary investigation and create a plan for all aspects of the development task. This phase must include tracking down any references necessary to complete the project and gather (and becoming familiar with) any legacy code which is available. The primary developer will define the inputs and outputs of the new model (variables and also file input/output issues) during this phase, summarize any record keeping which might be needed, and determine how the module will interact with surrounding programming components. The documents required by this phase will consist of electronic documents which include as a minimum a discussion of the proposed feature, legacy versions or sources for the new feature, a

testing plan including data available for verification of the module, system/equipment diagrams, pseudo-code which describes the logic and structure of the modules, the proposed addition or changes to the IDD, the proposed IDF structure, and the variable naming, and output variables that will be added. Note that this document will serve as a starting point for the required additions to Engineering Reference and Input Output Reference, and other documents in step 7 below.

- 4) *Preliminary Review.* The primary developer will present the plan to the team. Exact procedures may be different from group to group. The core of the requirement is this: you must develop a plan, review it with the team, revise, develop initial code and documentation, review/debug, final implementation, review, and documentation.
- 5) *Initial Programming and Documentation Phase.* The primary developer will begin by constructing a skeleton of the new module and programming the interactions with the other modules. The programmer should not yet begin work on the detailed calculations of the module. The resulting skeleton should include all of the comments required by the code template presented in an earlier section. In addition, the primary developer should prepare a draft of the engineering documents.
- 6) *Initial Code Review.* The primary developer will present the results of the preceding phase to the assisting team. They will check to make sure that the developer has stuck to the preliminary plan or can provide justification for changing the plan. Furthermore, they will comment on the draft engineering documents and suggest structure or content changes/additions. Again, if serious problems are uncovered during this review, it may be necessary to return to previous stages of the development process.
- 7) *Detailed Programming and Documentation Phase.* At this point, the primary developer should incorporate the details of the module including any calculations, input/output issues, record keeping, etc. that are necessary. During this phase, the programmer should also complete program documentation and construct a testing plan as the various portions of the module are developed. Documentation tasks include completing in-line comments in the source code and filling in the details of the engineering and interface developers documentation. The testing plan should address both unit testing (ranges of parameters to investigate, etc.) and interaction testing.
- 8) *Code Review Phase.* The assisting team should perform a code walkthrough with the primary developer to insure that the code will perform the desired tasks and conforms to the established EnergyPlus standard. Additionally, the team will discuss and revise, if necessary, the documentation changes and testing plan. Concerns about coding, documentation, or testing strategies should be addressed at this point before continuing with the testing plan.
- 9) *Testing Phase.* The primary developer proceeds with the testing plan documenting the results of the testing plan and modifying the code as needed. The user documentation is also drafted during this phase. Documentation requirements (including format) are discussed in the Guide for Module Developers.
- 10) *Testing and Documentation Review.* One or both of the assisting team members review the testing results and resultant documentation changes. Suggestions for further testing or changes are made, if necessary. Testing requirements, too, are covered in the Guide for Module Developers.
- 11) *Project Completion Phase.* After successful completion of the testing and documentation review, the primary developer is responsible for integrating the changes for this project into the current version of EnergyPlus using the version control system, final testing of the new version of EnergyPlus to insure that the integration was successful, and integration of the various model documents into the EnergyPlus documentation repository. This must include at least one example input file which exercises all the features of the new code. Any problems encountered during this phase should be brought to the attention of the EnergyPlus system integrator.
- 12) *Final Review.* The notified assisting member confirms that the code and documentation has been integrated properly and that the integration of the code into EnergyPlus has not introduced any errors into EnergyPlus or the new module.

Testing

This section describes testing that is done by the developer; testing for program releases is described in a separate document.

