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ENERGYBASE: THE MERGER OF BLAST AND DOE–2

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ABSTRACT

For the past several decades, the US government has maintained and supported two hourly building energy simulation programs, DOE–2 and BLAST. DOE–2 has been supported by the Department of Energy (DOE), and has its origins in the Post Office program written in the late 1960s for the US Post Office. BLAST has been supported by the Department of Defense (DOD), and has its origins in the NBSLD program developed at the US National Bureau of Standards (now NIST) in the same time period. For the loads calculation DOE–2 uses a room weighting factor approach and BLAST uses a heat balance approach.

The need for two separate government supported programs has been questioned for many years, and discussions of the possible merger of the two programs began in May 1994 with a DOD sponsored conference in Illinois. The project began in earnest in 1995 with a two-phase plan. The goal of the first phase is to combine the best features and capabilities of BLAST and DOE–2 into a new program. The new program will have a modular structure making it more amenable to accepting modifications and additions. The first phase is being done by a joint team with members from the University of Illinois, the Lawrence Berkeley National Laboratory, and the US Army Construction Engineering Research Laboratories. The goal of the second phase, which will begin in 1998, is to produce a new generation energy analysis tool using the lessons learned from not only the current programs, but the combined program as well.

The phase 1 combined program, called EnergyBase, incorporates several innovative features including variable time steps of less than an hour, built-in template and external modular systems simulation modules that are integrated with a heat balance based zone simulation, and generalized input and output data structures tailored to third party interface development. This paper presents an overview of the organization and capabilities of EnergyBase, describes the restructuring process that was necessary to build an easily extensible collection of modules, and explains the rationale behind the overall program organization.

INTRODUCTION

The Federal Government, as the largest owner and operator of buildings in the United States, has long been aware of the importance of energy conscious building design and operation. Energy conscious engineering has the potential to save building owners and tenants millions of dollars and contribute to the conservation of vital natural resources. In an effort to promote energy efficiency, both DOD and DOE have separately funded the development of building energy analysis tools since the 1970s.

At the outset, both research efforts charted separate courses toward the same goal, a robust and comprehensive building energy analysis program. There was no way of knowing a priori which path would achieve the goal; therefore, it was prudent to fund multiple development efforts toward the same end. As it turned out, both research projects succeeded in producing useful energy analysis tools. The DOD effort produced the Building Loads Analysis and System Thermodynamics (BLAST) program that has its origins in the NBSLD program developed at the US National Bureau of Standards (now NIST). The DOE effort produced the DOE-2 program that has its origins in the Post Office program written for the US Post Office. The two programs are comprised of hundreds of subroutines each designed to solve a specific problem in achieving the overall goal. In some cases, the subroutines developed by the DOE-2 team were more accurate. In other cases, the subroutines developed by the BLAST team were more accurate.

The research initiative outlined in this paper describes the current efforts to consolidate the research and development gains of the last two decades. The name chosen for the new program is EnergyBase. The goal is to take the best features and capabilities of BLAST and DOE-2 and combine them in a new program. Many new building technologies that cannot be evaluated by either BLAST or DOE-2 will be accessible with the new tool. In addition, a number of building simulation models that today can only be used by researchers will be included in the new program

THE STRUCTURE OF ENERGYBASE

Overall Program Structure

EnergyBase will be structured using a free format input file that contains a complete object-based description of the building and HVAC systems. This input file will be of a form that can be produced from the DOE-2 Building Description Language (BDL) file, the BLAST input file, or using preprocessing agents which may be developed in the future.

The building simulation will be based on the heat balance engine from IBLAST, a research version of BLAST with HVAC systems integrated into the building simulation. In order to provide maximum flexibility, an HVAC engine will be developed to handle the communication between the heat balance engine and the various HVAC modules, including DOE-2 and BLAST template systems, SPARK, HVACSIM+ systems, and other systems that may be developed in the future. The HVAC manager will also manage data communication between the HVAC modules and the input and output data structures.

