INCORPORATING A MODULAR SYSTEM SIMULATION PROGRAM INTO A LARGE ENERGY ANALYSIS PROGRAM: THE LINKING OF IBLAST AND HVACSIM+.

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ABSTRACT

Most currently available hourly energy analysis programs utilize separate and sequential simulations of the building, air handling systems, and primary energy plants. This results in a lack of feedback from the system to the building and from the plant to the system and building. This is especially a problem when an undersized system or plant is simulated. If an undersized system were actually installed in a building the zone cooling and or heating loads could not be met all the time causing the temperatures to float out of the desired range. An integrated building simulation can represent this condition well but the BLAST simulation, because of its sequential nature cannot. The BLAST program has recently been revised to eliminate the separate simulations. The resulting integrated program is called IBLAST and it contains a large library of system and plant types which can be selected and sized by the user. This work further improves user flexibility in defining system and plant arrangements by incorporating MODSIM, a program. element of the HVACSIM+ package, into IBLAST. The combined program is substantially enhanced and retains all of the functionality of both components. In addition, MODSIM can obtain all required system parameters from the IBLAST input file or they may be specified in a MODSIM data file.

The adaptive time step feature of MODSIM is utilized to allow the fast responding elements of a system to be simulated at a time step on the order of seconds. The slow response of massive building elements is simulated at larger time steps, typically fifteen minutes or longer, which are user specified. The **MODSIM** time step is always smaller, and adapts to provide an integral number of steps between IBLAST time steps.

This paper presents results obtained using MODSIM systems with IBLAST. Specifically, a single zone draw through and a multizone fan system are illustrated along with a description of the steps required to produce the MODSIM connection diagrams for each system. Methods used to símulate non-traditional systems are also discussed.

INTRODUCTION

Building and HVAC simulation software has been in existence since the 1970's, but generalized system simulation has not been developed sufficiently to gain widespread use. Earlier attempts at a component-based simulation that allowed user definable connections between the components have suffered from numerical instabilities, have been computationally prohibitive, and simulation set-up has often been lengthy and awkward. Recent advances in computational power and simulation techniques have warranted another look at generalized system simulation. The integration of MODSIM into IBLAST (Integrated Building Loads Analysis and System Thermodynamics) was identified as an approach which would create a software tool that researchers and designers could quickly and easily use.

The IBLAST program (Taylor et al. 1990, 1991, 1994) is a current generation building simulation program which was developed as a major revision to BLAST. IBLAST is capable of simulating a building and its mechanical systems for an entire year but differs from its predecessor by solving the zone, system, and central plant simulations concurrently instead of sequentially. This enables IBLAST to directly model interactions between the building, fan system and central plant simulations and eleminates entirely the concept of unmet loads. Unmet loads are generated by the BLAST program when a system or plant is improperly sized and, consequently, cannot meet the zone conditioning demand. Instead of unmet loads, IBLAST is able to show the how the zone temperatures are affected by the by the incorrectly sized equipment. An added benefit of the IBLAST integrated building simulation method is that it is more suitable for adding a generalized system simulation to than BLAST.

In IBLAST the system simulation solves the zone heat balance for the system and plant output by using a zone temperature setpoint and by lagging the zone response to the system by one time step which may be arbitrarily defined by the user though experience with the program has shown that a time step between 10 to 15 minutes, substantially shorter than the one hour BLAST time step, works well. The fan system and central plants are then solved simultaneously assuming that the dynamics of any interactions occur on a much shorter time scale than the user defined time step. In fact, the system-plant simulation time step is allowed to vary during the simulation and has a maximum value equal to the user specified time step. Finally, the zone supply air conditions and the system output are sent to the zone heat balance calculation which updates the zone temperature. If the fan system has sufficient capacity, the zone temperature will be very close to the setpoint. But, if the system is not sized correctly, the zone temperature floats until the energy balance is satisfied.