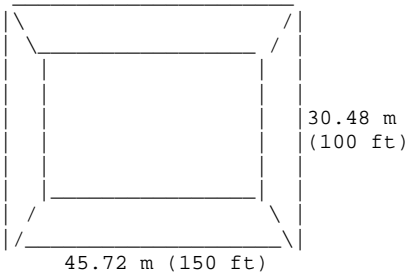
The kind of testing that will be done by a developer is somewhat dependent on the type of development project undertaken and thus will always rely to some extent on the developer's good judgement. A straightforward case to discuss is the development of a new HVAC component module. The development and testing might proceed in the following stages.

- Specify the input with a Data Dictionary (IDD) entry. The new IDD can be tested for syntactical correctness by simply running one of the EnergyPlus test suite inputs using the new IDD.
- Design the module data structure and write the input (Get) subroutine. Create test input for the component and add it to an existing EnergyPlus input (IDF) file. Test that the input data is being correctly read by the input subroutine and stored correctly in the module data structures. This testing will be done in the debugger. Create informative error messages for incorrect user input.
- Write the rest of the component module code and test it in a standalone fashion. This allows for rapid, repetitive testing that covers the range of possible component inputs. These tests will also be done in the debugger.
- Create a full EnergyPlus input incorporating the new component in a realistic manner. Sometimes you can modify an existing test suite file.
- Add the new EnergyPlus module to the full program. Using the debugger test that the new, full input is functioning correctly
- Using the EnergyPlus reporting capabilities and a spreadsheet, test that the new component is functioning as expected in a variety of conditions.
- Run the entire EnergyPlus test suite and make sure nothing has changed when the new component is not part of the input.
- Add one or more new test files to the EnergyPlus test suite. These are really examples to the user for EnergyPlus Features.
- Document the test files using the documentation template (see below) as your guide. Highlights of the input file is placed in the ExampleFiles.xls spreadsheet.
- Perform full annual runs on the test files that you will add as example files.
- Perform the "reverse DD" test – this requires that you put in two design days (preferably summer and winter); run once with "normal" design days; reverse the design days and run again. The results (when you reverse the results for the second run) should be **exactly** the same.

Input File Documentation

```
! <name of file>
! Basic file description: <specify number of zones, stories in building, etc>
! Highlights: <Purpose of this example file>
! Simulation Location/Run: <location information, design days, run periods>
! Location:
! Design Days (should have SummerDesignDay,WinterDesignDay designations):
! Run Period (Weather File):
! Run Control (should include this):
!
! Building: <more details about building.  metric units, if also english enclose in []{} or ()>
! Floor Area:
! Number of Stories:
!
! Zone Description Details:
! Internal gains description: <lighting level, equipment, number of occupants, infiltration, daylighting,
etc>
! Interzone Surfaces:
! Internal Mass:
! People:
! Lights:
! Windows:
! Detached Shading:
! Daylight:
! Natural Ventilation      :
! Compact Schedules (preferred):
! Solar Distribution:
!
! HVAC: <HVAC description and plant supply, as appropriate>
! Purchased Air:
! Zonal Equipment:
! Central Air Handling Equipment:
! System Equipment Autosize:
! Purchased Cooling:
! Purchased Heating:
! Coils:
! Pumps:
! Boilers:
! Chillers:
! Towers:
!
! Results: <how are results reported>
! Standard Reports:
! Timestep or Hourly Variables:
! Time bins Report:
! HTML Report:
! Environmental Emissions:
! Utility Tariffs:
```

