EXPERIMENTAL RESEARCH ON REDUCTION OF HEATING ENERGY BY A DEMAND-ADJUSTED HVAC SYSTEM

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ABSTRACT

The paper describes a method of measuring the reduction of energy consumption in private buildings. A heating energy reduction obtained by demand-adjusted HVAC (Heating Ventilation and Air-Conditioning) control is the main topic of the research. A number of real-world experiments were made for the innovative presence-dependent demand-adjusted HVAC control. The paper presents a comparison of practice oriented energy demand for the conventional and the new styled HVAC systems as well as conclusions and discussion about chances for industrial applications.

KEYWORDS

Heating energy, presence-depended demand-adjusted HVAC, occupancy-led demand-adjusted HVAC, reducing of heating energy, measurement method.

1. INTRODUCTION

Strategies to reduce and optimize energy consumption are a global challenge, both economically and environmentally. For example, in Germany nearly 14% of primary energy consumption is used for the air heating in buildings [1]. A simple optimization of the heating energy consumption could have more potential than essential progress in the reducing of energy consumption in other branches.

One of the possible strategies to reduce the heating energy consumption in buildings is a demand-driven HVAC control [2, 3].

In order to implement this strategy in the building industry the technicians must know its key characteristics. One of the characteristics is a realistic potential of demand-adjusted HVAC control to reduce the demand on heating energy (pre-implementation data). Another characteristic is a real energy demand reducing rate for the installed system (post-implementation data).

A common method to obtain these two characteristics could be a direct measurement of reduction of heating energy consumption for the real buildings. Obtaining the characteristics, by a simulation of the building's thermo-dynamic processes, is today (in case of demand-adjusted HVAC control strategy) very unreliable and expensive, because of an absence of reliable dynamic building models.

The nature of measurement of energy consumption reduction asks for the comparison of two components: actual energy consumption for the demand-adjusted HVAC control strategy, as well as energy consumption for the normal HVAC control. Both energy consumption measurements should be made in the absolute same conditions (except control strategy). It can not be achieved in real world applications.

A new method of measurement for a reduction of heating energy consumption in private buildings will be discussed in this paper. In addition, some real world measurement results are presented, which demonstrate the realistic potential of demand-adjusted HVAC control.

2. DEMAND-ADJUSTED CONTROL

The demand-adjusted indoor climate control is an occupancy-led individual room HVAC control and could be divided in following categories [2, 3]:

- Optimised demand-adjusted control
  - Presence-depended control
  - Activity-depended control
- Optimal demand-driven control
  (a combination of both mentioned above control strategies)

The presence-depended demand adjusted climate control switches a HVAC system into a stand-by modus and reduces heating energy consumption during the absence of occupants in the controlled room. The room will be quickly warmed up if an occupant comes back into the room.

This heating strategy is relatively easy to implement (see Fig.1). Theoretically it has a large potential for the reduction of heating energy in the private sector.

FIG.1 QUALITATIVE COMPARISON OF DIFFERENT DEMAND-ADJUSTED HVAC CONTROL STRATEGIES

Energy demand reducing strategies	Efficiency in reducing energy demand	Technical complexity and functionality range	Costs	comments
Presence-depended control	◖	○	◖	Not suitable for apartments with continuous presence or big occupation factor
Activity-depended control	○	◖	◖	Not suitable for apartments with steady occupants behavior (Burros, Plants, etc.)
Presence- and activity-depended control	●	●	●	Suitable for all usage preferences

● - large, ◖ - moderate, ○ - small

The presence-depended demand-adjusted climate control was implemented in the SmartHOME Laboratory [4]. All following investigations were made for this particular demand-adjusted HVAC control strategy.