Since system output is not approximated in IBLAST, the zone conditions accurately reflect the system output. System control strategies that are dependent on conditions other than the zone temperature (such as ventilative cooling and purge cycles) can now be simulated accurately since zone conditions are controlled by the system response alone. However, as previously reported (Taylor et al. 1990, 1991) the actual behavior of the system and the stability of its response to controls are dependent on the relative size of the load compared to the system capacity. An undersized system will not be able to control the temperature in the zones it serves. An oversized system will have the capability of maintaining the desired conditions, but may become unstable because the sensitivity of zone temperature to controller signal is large.

THE NEED FOR GENERALIZED SYSTEMS SIMULATION.

One of the attractive features of generalized simulation packages is the relative ease of creation of new systems and new system components. In IBLAST, there is a system simulation subroutine specific to each system which calls a fixed set of system component subroutines in an order appropriate to that system. In IBLAST, modification of systems or the addition of new ones requires existing code to be changed. If the system requires parameters not already present in the input file structure, changes must be made to the input file parser and data structure as well. A way to create new systems needs to be made available since the diversity of systems being used in practice is increasing faster than it is possible to develop and implement them. Integration of MODSIM into IBLAST also allows new or non–traditional systems to be easily compared with more common ones. The combination of IBLAST and MODSIM provides the user with a robust and relatively easy to use program which does not require intimate knowledge of the program's internal structure.

HVACSIM+

HVACSIM+ (HVAC SIMulation PLUS other programs) (Clark and May 1985) was produced by the National Institute for Standards and Technology (NIST). The HVACSIM+ package consists of several programs: MODSIM (MODular SIMulation), the main simulation code; HVACGEN, a menu based preprocessor to create simulation files and SLIMCON, which converts simulation files into MODSIM input files. Also included are CTFGEN, a utility for using the zone model supplied; CRWDTA and RDTAPE, used for processing weather data and SORTSB, a post processing utility. In addition to the programs provided, a library of HVAC component routines is provided.

MODSIM uses a modified Newton-Raphson method as its primary solution technique. Simulation units are grouped into blocks and blocks may then be grouped into superblocks. At the block level the Newton-Raphson method is used, but a sequential solution method is used between superblocks. Blocks are collections of units which are simulated simultaneously. They should be comprised of components which are tightly coupled or units that logically comprise subsystems. However, for small simulations it may be appropriate to use only one block. Blocks within an individual superblock are solved simultaneously, but no simultaneous equations are defined between superblocks. The division of the simulation into block and superblock groupings reduces the number of active state variables for each level of solution, allowing for a faster simulation.

MODSIM also allows variables to be "frozen if an output of a unit is changing less than the error tolerance with each call. The variable is still calculated but is considered resolved for that time step. Therefore, the solver does not attempt to find its derivatives for the Jacobian matrix. This can greatly increase the speed of the simulation though some error may be introduced. Freezing is recommended for algebraic outputs, but discouraged for differential equations and outputs of routines that contain discontinuities.

MODSIM has the capability to use an adaptive time step. The user specifies a minimum and maximum time step, and can set the criteria for changing the step size. This allows the user to capture the dynamics of an HVAC system, but still achieve reasonable computational performance. An example of when this feature would be advantageous would be a building exposed to a step change in setpoint temperature causing conditions to rapidly change for a short period of time. A complete description of this feature is in the HVACSIM reference manual (Clark 1985).

