5. Real-Time Predictive Optimal Control of Active and Passive Thermal Storage Systems

Progress in Past Quarter and Current Status:
The project has two main phases as outlined in the Statement of Work:

- Phase I: Laboratory testing to determine the performance of the proposed TES optimal controls under controlled environment using the HVAC laboratory at the University of Colorado.
- Phase II: Field testing to evaluate the TES optimal controls for two buildings: one in Colorado and the other in Nebraska.

Table 1 summarizes the various tasks and the status of each task. Specifically, we did focus on all the tasks for Phase I.

Table 1: Status of various tasks described in the Statement of Work as of 9/30/2004

PHASE Task No.	Description	Status
PHASE I	**Design and Laboratory Testing**	
1	Design a Prototype Controller	Complete
2	Prepare HVAC Laboratory	Complete
3	Design Lab Experiments	Complete
4	Conduct Lab Experiments	On-going
5	Analyze and Interpret Lab Experiments	On-going
6	Phase I Documentation	To start after completion of Task 5
PHASE II	**Field Testing**	
7	Identify Potential Field Test Sites	One site in Colorado has been identified
8	Prepare Field Sites	On-going
9	Design Field Tests	On-going
10	Conduct Field Tests	To start in May 1, 2005
11	Analyze Field Test Data	To start in May 1, 2005
12	Phase II Documentation	To start in May 1, 2005
	Final Report	To start after completion of phase II

Task 1 (Completed): Design of a Prototypical Controller.
The TES controller being implemented in the laboratory as a DDC-based software that interacts with an external computer to carry out the simulation analysis. In particular, the software performs the following tasks:

1. Read data from data acquisition system for current and future conditions (i.e. zone temperatures, ice level, energy use for various equipment)
2. Calculate through the simulation environment the operating set-points for air-handling unit supply and return fans, chiller and active thermal storage system that result in a minimum energy/demand costs, and
3. Write the set-points and operating modes for the active TES system to files accessible from the building automation system to ensure implementation of these set-points.

For the active TES system, the following operating modes are defined:

- Chiller cooling mode: the chiller is operated to meet directly the cooling load.
- Chiller cooling and charging mode: the chiller is utilized simultaneously to meet the cooling load and to change the ice tank.
- Chiller cooling and discharging mode: the chiller and the ice tank are used to meet the cooling load.
- Charging mode: the chiller is utilized only to charge the ice tank.
- Discharge mode: the ice tank discharges to meet the cooling load.

Currently, the simulation environment based on EnergyPlus is used to adequately mirror the actual building dynamic response. Preliminary results -summarized below- indicated the simulation provide an adequate model for the real dynamic behavior of the HVAC laboratory.

Task 2 (Completed): Prepare the HVAC Laboratory.

Figure 2 provides a view of the HVAC laboratory at the University of Colorado. All the relevant sensors (temperatures, air flows, water flows, ice level, energy use of chiller, pumps, and fans) have been calibrated.

