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ADAPTIVE CONTROL FOR ENERGY CONSERVATION

LOS ALAMOS SCIENTIFIC LABORATORY

CONTRACT NUMBER W-7405-ENG-36-0504

PRINCIPAL INVESTIGATOR DONALD R. FARRIS

PERIOD OF CONTRACT: Begin 1976 End Continuing

OBJECTIVE

The objective of this project is to investigate the use of adaptive control concepts in buildings with solar-assisted heating, ventilating, and air-conditioning (HVAC) systems to maintain occupant comfort conditions while minimizing auxiliary energy use. Accomplishing this objective requires an energy management system capable of making sound tradeoffs. Optimal control theory is used along with a system identification technique to provide an adaptable strategy. The resulting overall approach is known as adaptive optimal control (AOC).

CONCEPT

The AOC concept can be explained with the system block diagram of Fig. 1. The building (plant) represents the nonlinear dynamics of the building and entire HVAC system. As control and exogenous disturbances (e.g., outside temperature) are applied in time, the dynamic building responds and the state of the building results. The applied control, the exogenous inputs, and the building state are measured as functions of time. These measured values are then used by the model identification block to estimate the parameters for a linearized system. This linearized system is valid only in a region about the operating point, so a subsequent estimation of the parameters will be needed when the operating point changes significantly.

The linearized system parameters are then used by the optimal control computation block to determine the control parameters. The optimal control computation is performed so as to minimize a performance index. This performance index is an integral quadratic form and its terms include deviations of room temperature from a set point and use of auxiliary energy. Because some of the tradeoff parameters in the performance index may change with successive optimization computations (e.g., the performance penalty for room temperature deviations might be relaxed at night), optimization data are

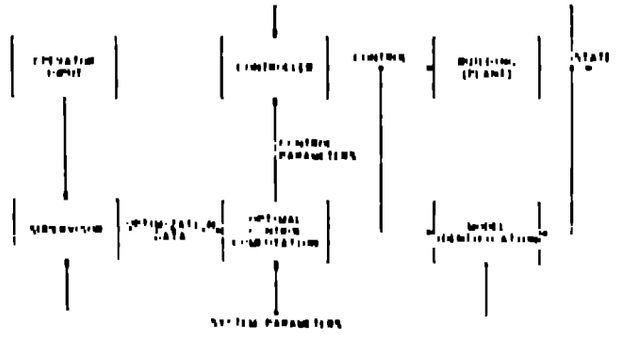

Figure 1. System block diagram.

supplied by the supervisor block. The supervisor also provides a channel for the human building operator to communicate data to the system.

The optimal control computation produces the control parameters (gains, offsets) that are used by the controller to implement the closed-loop control. The building then operates with this optimal control for a period of time that would probably not exceed 15 minutes, and the process of model identification, optimal control computation, and controller implementation repeats itself. The AOC system is thus updated or adapted to remain optimal as the system undergoes changes of various forms.

SUMMARY

This investigation of the use of adaptive control concepts began with the definition of an HVAC system model to be used for simulation studies. Building operation was simulated under control of a conventional controller that embodies current strategies and under control of an AOC controller. System performances were compared for both heating and cooling. The heating results are more comprehensive and this report will focus on them. Both controllers maintained the room temperature quite well. The AOC controller; however, did so with significantly less auxiliary energy. Depending on simulation conditions the AOC auxiliary energy savings over the conventional controller were as high as 51% for a two-day simulation and 95% for a month-long simulation.

It must be remembered that these are savings in auxiliary, or back-up, energy that is used when the solar energy system cannot meet the heating or air-conditioning demands alone. When comparing controllers as we have, a claim of 100% savings in auxiliary energy means that the claiming controller is able to operate the solar energy system to meet the heating or air-conditioning demand without any back-up.

Still, the question of how the AOC controller is able to achieve these savings in auxiliary energy remains. The answer is that the AOC controller provides better management of the available sources of energy. In the two day simulation that saved 51% of the auxiliary energy, the weather was sunny and very cold; and the AOC controller operated the storage tank at a lower temperature to improve collection and utilization of solar energy. In the month-long simulation, the weather varied, but was generally milder. One aspect of the AOC controller's management of the building is that the air-handling system is controlled to exhaust much less heated air to the outside. To illustrate, the AOC controller exhausts about 2,500,000 less Btu than the conventional controller. The reduction in auxiliary energy use is about 1,950,000 Btu and the reduction in solar energy use is about 1,150,000 Btu.

The complexity of large solar HVAC systems generates many sets of conditions for the controller to handle. The best operating strategies are not completely understood and, perhaps more important, they vary from one set of conditions to another as the above simulations indicate. The AOC technique has the power to examine those conditions on a regular basis (several times each hour), determine the best strategy at the moment, and implement the control automatically.

Plans have been made for a project to implement and test the AOC controller in the highly-instrumented National Security and Resources Study Center (NSRSC) at the Los Alamos Scientific Laboratory (LASL).

Significant industrial interaction has taken place to effect technology transfer. Industrial visits, seminars at universities, and paper presentations at conferences have been received with interest, and in several instances, further interaction has resulted.

TECHNICAL ACCOMPLISHMENTS

Some of the recent technical accomplishments are discussed below. For further information, the reader is referred to the publications listed and described at the end of this report.

- Set-Point Computation. To operate a building HVAC system with an AOC system, set points are needed. These set points are desirable values of system and control variables that the controller tries to attain. Two set-point computation methods have been tested, both of which resulted in improved system performance. One approach is based on the assumption that the set points define a system equilibrium. This approach leads to somewhat erratic solution behavior. A second approach under test at this time establishes schedules for set points based on time of day and/or various system variables. This second approach appears to work quite well.

- Riccati Equation Solution. In the optimal control computation, the present technique of integrating the differential equation to the steady state ($dP/dt = 0$) is time consuming if allowed to converge without help, and attempts to speed convergence sometimes lead to convergence problems. A potentially faster and more practical solution method has been identified and applied to the AOC. The method is related to an eigenvector approach, but uses Schur vectors. Code debugging and simulation testing have yet to be carried out.

- Long-term Simulation. The heating simulation codes have been modified to permit lengthy simulation periods (on the order of months). Preliminary AOC results have encountered problems with the numerical solution of the matrix Riccati equation. Even though these problems exist, the results have been very encouraging; and they can only improve as the Riccati solution is improved.

- Gain-Scheduling Study. A study has been done at the University of Notre Dame to investigate the use of precomputed and stored sets of controller parameters to be switched in and out in response to various system conditions. Based on the simple model used, preliminary results indicate this could prove a successful approach. This approach eliminates the need for much of the on-line computation in the AOC approach. If it proves successful, it would simplify AOC implementation.

FUTURE ACTIVITIES

Contract Activities. Plans have been made for a joint project with Johnson Controls, Inc. to implement and test the AOC concept in the NSRSC. Successful completion of this project will demonstrate that the AOC approach is practical and implementable. Implementation will permit a thorough comparative evaluation of the AOC, and the hardware that is installed in the NSRSC will be adequately flexible to permit study of other advanced control techniques. Recent DOE controls program developments have led to uncertainty about this project and it is not clear, as of this writing, whether the project will be completed.

Post-Contract Activities. If the above project is completed, a great deal of information will be available to aid industry in the development of advanced, energy-conserving, building controllers. If the project is terminated, the reports will still contain substantial information to aid industry, but the practical developmental experience will not exist.

PUBLICATIONS/REPORTS/REFERENCES

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Space does not permit a complete listing of publications, but the remaining publications on this project may be found in Ref. 1.