The calculation engine will write results into an output data structure accessible to output post-processing agents. The output data structure will be simple yet complete so that interface developers can easily access the results of the simulation without modifying the calculation engine. The overall program structure is summarized in Figure 1.

Solution Technique: Integrated Simulation

There is strong consensus in the design community that a tool with additional capabilities is needed. Recent user surveys by both DOE and DOD indicate strong support for the project. This is in large part due to the inclusion of integrated simulation capabilities in the new program. EnergyBase will utilize the IBLAST integrated solution technique to correct the most serious deficiency of the BLAST and DOE-2 sequential simulations — the inaccurate prediction of space temperatures. Accurate prediction of space temperatures is crucial to energy efficient system engineering. System sizes, plant sizes, occupant comfort and occupant health are dependent on space temperatures.

Integrated simulation allows engineers and architects to evaluate a number of energy saving measures that cannot be simulated adequately with either DOE-2 or BLAST. These include:

1. "Free cooling" using outside air.
2. Realistic system controls.
3. Moisture adsorption and desorption in building elements.
4. Radiant heating and cooling systems.

Program Elements to be Combined

In addition to providing users the capability of using either BLAST or DOE-2 input formats, EnergyBase will incorporate features from both programs into the calculation engine. The table below summarizes the capabilities of each program that will be used.

Table 1. Source of EnergyBase Program Elements

Concepts to be taken from IBLAST
- Heat Balance Engine
- Simultaneous Solution Technique
- Coil Models
- Interior Convection
- Internal Mass
- MODSIM Connection
- System and Plant Models
- Combined Heat and Mass Transfer
- Radiant Heating and Cooling
- Thermal Comfort

Concepts to be taken from DOE-2
- System and Plant Models
- SPARK Connection
- Input Function Capability
- Daylighting and Luminance
- Advanced Fenestration
- Switchable Glazing
- Sky Models

New Features
- HVAC Water and Air Loops
- Interzone Airflow

Implied New Programming for Infrastructure
- New Reporting Mechanism

Simulation Management

At the outermost program level, a Simulation Manager Module (shown schematically in Figure 2) controls the entire loop structure of the simulation. This includes all of the simulation loops from the subhour level up through the complete simulation period, which may be a season or a year or several years. The actions of the individual simulation modules are directed through simulation status flags. These flags tell the simulations to take certain actions such as initialization, reporting or record keeping.

The Heat and Mass Balance Engine

The EnergyBase program will incorporate a heat balance model for building thermal zone simulations. Several fundamental assumptions are implied in the formulation. The most fundamental of these is that the air in the thermal zone can be modeled as well-stirred. This means it has a uniform temperature throughout the zone because it mixes by motion within itself. There is ongoing research into more complex models lying somewhere between the well stirred model and a full CFD calculation. The EnergyBase modular structure will allow these models to included into an energy simulation so their overall effect on can be evaluated from many viewpoints.

The other major assumption in the current heat balance model is that the surfaces of the room (walls, windows, floor, etc.) can be treated as entities having:

- uniform surface temperatures,
- uniform long and short wave irradiation,
- diffuse radiating surfaces, and
- one dimensional heat conduction within.

Within the framework of these assumptions, the current heat balance model can be constructed out of four distinct processes:

1. The outside face heat balance.
2. The wall conduction process.
3. The inside face heat balance.
4. The air heat balance.

The air heat balance also implies an air mass balance which takes into account various mass streams (exhaust air, infiltration, etc.). The relationships between the four fundamental processes are shown schematically in Figure 3. Each of the fundamental processes is shown in a rounded box in the figure. The energy flow is indicated with arrows. If an energy exchange is taking place, the arrows point in both directions.

The processes depicted in Figure 3 are for an opaque surface. A transparent surface would be similar except the absorbed solar energy would be split into an inward and an outward flowing fraction. These, in turn, would participate in the corresponding surface heat balances. Except for the air heat balance, the processes shown are repeated for each surface in the zone or space.