3. THE MEASUREMENT PROBLEM

In order to measure the key characteristic of any energy demand reducing system, a comparison of energy consumptions for two control strategies (Innovative and Standard system strategy) should be made. The energy reduction can be calculated as a difference in energy consumptions (1) or as an energy demand ratio (2).

$$\Delta Q = Q_S - Q_I \qquad (1)$$

$$ER = \frac{Q_I}{Q_S} \qquad (2)$$

Where Q_I is a heating energy consumption incurred in a building due to using an innovative HVAC control during a certain time period and Q_S is a heating energy consumption incurred due to using standard HVAC control during the same period.

There are two ways to determine the Q-values. One is a simulation, and the second it is a direct measurement.

The characteristic of any occupancy-led control is a highly dynamic thermal process. Its simulation is a complex operation. It requires a validated model, adequate data, and configuration efforts. In many practical cases the dynamic simulation couldn’t be applied.

Both Q-values cannot be measured on the same object during the same time period. Either two identical buildings in identical environments (inclusive identical occupancy) or a single building with reproducible weather conditions (time-shifted measurement) are needed for accurately obtaining the Q-values. A realization of this is impossible.

4. THE MEASUREMENT METHOD

An advanced measurement method to determine a reduction of heating energy consumption is suggested as a combination of a direct measurement and a simplified building simulation.

Due to the real measurement the energy consumption data will be obtained for the dynamic demand-adjusted control process. Due to the quasi static building simulation, the energy demand data will be obtained for the standard controlled process. Because the simulation is made by using the real measured environmental data, the only differences between measured and simulated results are

the control strategies and the dependence on its energy demand (see. Fig.2)
Because the simulation is applied only for the standard HVAC control strategy (a quasi static thermodynamic process), it can use simple modelling methods, which are widely available. For example [5, 6, 7].

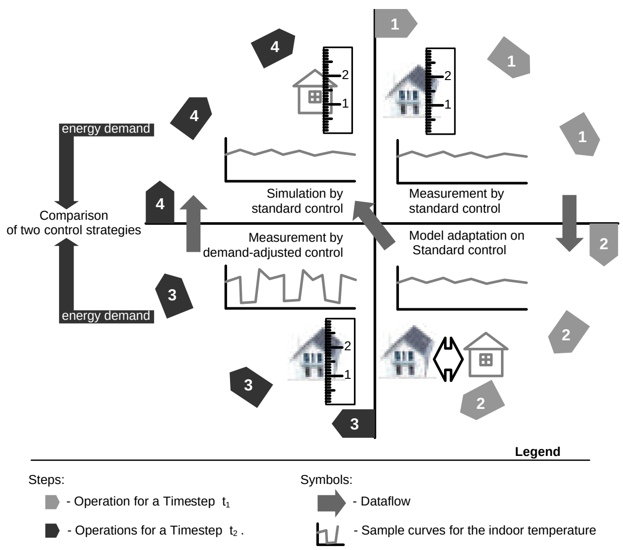

FIG.2 MODEL-BASED METHOD TO MEASURE A REDUCTION OF HEATING ENERGY DEMAND, WHICH IS PROVIDED BY A DEMAND-ADJUSTED HVAC CONTROL STRATEGY.

As shown in Fig.2, the measurement process consists of the following five parts:

1. *Direct measurement* of the environmental and process values. The system works with a standard control strategy.
2. *Model adaptation*. The parameter of a simple quasi steady state model should be adjusted to conform to the data measured in 1.
3. *Direct measurement* of the environmental and process values. The system works with a demand-adjusted control strategy.
4. *Simulation* of the standard controlled process. The environmental data corresponds to the conditions in 3. The model parameter set corresponds to the conditions mentioned in 2.
5. *Comparison* of energy demands obtained in 3 and 4 accordingly to (1) or (2).