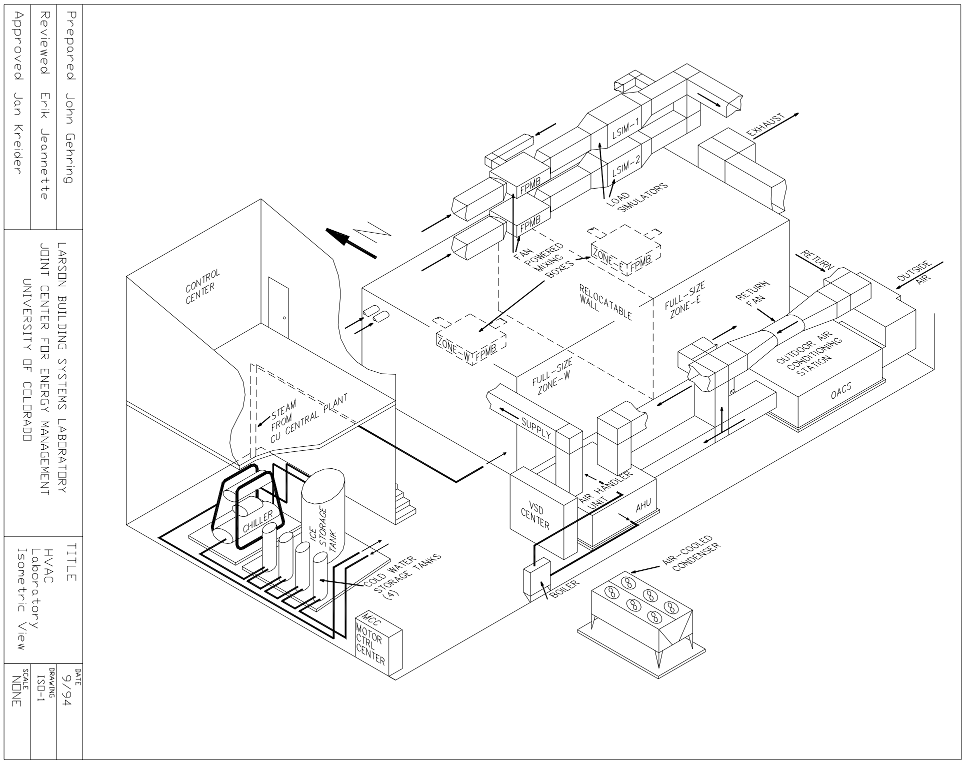

Figure 2: Isometric View of the Full-Scale HVAC Laboratory at the University of Colorado

Task 3 (Completed): Design Lab Experiments.
The two full zones in the HVAC laboratory (see Figure 3) have been set to simulate a typical cooling load profile for office space using the electric baseboards.

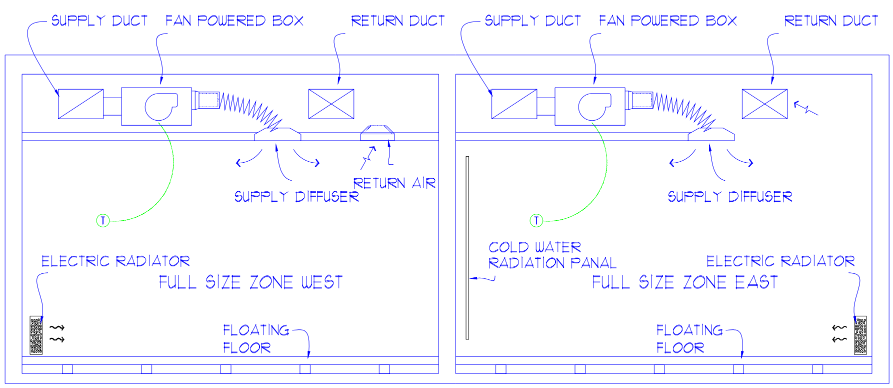

Figure 3: Set-up for the two full-sized zones in the HVAC laboratory

Task 4 (80% Completed): Conduct Lab Experiments.
Most of the laboratory experiments have been completed. Examples of testing results for indoor air temperature are provided in Figures 4 and 5 for various TES controls for respectively, west zone and east zone of the laboratory.