The HVAC Engine

The sequential simulation of building, air distribution system and central plant found in DOE-2 and BLAST imposes rigid boundaries on the program structures. The simultaneous solution technique used in EnergyBase allows for the redrawing of those boundaries.

The schematic in Figure 4 visualizes a typical system in the context of the EnergyBase simulation. The HVAC systems have been divided into three Blocks on the basis of information flow. The goal was to minimize the information flow paths between blocks so that data could be localized to the greatest extent possible. The heat extraction block represents the interaction with the heat balance engine. This is indicated by the squares labeled zones. The schematic shows only two zones per system type, and two system types, but these numbers can be increased arbitrarily. The information that passes between the interface block and the heat extraction block consists of airflow rates, enthalpies, and temperatures. This is the information needed by the air balance part of the heat balance engine.

The supply component block contains the code to simulate the primary energy components such as boilers and chillers. Again, the information that is passed to the interface block consists of flow rates and temperatures, in this case of fluid which could be water, brine, refrigerant or other heat transfer medium.

The interface block contains the routines necessary to simulate the pumps, fans, coils, and airflow control devices. Of these, the coil simulation is the most difficult, and a modular structure within the block allows alternative coil models to be substituted easily.

The EnergyBase HVAC simulation will be based on “water distribution loops” and “air distribution loops” rather than equipment types. This structure results in a blurring of the traditional boundaries between the building, the air distribution system and the central plant.

SOFTWARE DEVELOPMENT PLAN

Programming Goals

FORTRAN90 (F90) was selected as the programming language for EnergyBase for two reasons:

1. Both BLAST and DOE-2 were written in previous versions of FORTRAN.
2. F90 allows movement toward an object-based simulation by providing a modular structure.

In the context of this development, F90 refers to the full American National Standard 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). Two subclasses of code will be allowed in the program:

- FORTRAN90 Strict — Code that adheres to at least the FORTRAN77 standard and includes all new features of FORTRAN90.

- FORTRAN90 Pure — Code that does not contain any of the features which have been ruled obsolete by the FORTRAN90 standard.

Three types of code may coexist in any particular version of the program at one time:

- Legacy Code — Program code from IBLAST and DOE-2 that will not be revised (no algorithm changes) for reasons of time constraints, testing considerations, etc.
- Reengineered Code — Concepts that have been reengineered based on first principles and then modified to fit the proposed guidelines agreed upon by the team members. The starting point for reengineered code is capabilities from either IBLAST or DOE-2.
- New Code — Code which has been written from scratch, i.e., completely new code.

However, while these types of code will coexist in the EnergyBase source, different expectations on the relative "purity" of the code will be enforced. All legacy code that is included in EnergyBase must be at least F90 strict. Mildly reengineered code (near legacy) which 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 pure standard.

Modularization of the Code

In order to facilitate easy extensions to the basic capabilities of EnergyBase, the developers are following a modularization process that results in a more object oriented structure. Three types of modules are being used: modules that contain data only, modules that contain both data and procedures, and some modules that only contain procedures. The data only modules are used to make global data available to modules throughout the code. The data plus procedure modules are the workhorses of the simulation, and the procedure only modules supply utility functions. In order to make the modularization possible it is necessary to incorporate a series of manager modules. The function of these modules is to control the overall execution of the program.

The Reengineering Process

The modularization described in the previous section involves a major restructuring of the code contained in either DOE-2 or BLAST. Such a restructuring could result in major rewrites involving a long development time period, and very extensive testing to ensure the new code performs as intended. However, because the development team has chosen Fortran90 as the language with Fortran77 as a subset, the development can proceed using a process which we call Evolutionary Reengineering (ER). This is a newly developed process that incrementally moves 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.

The process is shown schematically in Figure 5 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.