The following data should be available for the investigated building in order to achieve the above discussed measurement process:

1) Environmental dataflow (measured data)
   a) Outdoor
      i) Weather data
      ii) Time
   b) Indoor
      i) Heating energy flows
      ii) Occupancy dataflow
2) Physical data describing the buildings envelope and nature of distributed HVAC components (parameters)

Normally, it is essential to involve a comprehensive measurement system in order to obtain accurate values for the heating energy flow as well as for occupancy data in each room of the investigated building [8, 9]. The thermal building state and the state of all HVAC components, electrical energy consumers, etc. are important.

5. THE EXPERIMENTS

The experiments aim to determine a realistic reduction of heating energy consumption in private buildings by using a presence-depended demand-adjusted HVAC control. This was made in the SmartHOME Laboratory, on the campus of University Bundeswehr Munich [4].

Two typical scenarios (a Single-apartment and a Family-apartment) were investigated. The single-apartment consists of two heated rooms: a kitchen and a bedroom /both 10 m²/. It has only one occupant. The family-apartment consists of three heated rooms: a kitchen, a children’s-room /all 10 m²/ and a bedroom /38 m²/. The family-apartment consists of four occupants: two parents and two children.

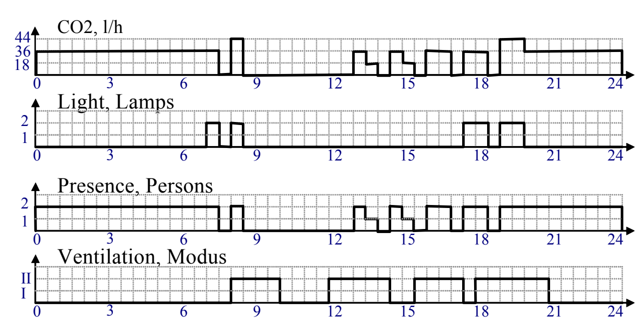

FIG.3 SAMPLE OCCUPANTS SCENARIO FOR A CHILDREN’S-ROOM (TWO KIDS).

The scenarios are represented by the typical occupation for the respective apartment type (For example see Fig.3). The occupation scenarios are reproducible because of the absolutely exclusion of human unreliable behaviour. The occupancy and the respective thermal flow from the occupants were simulated by thermal dummies [10] (Fig.4). The dummies were time-controlled.

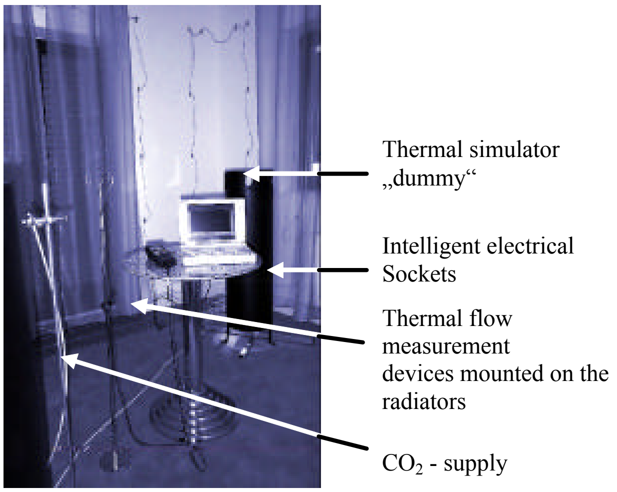

FIG.4 SIMULATION EQUIPMENT IN THE TEST ROOM OF THE SMARTHOME LABORATORY.

