NIGHT VENTILATION FOR COOLING PURPOSES
PART I - REFERENCE BUILDING AND SIMULATION MODEL

Janet X. Ren and Jan-Olof Dalenbäck
Building Services Engineering, Chalmers University of Technology
S-412 96 Göteborg, Sweden. Fax +46-317721152

ABSTRACT

The aim of this study is to form the basis of a further analysis on night ventilation for cooling purposes in modern Swedish office buildings. An existíng Swedish office building with night ventilation has; been monitored and a complementary study on building energy end-uses with the help of the DOE-2 building simulation program. has been carried out.

Measurements show that the building's energy usage is on a low level regarding thermal as well as electrical energy end use. The total annual electricity use in the office building studied i.e. by fans, office lighting, equipment and elevators, amounted to 57 KWh/m2 office arca.

In order to makc a comprehensive study on night ventilation, the detailed performance of the simulation model needs further calibration, although an acceptable agreernent between measured and simulated electricity usage on a monthly basis is achieved. Irregular occupancy, manual air-handling system operation (especially night ventilation control) and partly unsuitable default fan part load curves in the DOE-2 model clearly show the need for more detailed analyses in order to hav, e an acceptable agreement between measurements and simulations during the summer period.

KEYWORDS

Office building, cooling, night ventilation, electricity, measurements, simulations

INTRODUCTION

The major growth in electrical energy usage in commercial office buildings since the 1970's is rclated to non-heating purposcs, i.e. lighting, office equipment, air conditioning (cooling). In Sweden, this kind of electrical energy use in commercial buildings represents 10% of the total national electricity usage. Several surveys, e.g. by Holtz [1], have revealed that this type of electrical energy usage can be reduced significantly by more careful designs. One possibility to consider is night ventilation for comfort cooling purposes instead of using refrigerant water chillers or air conditioners.

The main objective of a study performed at the Department of Building Services Engineering is to analyse the influence of building design, internal heat gains and control strategies on the potential use of night ventilation for cooling purposes, based on measurements in an existing modern office building with night ventilation. In this paper, the first part of our study, i.e. the reference building and the initial creation of a building simulation model in DOE-2 [2] for the building type studied, is presented.

- An occupied office building, where features which are considered to affect the building energy usage are identified with measurements [5], serves as a reference. The DOE-2 (Version 2.1D) simulation program is then used to simulate the building's energy performance so that night ventilation can be analysed in a more general way. The overall measurements in the reference building and major findings from simulations using derived typical occupancy schedules, etc., are presented.

REFERENCE BUILDING

Building description

The reference building, a typical modern Swedish office building, located in Stockholm, is part of a large building complex with 23.000 m² of floor area [5]. It is a sixteen-storey multi-purpose quadratic shaped tenant office building which comprises a total floor area of 5.700 m², where each floor has 263 m² of cellular office rooms and 93 m² of corridor and elevator space. The reference building consists of elevator shafts and stairwells of slip form concrete, a steel skeleton with concrete floors and curtain walls covered with bronze-tinted glass. The windows have triple glazing (outer pane bronze-tinted) with a U-value of 1.65 W/m².K and the building is oriented with the corners facing north/south. There are no external shading devices, but the occupants may use venetian blinds installed between the two outer panes.

Air-handling system

The reference building is served by one Variable Air Volume (VAV) air-handling system with a design supply air flow of 10 m³/s and a total Specific Fan Power ratio (SFP) of 2.8 kW/(m³/s) (see Fig.1). The supply and return air fans have variable inlet vanes and two-speed motors. A dry-bulb temperature-controlled economiser (constant supply air temperature 16.5 °C) is used for air-to-air heat recovery and hydronic radiators are used for additional space heating when necessary. The air-handling system operates normally from 8 a.m. to 6 p.m. weekdays only. The air is supplied to the offices and the return air is taken from the corridors.

Instead of utilising refrigerant water chillers to cool the supply air (or air conditioners), cooling demands in the summer season are to be covered by operating the fans during the night, i.e. to utilise cooling energy stored in the building structure. The major control strategy of the night fan operation is as follows: Night fan operation is activated when the room air temperature is above 21 °C and the ambient air temperature is between 10 °C and 24 °C (and below room air temperature). The night fan operation is turned off when the room air temperature has dropped to 16°C.