SIMULATION INPUT FILE CONCEPTS

While both DOE2 and IBLAST have structured input file definitions that have grown over time, EnergyBase has been designed as a product for the "future". In order to maintain the possibility of accepting simulation inputs from many sources, such as CADD systems, programs which also do other functions, and similar pre-processors that have been written for BLAST and DOE2, we have chosen to keep the actual input file very simple. It is not intended as the main interface for the end-user. We intend that users will be hooked into other systems. The actual input file, while readable, will be cryptic and definitely not "user-friendly".

There will be a modicum of words that denote "objects" of the building simulation, such as WALL, MATERIAL, LIGHTING, SYSTEM, HEATING COIL, etc. Following each object will be a list of values, which describe to EnergyBase the intentions for that item in the simulation. By working with outside interface developers, we intend to keep this file easy to produce from most programs that building designers will use. In addition, with the very loose structure (which will be more rigorously depicted in a Data Dictionary), we intend that new module developers will find it easy to add capabilities to EnergyBase.

CONCLUDING REMARKS

The EnergyBase project not only combines the best features of the BLAST and DOE-2 programs, but also represents a significant step towards next generation building simulation programs both in terms of computational techniques and program structures. Connectivity and extensibility are overriding constraints in the design process. This will ensure broad participation in program enhancement and facilitate third party interface development.

Every effort has been made to maintain continuity between the existing BLAST and DOE-2 programs and EnergyBase. The BLAST and DOE-2 development teams were merged into a single team for the EnergyBase project, and a high priority has been placed on an input format and program structure that facilitates transition to the new program.