Some good examples (not necessarily meeting all the above):

```
! LgOffVAV.idf
!
! Basic file description: Prototypical 6-story large office building of new (post-1980) vintage
! in southern U.S. with a central VAVS system.
!
! Run: autosizing using Chicago winter & summer design days; simulation - 1 winter, 1 summer day.
!
! Building:
!
! 
!
! Floor area: 8361 m2 (90,000 ft2)
! Dimensions: 45.72 m x 30.48 m (150 ft x 100 ft)
! Floor height: 3.048 m (10 ft), no plenum
! 6 conditioned floors with unconditioned basement
! Shell characteristics
! Roof const: built-up roofing, 4" concrete,
!             insulation,air space, acoustic tile
! Roof insulation: 2.22 m2-K/W (12.6 ft2-hr-F/Btu)
! Wall const: stone, insulation, air space, gypsum board
! Wall insulation: 1.06 m2-K/W (6 ft2-hr-F/Btu)
! Window const: double-pane
! Window U-value: 3.4 W/m2-K (0.598 Btu/hr-ft2-F)
! Window SHGC: 0.782 (0.71 SC)
! Window-to-Wall Ratio (WWR): 0.50
! Infiltration: 0.0 occupied hrs, 0.30 ACH unoccupied hrs; 2.0 ACH in
! basement
!
!             Basement Wall F-factor: 4.32 W/m-K (2.50 Btu/hr-ft-F)
!
! Each floor is modeled as four perimeter zones and one core zone. The perimeter
! zones are all 4.57m (15 ft) deep. Windows are modeled as a horizontal strip of
! glazing running the length of each perimeter wall from the middle to the top of
! the wall, for a Window-to-Wall Ratio (WWR) of 0.50. The 4 intermediate floors
! are modeled as 1 floor with a zone multiplier of 4 applied to each zone. The floors
! and ceilings of the zones on the intermediate floor are modeled as adiabatic surfaces.
!
! The building is oriented with its long axis east-west.
!
! Internal loads (peak) are :
!
! Occupancy 36.23 m2/person (390 ft2/person)
! Lighting load 12.59 watts/m2 (1.17 watts/ft2)
! Equipment load 8.07 watts/m2 (0.75 watt/ft2)
! Elevator load 27.75 KW (NOT IMPLEMENTED YET IN THIS FILE)
! Hot-water usage 0.889 l/hour/person (0.0039 gal/min/person) (NOT IMPLEMENTED YET IN THIS FILE)
! Occupied hours 8 through 18 weekdays, 8 to 13 weekends
!
! System controls are:
!
! Heating 21.1 C (70 F) occupied hours, 12,8 C (55 F) unoccupied hours
! Cooling 23.9 C (75 F) occupied hours, 32.2 C (90 F) unoccupied hours
! The basement is unconditioned but has a constant heat source of 6766 watts representing
! the losses from the plant
! Heating and cooling turned on 1 hour early, and turned off 1 hour late
! Outside-air 25 m3/hr/person (15 CFM/person)
! Economizer with limit temperature at 20 C (68 F) (BUT IS SET TO NO ECONOMIZER IN THIS INPUT)
!
! HVAC:      Standard VAV system with minimum outside air , hot water reheat
!            coils, central chilled water cooling coil. Central Plant is single
!            hot water boiler, electric compression chiller with water cooled
!            condenser. All equipment is autosized.
!
!            The supply air temperature setpoint is established by a seasonal reset.
```

Appendix A: Definitions and Notation

The following definitions will be applicable for this document:

- **EnergyPlus** — The name of the program chosen by team members to represent the best pieces of the DOE-2 and (I)BLAST programs. EnergyPlus as defined by the team members is only responsible for performing building energy analysis. It will not serve either as a user interface or as an output processor. This will have some bearing on the topics detailed in this standard.
- **Legacy Code** — Program code from (I)BLAST and DOE-2 which will not be revised (no algorithm changes) for reasons of time constraints, testing considerations, etc.
- **Reverse Engineering** — The process of determining the data flow and algorithms used for various program codes.
- **Reengineered Code** — Code which has been reverse engineered and then modified to fit the proposed guidelines agreed upon by the team members. The starting point for reengineered code is code from either (I)BLAST or DOE-2.
- **New Code** — Code which has been written from scratch, i.e., completely new code.
- **Superblock** — A grouping of modules with a common purpose. All of the heat balance modules would be considered part of the heat balance superblock; system modules would be part of a system superblock, etc.
- **Fortran 90/95 or F90/95** — This refers to the full ANSI Fortran 90 language as defined in the American National Standard Programming Language Fortran 90, ANSI X3.198-1992 and International Standards Organization Programming Language Fortran, ISO/IEC 1539:1991(E). F95 is a slightly revised standard – a bit later than F90. F2000 and F2003 is a later standard than F95 and contains some substantial revisions.
- **Fortran 90 Strict** — Strict means that the code adheres to at least the Fortran 77 standard and includes new features of Fortran 90.
- **Fortran 90 Pure** — Pure means that the code does not contain any of the features that have been ruled obsolete by the Fortran 90 standard.
- **Verb-Predicate Rule** — A method for naming subroutines consistently and logically based on the functionality of the routine. Every subroutine performs some action (the “verb”) on a particular item or data set (the “predicate”). The subroutine name is thus constructed using the verb-predicate combination to arrive at a unique name for a particular algorithm.
- **ANSI** – American National Standards Institute, keeper of Fortran language standards.
- **ISO** – International Standards Organization, keeper of Fortran language standards since F90.