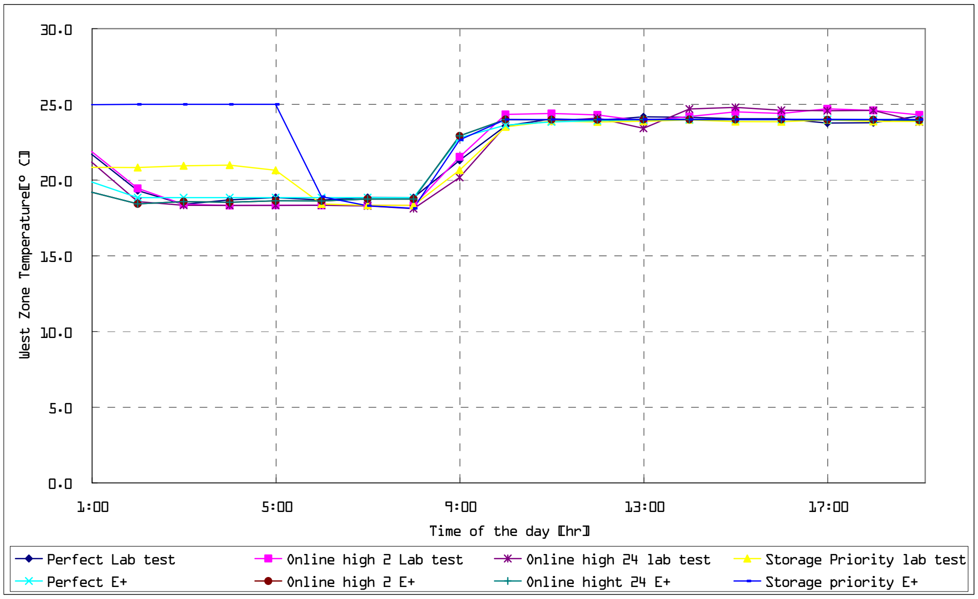

Figure 4: Measured FSZW temperature for rate 1 and for all tested TES controls

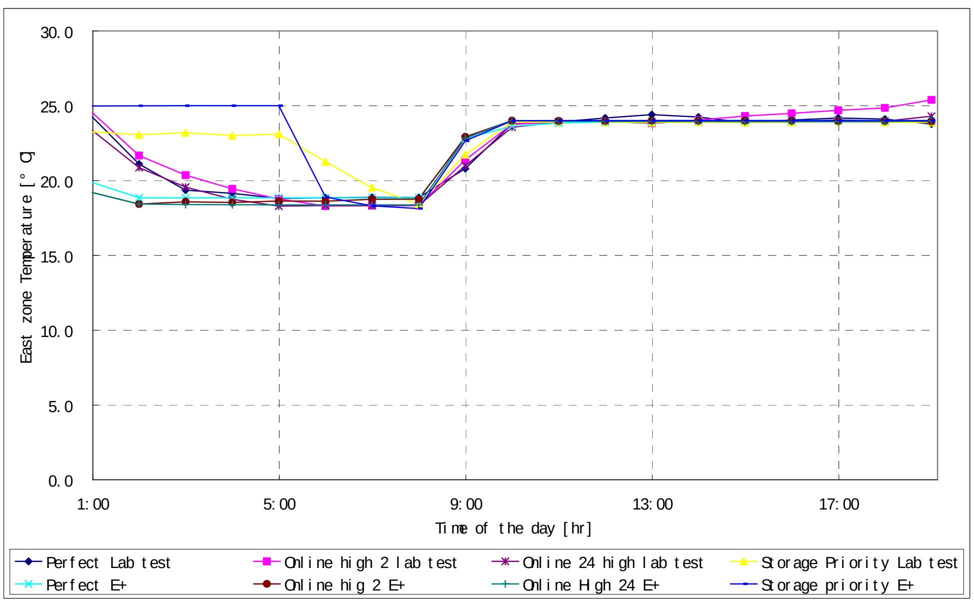

Figure 5: Measured FSZE temperature for rate 1 and for all tested TES controls

Figure 6 provides some results for the ice level measured for various control strategies.