INTEGRATION WITH IBLAST

IBLAST is separated into three fairly distinct computational areas: zone loads, fan systems and central plants. The system calculations are solved by lagging the loads one user defined time step (usually 10-15 minutes). The central plants are solved simultaneously with the systems by assuming quasi-steady conditions. Complete details of the calculation methods used are documented in (Taylor et al. 1991, 1994). IBLAST uses the BLAST heat balance in its zone model. But, it was necessary to introduce zone capacitance into the equation because of problems with stability. The heat balance equation with capacitance is shown below.

$$C_z \frac{dT_z}{dt} = \sum Q_c + \dot{m}_{\sup} c_p (T_{\sup} - T_z) + \dot{m}_{\inf} c_p (T_\infty - T_z) + \sum_{i=1}^{n_{zones}} \dot{m}_i c_p (T_{zi} - T_z) + \sum_{i=1}^{n_{surfaces}} h_i A_i (T_{si} - T_z) \quad (1)$$

where

C_Z	zone capacitance term (includes air and zone furnishings constructed of light materials)
$\sum Q_c$	non-flow heat source terms
$\dot{m}_{\sup} c_p (T_{\sup} - T_z$	heat from supply air
$\dot{m}_{\inf} c_p (T_\infty - T_z$	heat from infiltration
$\sum_{i=1}^{n_{zones}} \dot{m}_i c_p (T_{zi} - T_z)$	heat due to cross mixing from other zones
$\sum_{i=1}^{n_{surfaces}} h_i A_i (T_{si} - T_z$	heat due to convection from surfaces in zone

Initially, the IBLAST method of solving this equation was retained with the hybrid program, but the system became unstable when the MODSIM and IBLAST time steps were allowed to be independent. The zone air temperature must be updated at every MODSIM time step. Accordingly, when a MODSIM system is invoked by IBLAST the heat balances for the zones served by that system are solved using MODSIM's built-in differential equation solver. A new MODSIM type subroutine, Type 70, was developed specifically to accomplish this. This was a departure from the IBLAST program which uses explicit finite differencing to solve Equation (1) and calculate the new zone temperatures. In effect, MODSIM mirrors the IBLAST zone temperature update procedure and the two methods run in parallel so that a mix of IBLAST and MODSIM systems may be used in a single input deck. In addition to updating the zone temperatures, MODSIM also determines the output and performance of each MODSIM system.

INTEGRATION MECHANICS

Both IBLAST and MODSIM exist as self contained programs, and neither lends itself to being a subroutine called by another program. Calling one program and then the other on a single time step basis would work except that it would require massive code restructuring. As the goal of this project was to simulate the system using MODSIM leaving the other components of the zone heat balance to be determined by IBLAST the best solution was to have IBLAST call MODSIM. This allowed the retention of MODSIM's adaptable time step feature which was very desirable because it allowed system and control transients to be tracked accurately. In addition, this meant that the constant, though user definable, time step for the IBLAST load calculations could be retained. This solution was compatible with the physics of the problem in that the fan systems and the zone air temperatures respond much faster than variables associated with zone surfaces.

The resulting combined program should continue to be easy to use for people familiar with either BLAST or MODSIM. Both input files were retained, though some overlap now exists. Many of the quantities needed in the system simulation can be obtained from either file. Therefore, a set of simplified components that act similarly to their IBLAST counterparts was constructed, allowing a user to create systems comparable in function to IBLAST systems.

PROGRAM MODIFICATIONS

Even though MODSIM became a dependent subroutine of IBLAST every effort was made to limit modifications to MODSIM. The main MODSIM routine was split into three sections by using FORTRAN's alternate entry and return statements. This allowed the initial set-up to be called once, the main time step loop multiple times, and the wrap-up once at the end of the simulation. This allowed MODSIM to be used intact with only minor code additions and changes. Printing current time step information to the screen was also supressed. If future revisions of MODSIM are released, they easily can be linked to IBLAST.

Modifying IBLAST to call MODSIM presented a bigger challenge. First, the MODSIM method of determining system response was made to look indistinguishable from other systems by wrapping MODSIM in a dummy system routine. Second, the portion of IBLAST that called the systems had to be modified to because zone temperatures are updated after all the systems have been called. The routine was revised to exempt MODSIM controlled zones from this updating, because their zone temperatures are revised within type 70 at every MODSIM time step.