Appendix B: Development of the Standard

Why Standards?

Standard: An acknowledged measure of comparison for quantitative or qualitative value; a criterion.¹

Without standards, software development is an uncontrolled activity or, often, an activity out of control. With standards, the quality of software within the development group can continuously improve to the detriment of no individual contribution. In addition, standards may be able to help us meet various goals for the development (such as cost, timeliness, and focus on the product).

At the July 1995, joint team meeting², several goals for the project were outlined:

- 1) Take best of existing DOE-2/BLAST/(IBLAST) capabilities, applications, and methods/structures. Combine with existing best of others.
- 2) Reuse existing code and structures where possible.
- 3) Short Time Frames (< 24 months)

During April 1996, the "Champaign Best of" group met and determined priorities for development within, at least, their portion of the "Best of" development. Using a list³, the following weightings were determined, in descending order of importance (Level 1 more important than Level 2):

- Level 1: Maintainability, Robustness, Reliability, Testability, Understandability(Readability)
- Level 2: Portability, Reusability
- Level 3: Speed, Size

Thus, we established a standard both for coders as well as for reviewers. When we code or review, we will try to keep these elements in mind. Should a trade-off be needed, the decision either at coding time or review time will fall to the priorities established.

These items are defined (for the most part) in Code Complete⁴ along with a table that shows how focus on one may hinder another. The pertinent definitions are repeated here:

- **Maintainability:** The ease with which you can modify a software system to change or add capabilities, improve performance, or correct defects.
- **Robustness:** The degree to which a system continues to function in the presence of invalid inputs or stressful environmental conditions.
- **Reliability:** The ability of a system to perform its required function under stated conditions whenever required -- having a long mean time between failures.
- **Testability:** The degree to which you can unit-test and system-test a system; the degree to which you can verify that the system meets its requirements.
- **Understandability:** The ease with which you can comprehend a system at both the system-organizational and detailed-statement levels. Understandability has to do with the coherence of the system at a more general level than readability does.
- **Portability:** The ease with which you can modify a system to operate in an environment different from that for which it was specifically designed.
- **Reusability:** The extent to which and the ease with which you can use parts of a system in other system.

¹ *The American Heritage® Dictionary of the English Language*, Third Edition copyright © 1992 by Houghton Mifflin Company. Electronic version licensed from InfoSoft International, Inc. All rights reserved.

² Meeting Notes, Dru Crawley, attachments to mail messages.

³ *Debugging the Development Process*, Steve Maguire, Microsoft Press, ©1993.

⁴ *Code Complete: A Practical Handbook of Software Construction*, Steve McConnell, Microsoft Press, ©1993, pp 557-560.

- Speed: Related to Efficiency: execution time.
- Size: Related to Efficiency: memory requirements.

Not on our original list but included in the reference:

- Efficiency: Minimal use of system resources, including memory and execution time.
- Readability: The ease with which you can read and understand the source code of a system, especially at the detailed-statement level.
- Accuracy: The degree to which a system, as built, is free from error, especially with respect to quantitative outputs. Accuracy differs from correctness; it is a determination of how well a system does the job it is built for rather than whether it was built correctly.