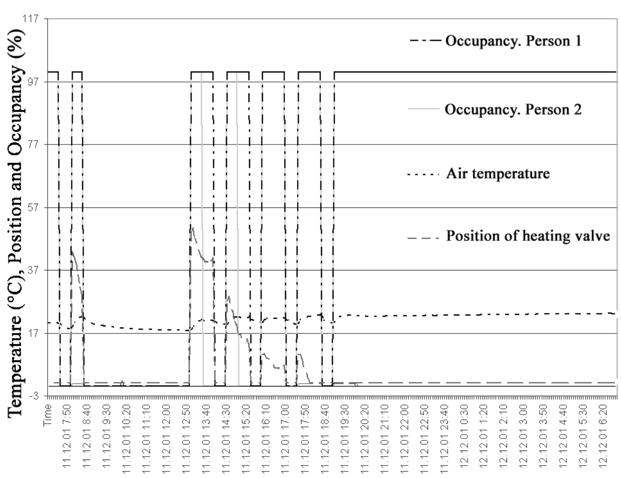

FIG.5 EXPERIMENTAL DATA FOR ONE DAY OF PRESENCE-DEPENDED DEMAND-ADJUSTED HVAC CONTROL. SCENARIO CORRESPONDS TO CHILDREN'S-ROOM.

In order to exclude an accidental weather condition influence on the suspected results, the duration of the experiments was set to one week. Thus each and the same scenario was continuously executed during the seven days. Some sample experimental data is shown in Fig.5.

A TRNSYS [7] model is developed to simulate a quasi steady state HVAC control strategy. It is a "one room - one thermal node" model (see Fig.6) and describes thermal characteristics of twelve wall types and five window types. The transfer function method is applied to calculate dynamic thermal processes in the building envelope. It works well if the dynamic of the thermal process in the building is slow. The overall obtained mistake for the standard HVAC control with sinking of night temperature was less than 1.5 %.

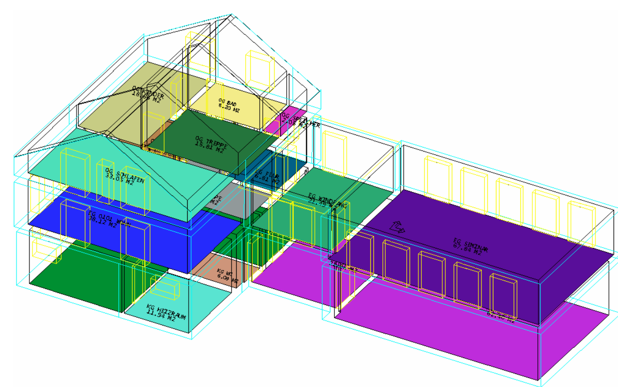

FIG.6 MODELLED IN TRNSYS THERMAL ZONES (NODES) FOR THE SMARTHOME LABORATORY MUNICH. TEST ROOMS ARE ON THE MIDDLE FLOOR.

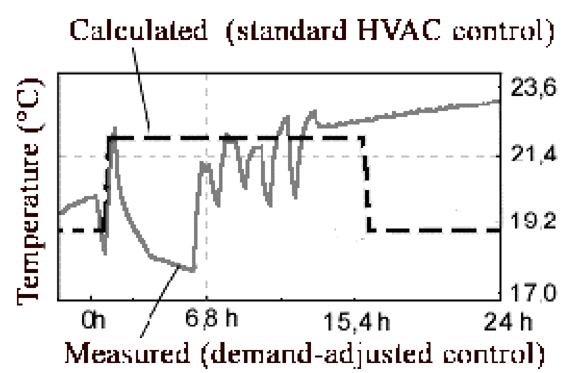

FIG.7. SAMPLE TEMPERATURES FOR MEASURED AND SIMULATED CHILDREN'S-ROOM SCENARIO BY RESPECTIVE PRESENCE-DEPENDED DEMAND-ADJUSTED AND STANDARD HVAC CONTROL.

FIG.8. EXPERIMENTAL DATA TO PRESENCE-DEPENDED DEMAND-ADJUSTED HVAC CONTROL.