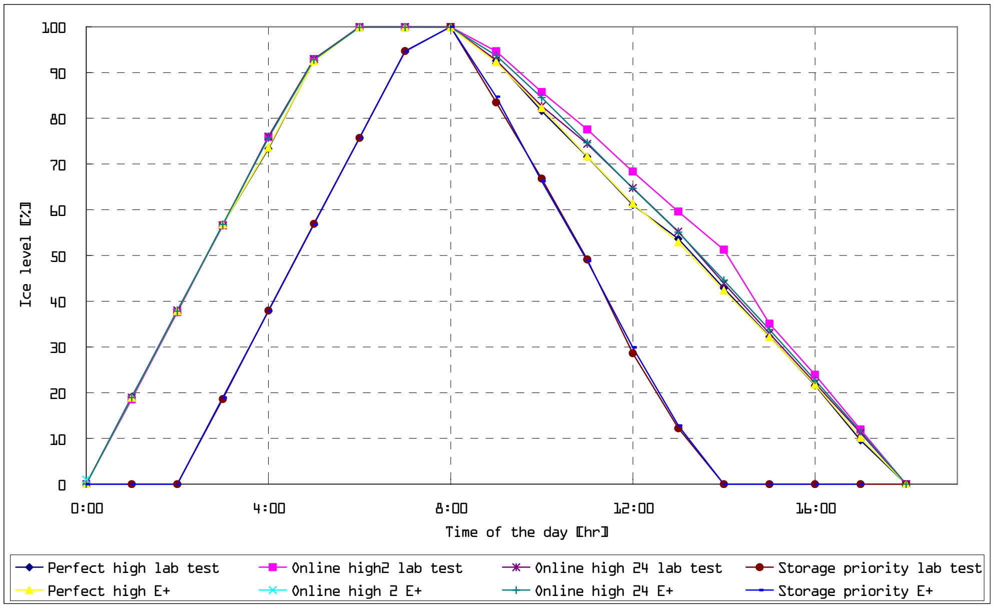

Figure 6: Measured Ice Level in the Storage Tank for rate 1 and for various control strategies

Task 5 (Status-on-going): Analyze and Interpret Lab Experiments.

Based on the results of the laboratory testing, a series of parametric analyses were carried out to determine the impact of selected variables on the performance of the simulation-based TES optimal controls. Figures 7 through 9 provide the potential savings from TES optimal controls as a function of the ratio of on-peak to off-peak period demand charges respectively, when both passives and active TES systems, only passive TES system, and only active TES system are utilized.

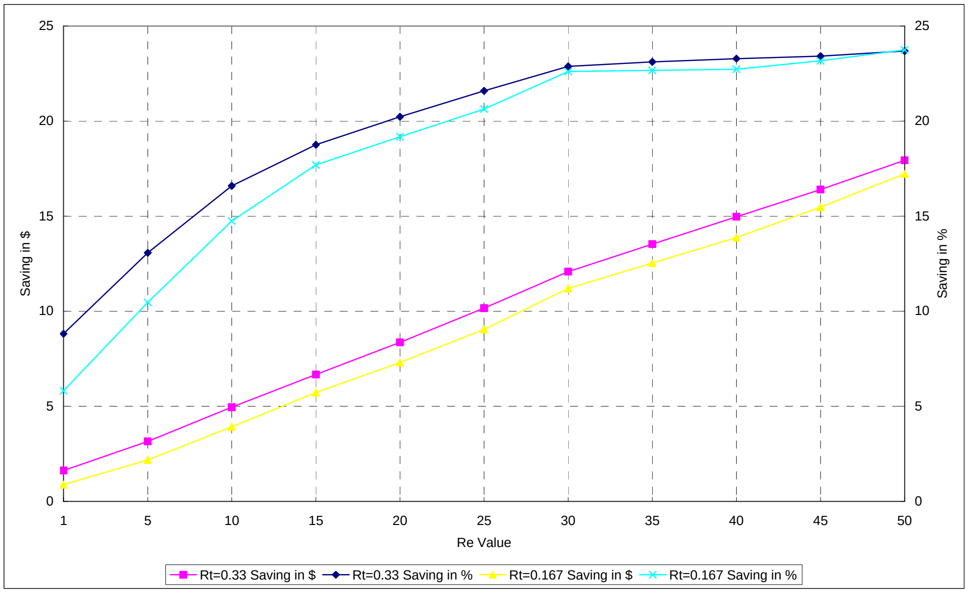

Figure 7: Variation of percent cost savings from optimal TES controls as a function of R_d for two R_t values when $R_e = 2$