Measurements

Compared to most other monitored office buildings, the measurements in this office building are quite limited. The total energy end use in the reference building has been monitored for five years and on an hourly basis for two years (1990 and 1991). In order to characterise the internal heat gains, the hourly measurements contain rather detailed measurements in one typical floor (here described as the monitored floor). The hourly measurements (sums and averages) comprise of the following items [5]:

- Total building electricity, i.e. electrical energy usage for; lighting, office equipment, elevators, VAV system supply and return air fans, and a computer centre (including air conditioning).
- Separate measurements for electricity used by; VAV system supply and return air fans, elevators and the computer centre.
- Separate measurements for electricity used for; lighting, office equipment and indoor temperatures (corridors), in one floor.

In this way it is possible to determine the total amount of electricity used for lighting and office equipment in the entire reference building, as well as the detailed electricity usage for lighting and office equipment in one floor. However, except for the maximum air flow, no air flow measurements are available.

Energy Usage

The total annual energy usage in the building complex amounts to: Heating 42 kWh/m² (floor area); operation electrical energy 84 kWh/m², in 1991. Fig. 2 shows total annual energy use in typical office buildings [8, 9], as well as in three modern Swedish office buildings [5]. The figure illustrates that the annual energy use in the building complex studied is rather low compared to that used in the existing office building stocks. The total annual energy usage in best practical examples are usually found in the region: Heating 50-100 kWh/m²; operation electrical energy 50-150 kWh/m² floor area. The figure shows also that a decrease in heating energy requirements, especially in Swedish commercial buildings in general, has resulted in an increase in operational electrical energy requirements.

The total annual electricity use in the reference building, i.e. by fans, office lighting, equipment and elevators, amounted to 270 MWh (i.e. 57 kWh/m² office floor area). The total annual electricity used by the VAV system supply and return air fans was 59 MWh (i.e. 12 kWh/m²). The total annual electricity

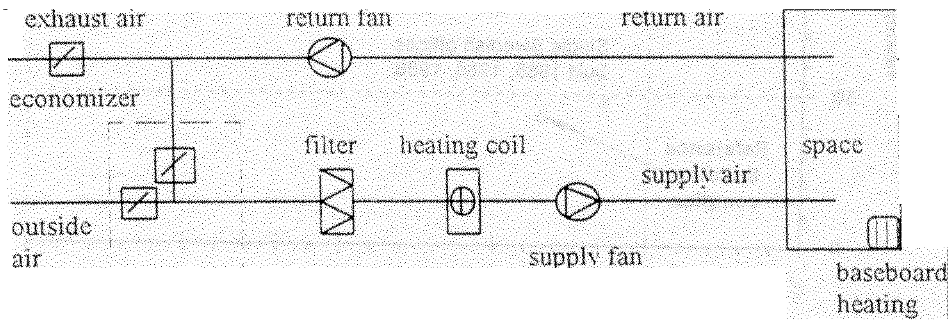

Fig. 1. Simplified schematic diagram of office building system

used for lighting and office equipment in the monitored floor was 11 MWh (i.e. 36 kWh/m²).

The installed power for the VAV system supply and return air fans is 26 kW (i.e. 5.4 W/m²), of which about 90% has been utilised in practice. The total installed electrical power in the monitored floor amounts to 11.5 kW (i.e. 32.3 W/m²), with moderate 4.2 kW (i.e. 11.8 W/m²) for lighting, of which about 50% has been utilised during normal working conditions.

BUILDING MODEL VALIDATION

The DOE-2 building simulation program has been chosen for the study. One reason is that this model has been used before in the department, another reason is to be able to compare the results here with results obtained with the newly developed design tool BV² [7], which is based on simulations using the DOE-2 model.

The first step is to determine the building specific parameters and describe the building in the Building Description Language (BDL) in the DOE-2 model input file. In our study, custom weighting factors and conditioned spaces have been used for the building model. The weather data from a nearby weather station in Stockholm for the year in question were converted to the DOE-2 accepted format.

When parameters for the building envelope and weather information are identified, the magnitude of the building's electrical energy usage is dependent mainly on building occupancy and building related system operation schedules. The next step is, thus, to determine a suitable base for a calibration of parameters that describes the electricity used for lighting, office equipment and the HVAC system. Different types of schedules are one of the most important inputs in order to correctly calibrate the building simulation model. Most of the schedules used here are derived from the measurements by analysing the monitored hourly electricity usage for the monitored floor during well-defined weekly periods. Typical sets of schedules for lighting and office equipment usage have been adopted to represent the entire year, together with a constant Shading Coefficient (SC = 0.38).