At the same time, we should consider what our references put forth.⁵ “Standards shouldn’t be imposed at all, if you can avoid them. Consider the alternatives to standards: flexible guidelines, a collection of suggestions rather than guidelines, or a set of examples that embody the best practices.”

What Standards?

Standards were established for development work as well as for language coding. This document primarily covers the standards and guidelines of language coding (currently Fortran 95/F2003). This also establishes less formal (and more formal) techniques within the groups: design and code reviews, design and code walk-throughs, automated version control (both for source code and documents), and other practices that generally affect the quality of software products.

Application of the Standard

How does one measure whether an item “meets” the standard? It could be said that:

One must measure objectively. Ideally, it would be automated either through the compiler used or the use of an auxiliary program if it didn’t require too many resources to set-up.

As some examples of concepts that encourage good coding, *Code Complete*⁵ puts forth the following techniques as being useful:

1. Assign two people to every part of the program.
2. Review every line of code.
3. Require code sign-offs.
4. Route good code examples for review.
5. Emphasize that code listings are public assets.
6. Reward good code.
7. An easy standard: Make the code readable!

This document will provide further information on ideas from various team members on producing good, consistent code for the EnergyPlus project. However, it should be remembered by all that the EnergyPlus project will rely heavily on the discipline and discretion of the various team members to conform to the guidelines established in this document as much as possible. Much of the information in this document will lean towards a “guideline” rather than a “standard”. The intention is to keep the code as uniform as possible without imposing too many rigid rules that in and of themselves become a hindrance to the successful completion of the project.

⁵ McConnell, Steve. 1993. *Code Complete: A Practical Handbook of Software Construction*, Redmond, Washington: Microsoft Press, pp 528-530.

Metrics

Metric: A standard of measurement.¹

Metric is another way of saying “standard”. Sections under this topic will illustrate various measures that might be applied to source code, documentation, user interface and other elements of a system.

Referring to *Code Complete*⁶, “the term ‘metrics’ refers to any measurement related to software development. Lines of code, number of defects, defects per...” and gives two solid reasons to measure the software development process:

- 1) Any way of measuring the process is superior to not measuring it at all.
- 2) To argue against metrics is to argue that it is better not to know what is really happening on your project.

Metrics are not an “absolute”; rather, they are methods for showing “abnormalities” that *may* need to be looked at to preserve quality code. In many cases, we will rely on the code reviewers subjective opinion on the understandability of the code. Listed below are some example metrics that developers might want to use as guides when writing EnergyPlus code. It is suggested that developers take some of the ideas from each of these and apply them to their coding assignments.

Complexity Metric

A complexity metric can be used rather than specify a number of lines that must be contained in a piece of source code. McCabe's technique for measuring complexity can probably be automated and has been correlated to reliability and frequent errors.⁷ The metric is simple, straightforward, and described in the following table.

Table 2. McCabe Complexity Measurement

Enumeration Technique
Start with 1 for the straight path through the routine.
Add 1 for each of the following keywords (or equivalents): if while repeat for and or
Add 1 for each case in a case statement. If the case statement does not have a default case, add 1 more.
Prescription
The routine is probably fine.
Start to think about ways to simplify the routine.
Break part of the routine into a second routine and call it from the first routine.

The code developer will probably find that for most EnergyPlus processes the absolute numbers presented in the second half of the previous table should be taken with some reservation. Most likely, for most processes such low limits on complexity would result in an inordinate number of unneeded subroutines. Again, this particular metric should be applied with common sense.

Lines of Code per routine

This has been put forth as a possible metric and is mentioned in *Code Complete*. Using such a metric might limit the number of lines of code per routine to say 100 or 200. While

⁶ McConnell, 1993, pp 544-547.

⁷ McConnell, 1993, pp 395-396.

programmers might be allowed to make exceptions, these reasons would have to be defended during any code reviews.