A third change was to make sure the custom modular system was called for every IBLAST time step. Regular IBLAST system routines are not called when they are scheduled off, but the MODSIM zones need to be called every IBLAST time step so that the zone temperatures are updated. This change was also needed to maintain synchronization of the IBLAST and MODSIM time steps. If MODSIM were not called, the system would simulate the hours it was shut off during the first time step of scheduled operation.

Other changes were made in the parser section of the IBLAST code. IBLAST obtains information about a simulation from an input file that is very structured so as to be readable by the user. One of the first steps in IBLAST execution is to parse the input file. Additional parser language was generated to recognize the new system type 'custom modular system'. A set of custom user defined hourly schedules was included to complement the MODSIM boundary file. The user defined schedules are made available in type 64, which is described in the types library (Metcalf, 1994).

COMMON VARIABLES

The type of information that needs to be shared between the two programs is simulation specific, with the exception of the simulation time step and zone supply air conditions. All other information from IBLAST may or may not be applicable, depending on how the modular simulation is constructed. Nearly all information in IBLAST is passed internally using common blocks. Information such as simulation time, system and zone number, and system output quantities must be converted from IBLAST variables to MODSIM variables. The required communication is accomplished mostly through the use of specialized types in MODSIM which include the needed IBLAST common blocks.

TIME STEP SELECTION

MODSIM uses seconds as the fundamental unit of time. IBLAST uses hours, but keeps track of time using separate variables for the hour, the number of the step in that hour, and the length of the time step. MODSIM's adaptive time step algorithm adjusts the last time step to reach the ending time exactly. This feature makes the stepping of MODSIM fairly simple; the MODSIM ending time is set to the next IBLAST time step. Additional control logic was required in MODSIM to accommodate IBLAST's resetting of time to zero after each warm-up day since MODSIM had not been designed to have the time reset to zero after the simulation had begun. However, the MODSIM boundary conditions file was retained allowing boundary conditions to change at non-hourly increments and providing a form familiar to MODSIM users.

MODSIM runs with a variable time step which has a maximum value normally set to the IBLAST time step. This allows the MODSIM time step to increase when zone conditions are changing slowly and speeds the overall simulation. Only zone air temperatures and the response of the system can change during the IBLAST time step interval. The result of this is the stair-stepping of the zone air temperature shown in Figure 1.

Abrupt changes in zone temperatures can cause an instability when IBLAST and MODSIM are running on different time steps. The wall temperatures and zone air temperature are coupled, but updates are out of phase with each other. The potential exists for a controller to oscillate while trying to control the zone air temperature because of this time lag in the wall variables. This tendency is damped out by including the capacitance of the air in the heat balance. In other words, by setting the sum of all zone heat sources and sinks equal to the rate of change of zone enthalpy instead of zero. Since this is a differential term it is approximated by finite differencing, and since the time step appears in the denominator the relative size of this term and thus its damping effect increases with the inverse of the time step.

COMPONENT LIBRARIES

The addition of new types to the standard HVACSIM+ library was necessary to accomplish the integration of IBLAST and MODSIM. Three classes of types were created: information types, internally connected types, and 'standard' types. The information types have no inputs; their only function is to provide IBLAST information within the MODSIM environment. The information passed by these types includes: weather data and zone temperature control setpoints. Because of the zone dependency of some information passed through information types, most require the IBLAST system or zone number as a parameter.

The internally connected types are ones that have inputs and outputs, but also modify or use IBLAST variables internally through the use of named common blocks. The most important of these is the zone heat balance, type 70, shown in Table 1. It merges information about the supply air stream with the rest of the zone heat balance terms to update the zone air temperature and humidity. It then makes the updated zone conditions available to both MODSIM and IBLAST. Other internally connected types utilize IBLAST information in their algorithms.

The zone temperature output of type 70 is actually the time derivative of T_{zone} as given by equation 1. MODSIM updates the zone temperature, and substitutes the value for the derivative when needed as an input for other types. The behavior of this differential equation, along with any other differential equations in the simulation, is used by MODSIM when determining the time step.