A large part of manual VAV system operation (especially night ventilation control) made it, however, necessary to assign hourly night fan

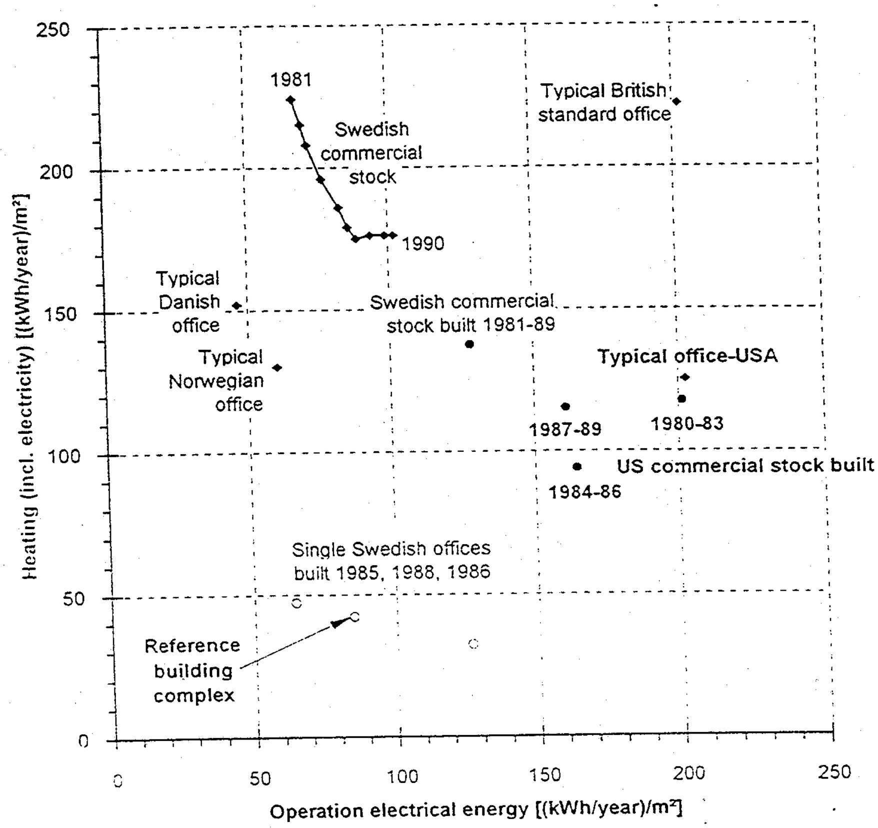

Fig. 2. Annual energy end-use in commercial buildings, especially office buildings, divided into heating energy and operation electrical energy [5, 8, 9].

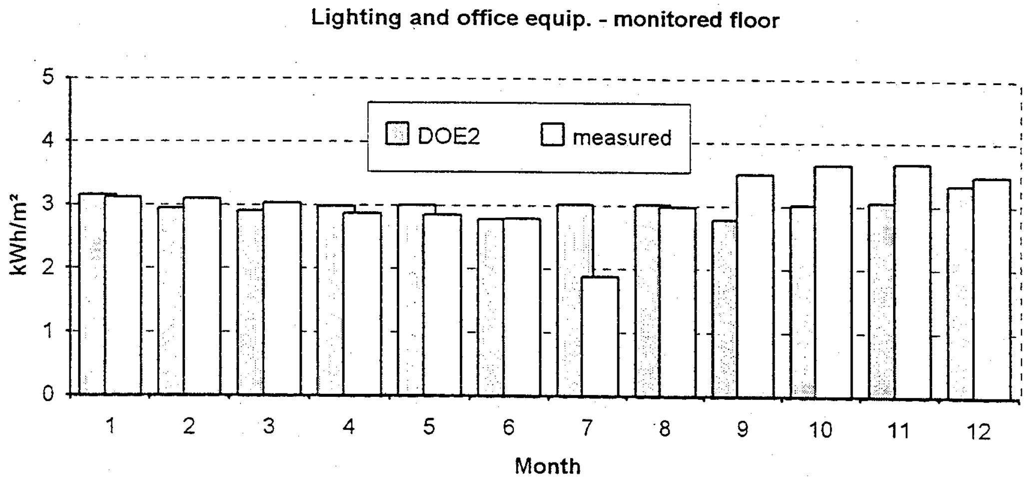

Fig. 3. Comparison between monthly measured and simulated electricity use (lighting and office equipment) in the monitored floor.