Appendix C: Evolutionary Reengineering

Evolutionary reengineering, or ER, might be defined as a process of slowly and selectively introducing new structured code in with legacy code. This process is to start out at the lowest level of module detail and slowly filter one “branch” up through the structure of the program until the main drivers are accessed. By testing a single branch of the module tree in each of the main sections of the code, it can be determined more quickly if the module structure that is being proposing for each section is valid.

This strategy is in some respects the opposite of starting with a clean slate and then trying to piece together the program. In effect, it moves incrementally from old unstructured legacy code to new modular code by incorporating the new code with the old. The existing code retains its capability to interface with the user input data, and is extended to generate parameters needed by the new code modules. In this way, the new modules can be verified without having to completely replace the entire functional capability of the old program with new code before any verification can take place. As the process proceeds, the parameters being supplied by old routines can be supplanted by those available from new routines and new data structures. This makes the transition evolutionary, and permits a smooth transition with a greater capability for verification testing. One main advantage of ER is that there will always be a working version of EnergyPlus available. One slight disadvantage is that there may be the need for temporary scaffolding code to transition from the mixed mode to fully modular code.

The process is shown schematically in the following figure as a series of four stages. The first stage is the starting point with legacy code and traditional input and output. The second stage, which could consist of several substages, incorporates new structured code with the legacy code. This new code receives all needed inputs from the legacy code, and produces only developers’ verification output. This stage is considered complete when it includes the fundamental initial modules, and has defined interfaces for new plug-in modules. In the third stage, the new input data structure is included to supply input to the structured code modules, which have been algorithmically verified. In the fourth stage, the new output data structure is incorporated, and the transition is complete.