In addition to the highly specialized types that connect MODSIM and IBLAST, a library of more traditional equipment was written. While MODSIM provides many components, they are often more complicated than required by IBLAST. These standard types are intended to be a consistent set of the simplest components that will provide a realistic simulation. Users wishing to improve the accuracy of a particular component, have the option of either using the types provided with MODSIM or writing their own. This arrangement allows the simulation to be detailed in the area of interest, and run a faster (but less detailed) model in others.

IMPLEMENTATION EXAMPLES IN IBLAST

CASE 1: SINGLE ZONE DRAW THROUGH

The first example system was the single zone draw through (SZDT), one of the simplest systems in common use. A typical SZDT schematic is shown in Figure 2. The heat recovery, preheat coil, return air heat gain, and return fan are omitted from the MODSIMmodel for simplicity. The system has a cooling and a heating coil, both of which are controlled by zone temperature. In actual systems, both heating and cooling is controlled by the same thermostat, but in mutually exclusive modes. In this example, however, separate controllers are used with a dead band built into their setpoints to avoid simultaneous heating and cooling coil operation.

To implement this system using MODSIM a connection diagram must first be developed. This is a graphical representation of the types used and the relationships between their inputs and outputs. Figure 3 shows the SZDT connection diagram for this example.

CASE 2: DUAL DUCT

The second test case was a dual duct system. This system has separate hot and cold air streams which are mixed at each zone to provide the desired supply air temperature. Typically, such a system is not very efficient but provides precise control over zone conditions. A properly sized dual duct system should maintain the space temperatures close to the midpoint of the zone temperature setpoint range. Further details of the model are not described here but may be found in (Metcalf,1994).

RESULTS

This MODSIM simulation was combined with the one zone Ft. Monmouth model from the BLAST User's Guide with appropriate modifications to be compatible with IBLAST. The combined simulation was run with an IBLAST time step of 15 minutes and an adaptable MODSIM time step that ranged from 1 second up to the IBLAST time step. Winter and summer design days based on New York City weather were used for the outside environment.

Figure 4 shows the zone temperature and the controller setpoints as a function of time for the single zone draw through simulation. IBLAST's warm-up days which ensure the elimination of start-up transients, are responsible for the eight days shown in the output. In IBLAST, a day is repeated a number of times until the simulation satisfies a periodic steady state convergence criteria. The last day simulated in each environment is the 'real' (non-warm-up) day. The abrupt change and subsequent dip in zone temperature at hour 96 is due to the step change of the environment from winter to summer. The outside air temperature jumps from -9°C to 23°C, and then proceeds to fall during the night. The warm-up days give the building and simulation a chance to adjust to the change in environment, so that by hour 168, all of the effects of the winter design day should be negligible.

Figure 5 shows the coil control signals and the zone temperature as a function of time. The model exhibits stable control of both coils, staying under the maximum capacity for both heating and cooling. It may be concluded that in this case the system has been reasonably sized.

The results for the dual duct system are shown in Figure 6. This system served two zones each of which were controlled to the same temperature. Figure 6 shows that, after a fairly substantial warm-up period the simulation tends to a steady periodic on a 24 hour cycle, similar to the single zone draw through case, and as expected The zones are controlled stably close to the upper limit of the desired temperature range during the occupied hours of the summer design day, but right at the midpoint of the range during the winter design day.

SUMMARY AND CONCLUSIONS

Combining the zone load model of IBLAST and the modular simulation of HVACSIM$^+$ creates a powerful design tool. By using the IBLAST/MODSIM hybrid, intimate knowledge of the program's internal structure is not required. Only components unique to each system need to be written; traditional components may be used without modification from a full library of IBLAST compatible equipment.

New simulations which utilize existing components may be constructed without having to recompile the program. Simple variations of traditional systems are relatively easy to construct. As an example, a user could evaluate system performance during equipment failures. Simulating stuck dampers or valves and missing control signals would not require the user to re-derive the system's governing equations.