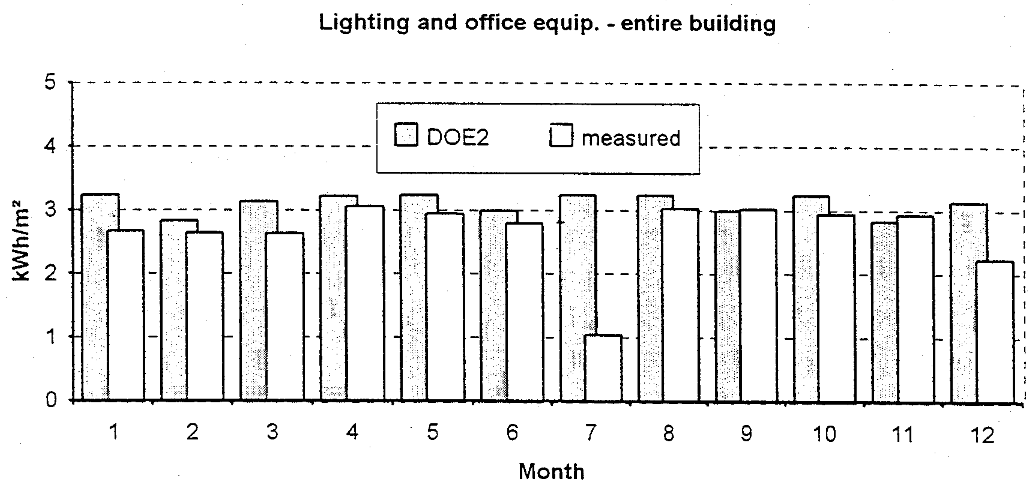

Fig. 4. Comparison between monthly measured and simulated electricity use (lighting and office equipment) for the entire reference building.

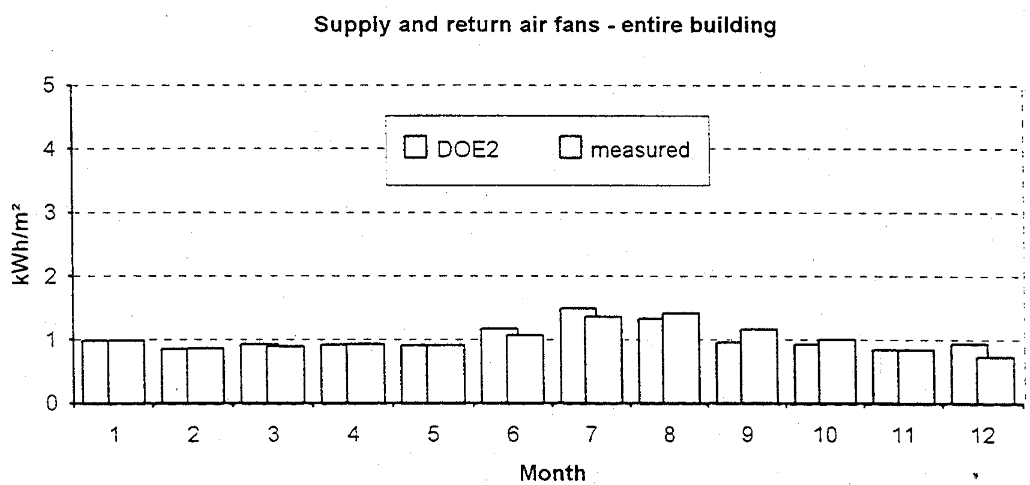

Fig. 5. Comparison between monthly measured and simulated electricity used by supply and return air fans (entire reference building).

operation schedules in the summer period, while an office hour schedule is applied for the rest of the year.

One way to validate the building simulation model is to make monthly and annual comparisons between measurements and simulations [4]. A basic model calibration results here in a rather good agreement between measurements and simulations on a monthly basis using intensities and typical schedules derived from the measurements. The simulated building electrical energy usage using information and typical schedules from the monitored floor results in 10% errors on average on a monthly basis.