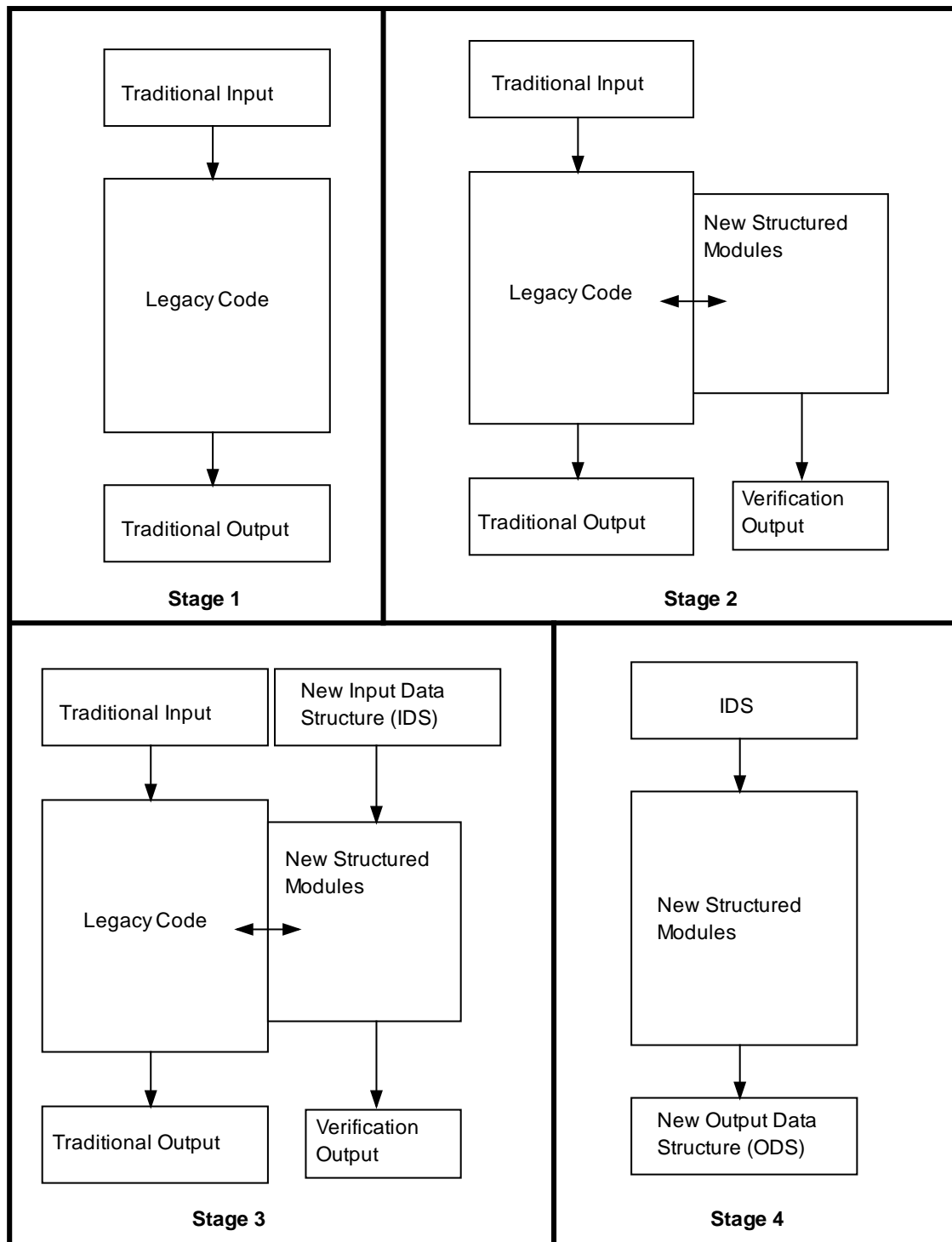


Figure 1. The Evolutionary Reengineering Process.

Appendix D: EnergyPlus Variable Abbreviations

It is preferred that the full word be used in EnergyPlus variables, but this can understandably lead to very long names. In these cases, the following abbreviations *should* be used.

<u>Term</u>	<u>Abbreviation</u>	<u>Term</u>	<u>Abbreviation</u>
Absorptance	Abs	Latitude	Latd
Atmosphere	Atm	Leaving	Leav
Boiler	Boil	Length	Len
Capacit-ance/-y	Cap	Longitude	Long
Chiller	Chill	Luminance	Lum
Coefficient of Performance	COP	Maximum	Max
Coefficient	Coef	Minimum	Min
Coiling Coil	CCoil	Mixed	Mix
Compressor	Compr	Month	Mon
Condensor	Cndsr	Number	Num
Conducti-on/-vity	Cndct	Outside/Outlet	Out
Control	Ctrl	Overhang	Ovrhg
Convection	Conv	Pointer	Pntr
Converge	Cnvrg	Preheat Coil	PCoil
Cooling	Cool	Pressure	Press
Delta	Del	Psychrometric	Psych
Density	Dens	Radiation	Rad
Design	Des	Reflectance	Refl
Diffuse	Dif	Reheat Coil	RCoil
Direct	Dir	Return	Ret
Electric	Elec	Saturated/ion	Satur
Emissivity	Emis	Schedule	Sched
Emittance	Emit	Setpoint	Setpt
Energy	Enrgy	Simulation	Sim
Entering	Entr	Specific	Spec
Enthalpy	Enthl	Summation	Sum
Environment	Envrn	Supply	Supp
Equipment	Equip	Surface	Surf
Evaporat-or/-ive	Evap	System	Sys
Exhaust	Exh	Temperature	Temp
Exterior	Ext	Temporary	Tmp
Factor	Fac	Thrott-l-e/-ing	Throt
Fraction	Frac	Total	Tot
Generator	Gen	Transmittance	Trans
Ground	Gnd	Turbine	Turb
Heating Coil	HCoil	Velocity	Vel
Horizontal	Hor	Ventilation	Vent
Humidity	Hum	Vertical	Vert
Illuminance	Illum	Visible	Vis
Infiltration	Infil	Volume	Vol
Inside/Inlet	In	Window	Win
Interior	Int		