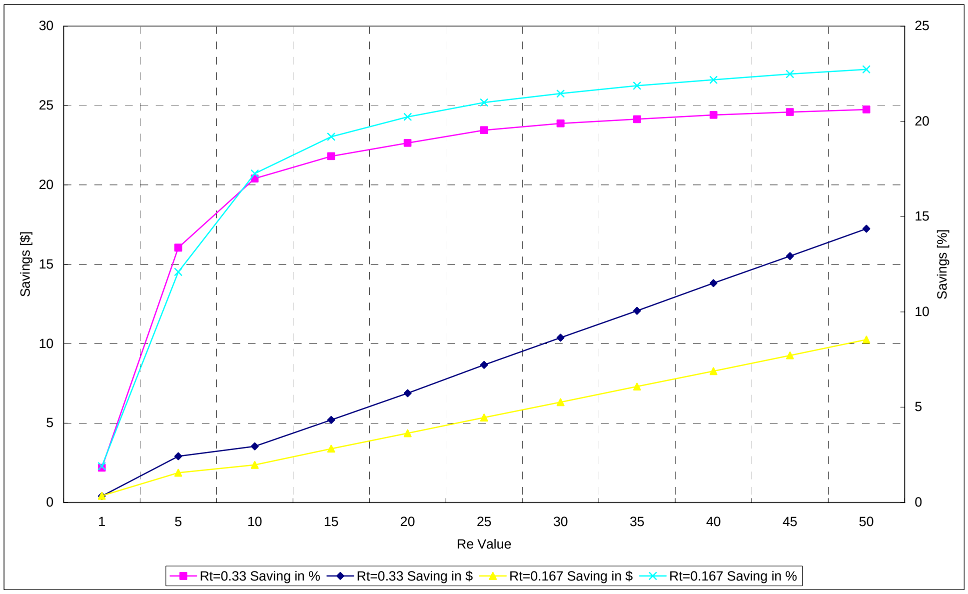

Figure 8: Variation of percent cost savings from optimal controls of passive thermal storage as a function of R_e for two R_t values when $R_d = 2$

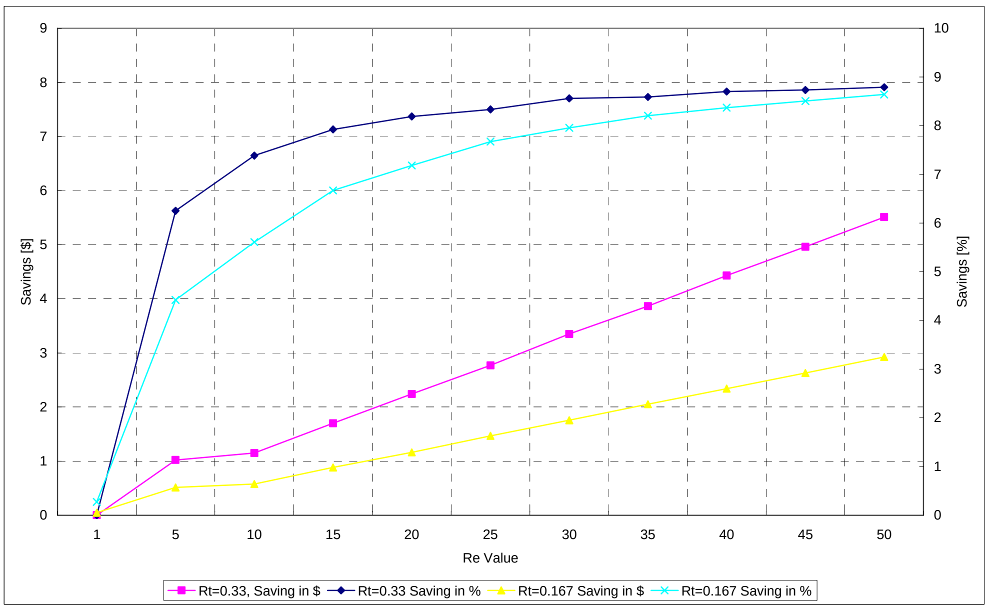

Figure 9: Variation of percent cost savings from optimal controls of active thermal storage as a function of R_e for two R_t values when $R_d = 2$