The hybrid combination does not force walls and other massive objects to run at the same time step as the air handling system. The walls usually use a 15 minute time step, while the system and air heat balance are allowed to run much faster, using the adaptive time step capability of HVACSIM$^+$. By running system components at small time steps, even less than a second, the program gains the ability to simulate real time controllers.

LIST OF REFERENCES.

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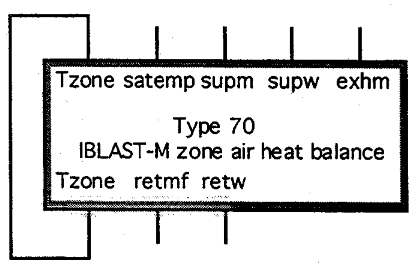
TABLE

Type 70: IBLAST Zone



	#	Name	Type	Description	
inputs	1	Tzone	temp	Zone temperature	(°C)
	2	satemp	temp	supply air temperature	(°C)
	3	supm	flow	supply air mass flow	(kg/s)
	4	supw	humid	supply air humidity ratio	(-)
	5	exhm	flow	exhaust air mass flow	(kg/s)
outputs	1	Tzone	temp	Zone temperature	(°C)
	2	retmf	flow	return air zone mass flow	(kg/s)
	3	retw	humid	return air humidity ratio	(-)
parameters	1	zone	-	IBLAST zone number	

Table 1: Type 70 (IBLAST Zone)