Experiment Nr.	Name of experiment	Heating energy consumption by demand-adjusted control kWh	Heating energy consumption by steady state control kWh (calculated)	Reduction of heating energy demand in accordance to (1) kWh	Reduction of heating energy demand in accordance to (2) as (1-ER)*100 %	Comments
0	bedroom and kitchen	26,299 (100 %)	26,24 (99,77 %)	0	0	Without ventilation. Tolerance: 1.5 %
1	Kitchen in single-apartment	84,3	121,4	37,1	30,6	
2	bedroom in single-apartment	116,1	131,9	15,8	12,0	
	Single-apartment	200.4	253,3	52,9	21,3	Weighted experiments 1 and 2
3	Kitchen (1 Person) family-apartment	67,7	114,7	47,0	41,0	
4	Children's-room (2 Persons) family-apartment	21,5 x 7	19,2 x 7	-2,3 x 7	-12,0	
5	bedroom (2 Persons) family-apartment	166,5	179,6	13,1	7,3	
	Family-apartment	384,7	428,7	44	9,8	Weighted experiments 3, 4 and 5

In order to calculate a heating energy flow in two test rooms the model input expects values of 112 variables. The calculation time step is set to 5 min. A sample calculated in comparison to measured data is shown in Fig.7 and Fig.8.

FIG.9 COMPARISON OF TWO DIFFERENT HVAC CONTROL TYPES.

	Family-apartment		Single-apartment	
	Heating energy consumption	Electrical energy consumption	Heating energy consumption	Electrical energy consumption
Standard HVAC control strategy (quasi steady state with nightly temperature sinking)	428 kWh	-	253 kWh	-
Presence -depended demand-adjusted HVAC control	385 kWh	9,52 kWh	200 kWh	5,04 kWh
Reduction of energy consumption	44 kWh	-9,52 kWh	53 kWh	-5,04 kWh
	9,8 %		21,3 %	
	Weighted average 16,9 %			
Equivalent consumption		-24,01 kWh		-12,74 kWh
Overall reduction of heating energy	2,8 kWh/d –	0,13 t/a CO_2	5,7 kWh/d –	0,46 t/a CO_2
Middle outside air temperature	-2,4 °C		-3,2 °C	
Recalculated to 4°C (Middle outside air temperature in Germany) reduction of energy consumption	10,2%		21,5%	
	Weighted average 17,2%			

6. THE POTENTIAL

A calculation of additional electrical energy, which was supplied to additional (specific for the control type) devices, was made supplementary to the thermal experiments. The device nomenclature includes bus devices, distributed sensors, and actors, as well as control devices.

It is important to take note that the calculation of electrical energy was made for the maximal power consumption. The effective electrical energy demand could essentially be smaller.

The summary of the mentioned experiments is shown in Fig.9. In the German condition, the overall reduction of heating energy consumption can achieve 17 % by implementing the presence-depended demand-adjusted HVAC control.

Even in worse case of electrical energy consumption, the positive energy balance will occur. The overall reduction of energy consumption achieves ca. 1.6 %.

7. CONCLUSIONS

A model-based method was discussed to measure a reduction of heating energy consumption by implementing an innovative demand-adjusted HVAC control. A reduction of heating energy consumption was measured for the real presence-depended demand-adjusted process.

The analysis of obtained results proves the possibility to reduce the heating energy consumption by demand-adjusted HVAC control strategies. By state of the art techniques, the realistic energy reduction result in 17 % of heating energy and 1.6 % total energy demand was achieved in Germany.

A large number of the electrical devices (what are essential for the realization of demand-adjusted HVAC functionality) distributed in the building must be energy effective, in order to make economical sense their existence. It is generally a good idea to combine many functions in one device (for example a single room controller), since the overall electrical power consumption is reduced.

An economical problem is the energy cost. Today the energy price does not distinguish ecologically favourable energy. For example, nuclear electrical energy could be much cheaper in comparison with oil heating energy, if the costs of disposition for ecological effects are included. The economic efficiency of demand-adjusted HVAC control increases with increasing energy costs. The innovative system could also be profitable if the ecological perspective becomes important for the industry.

ACKNOWLEDGEMENTS

This work was supported by the Bayerische Forschungsstiftung under Grant 283/98 (Intelligent instrumentation of Homes, IWO-BAY).

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