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FIGURES

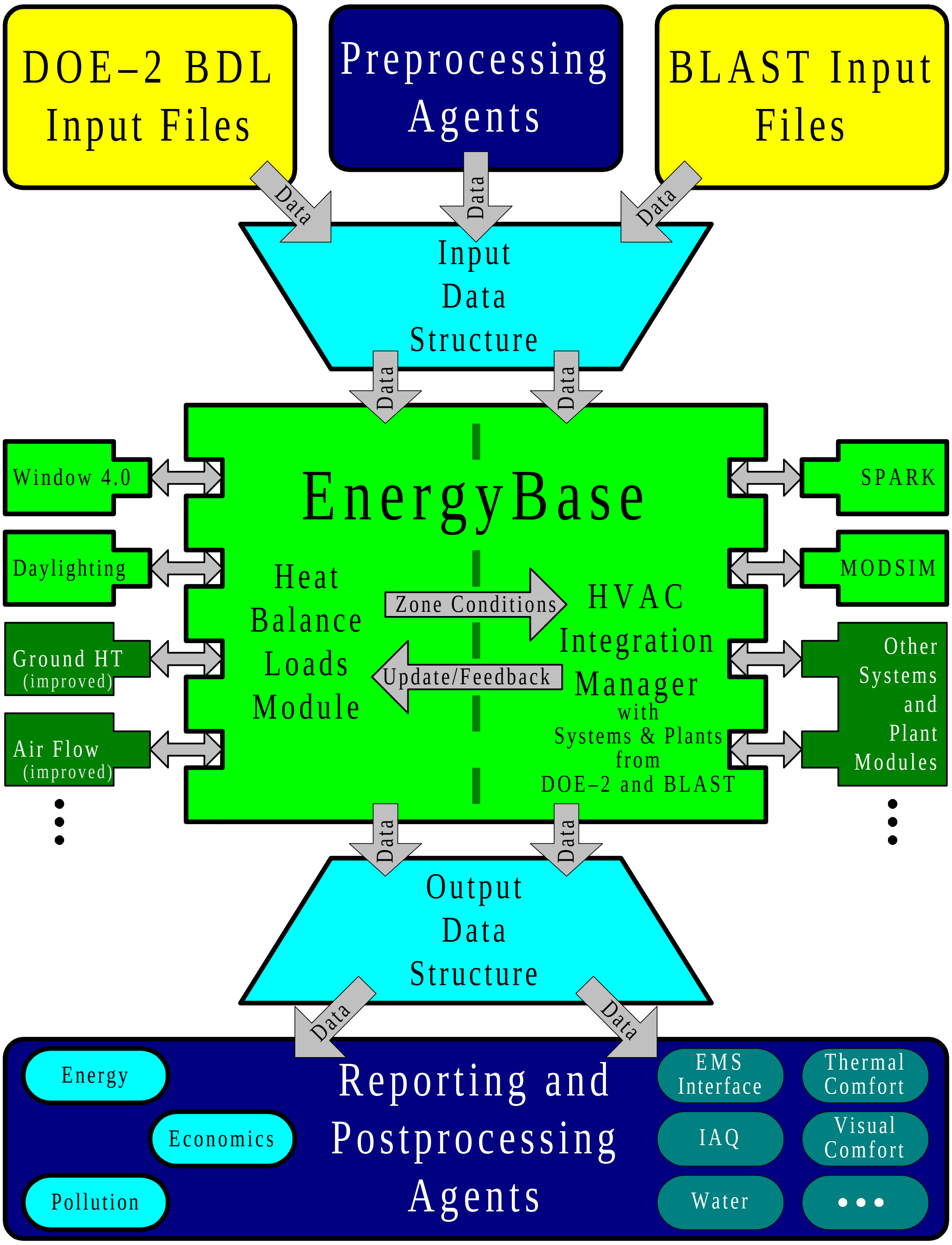

Figure 1. Simulation Overview

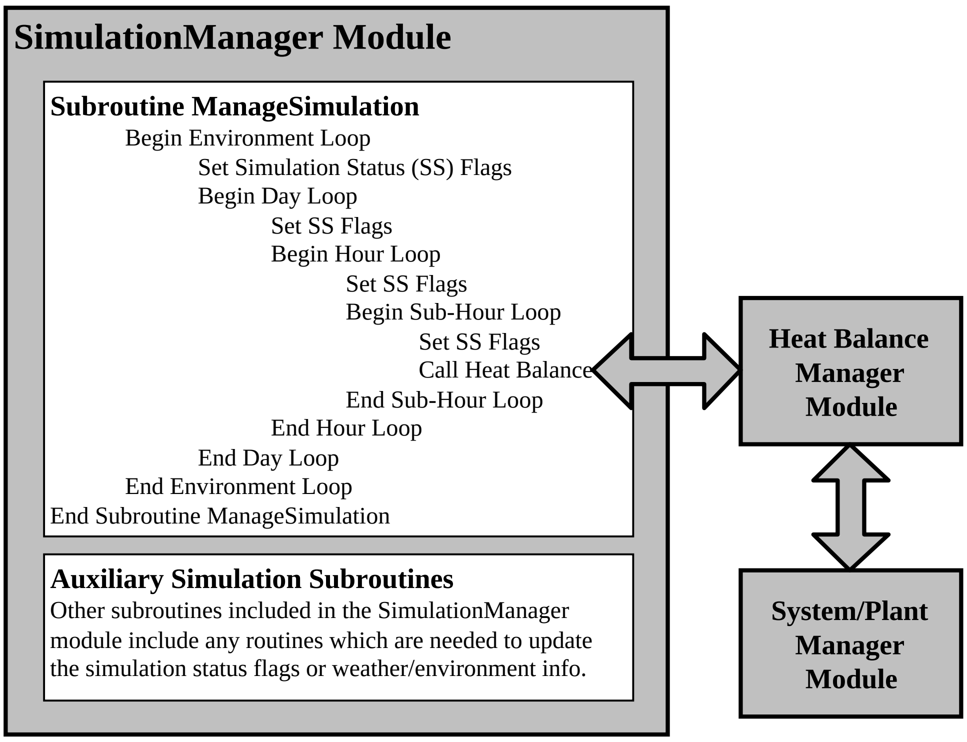