FIGURES

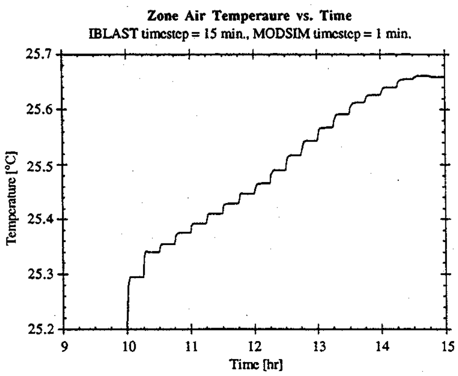


Figure 1: Effect of multiple time steps

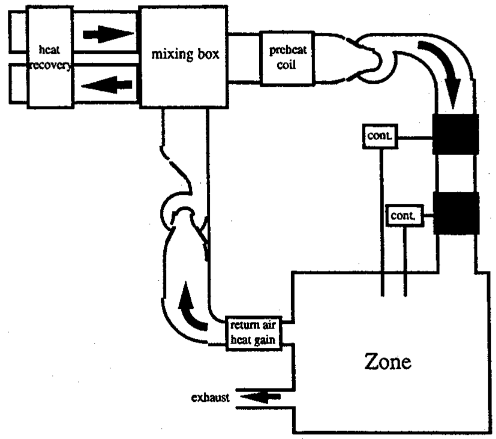


Figure 2: A Single Zone Draw Through System

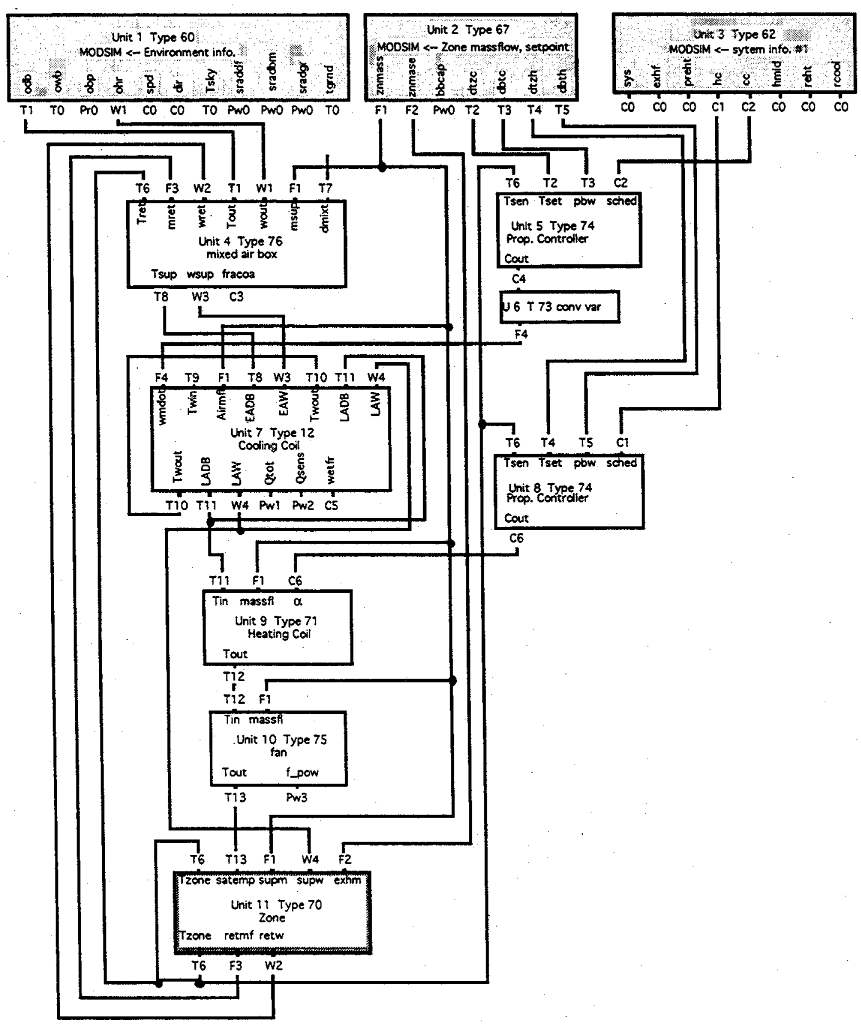


Figure 3: SZDT Connection Diagram

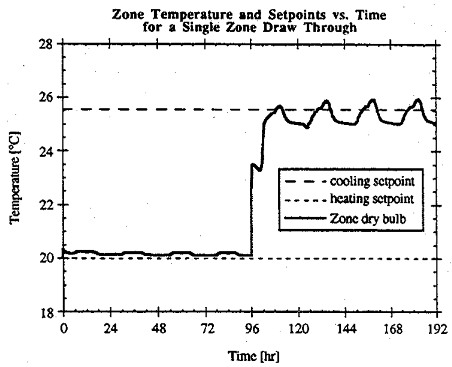


Figure 4: Zone Temperature for SZDT

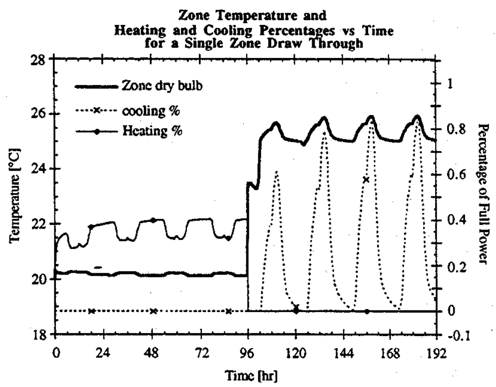


Figure 5: Zone Temperature, Heating and Cooling Percentages

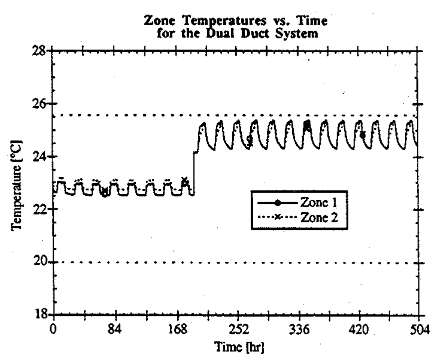


Figure 6: Zone Temps. for Dual Duct System