Figure 2. Simulation Manager

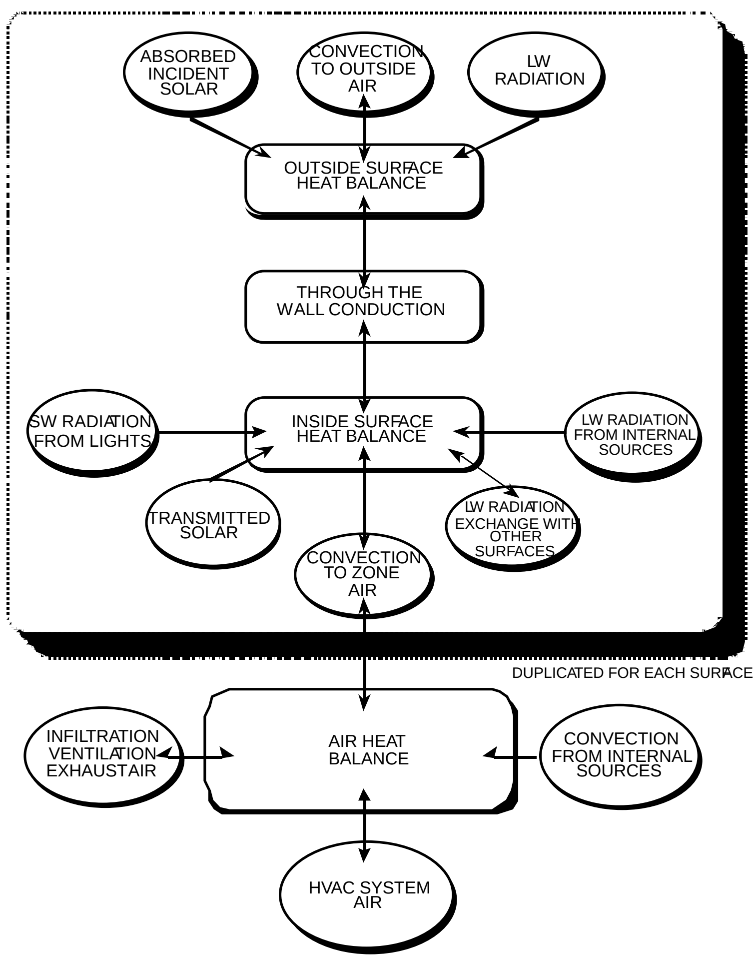

Figure 3. Heat Balance Solution Technique

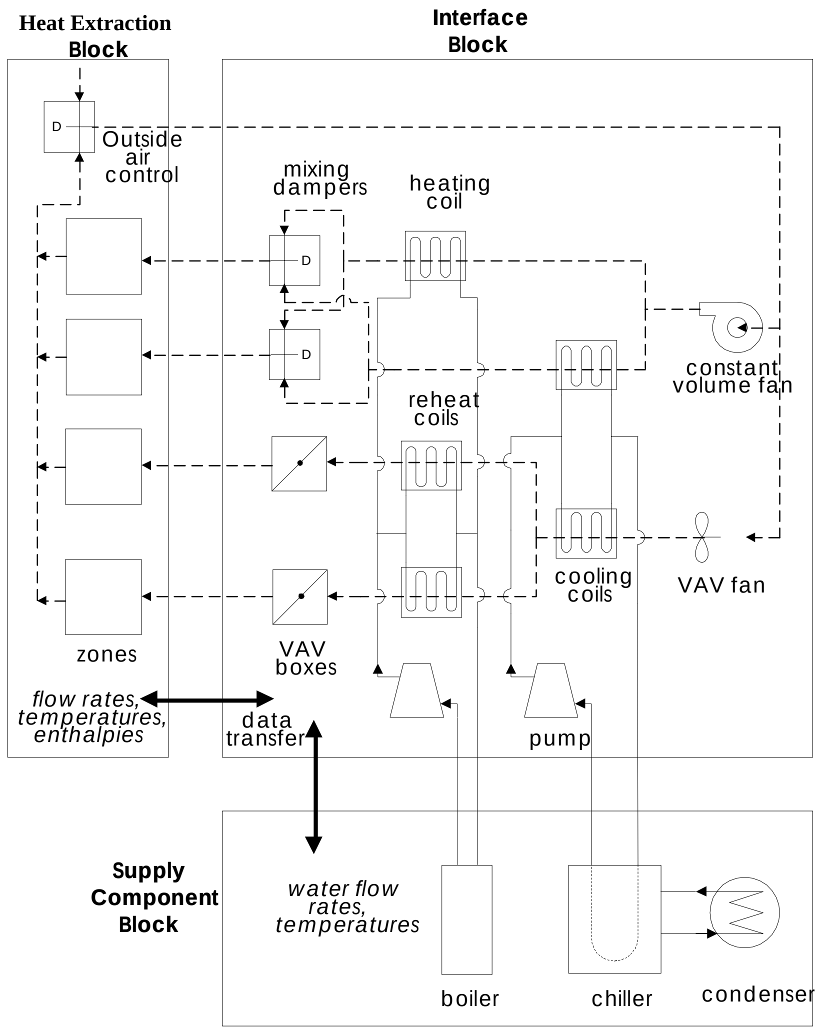

Figure 4. Schematic of Representative HVAC Simulation

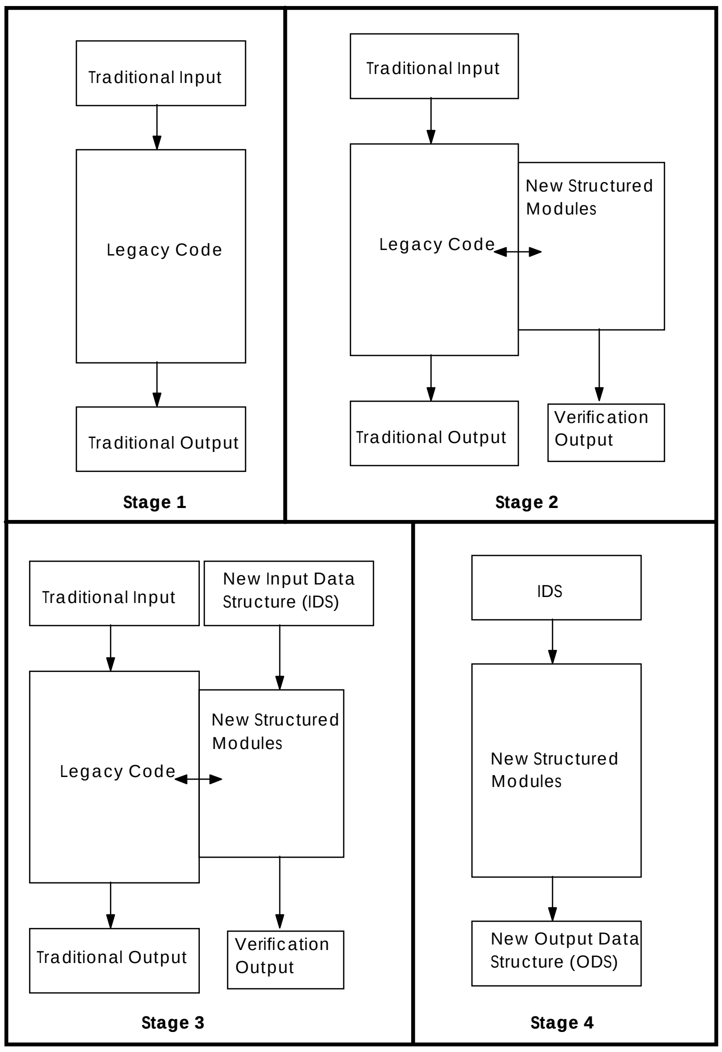

Figure 5. Evolutionary Re-engineering Process