Fig. 3 and 4 show comparisons for electricity used for lighting and office equipment in the monitored floor and total electricity used for lighting and office equipment (entire reference building), respectively.

Differences shown for the monitored floor (Fig. 3) are mainly related to differences between the simulation model using typical schedules and reality (occupancy, etc.), while differences shown for the entire reference building (Fig. 4) are also related to differences in occupation etc. between the monitored floor and the other office floors. The main reason for the large difference in July in the monitored floor (Fig. 3) is vacations, but the reason for the increase in September is not clear. The main reason for the large difference in July for the entire reference building (Fig. 4) is that a company that rented about 50% of the office space moved out during July (replaced

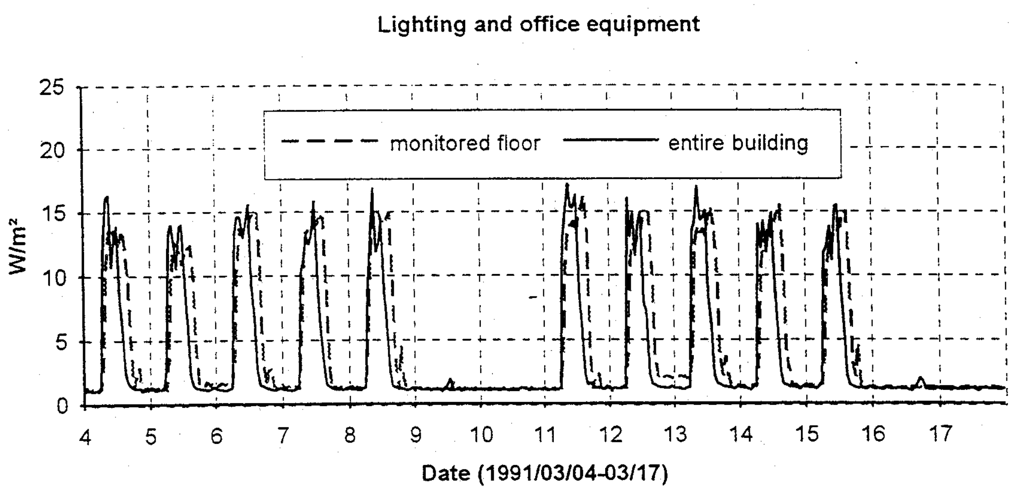

Fig. 6. Comparison between monitored electricity use for office equipment and lighting during two weeks in the monitored floor and the entire reference building.

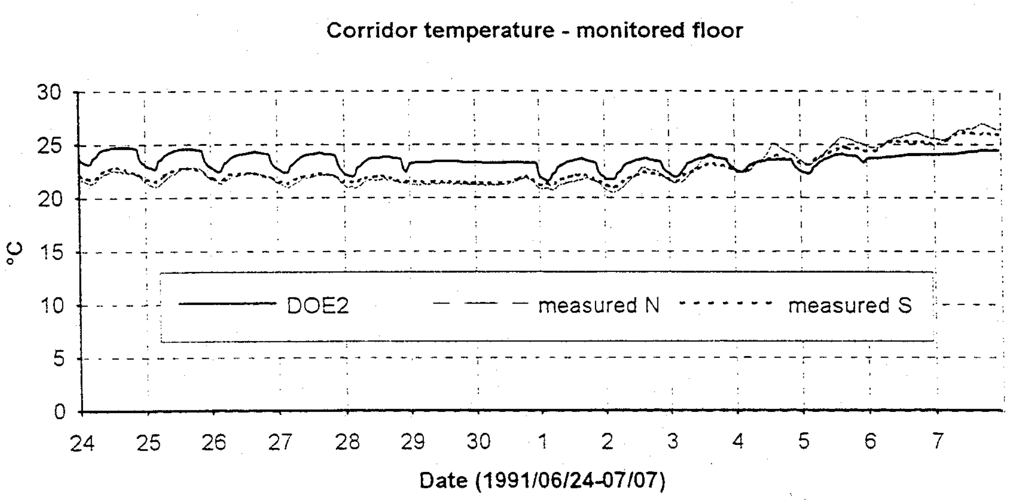

Fig. 7. Comparison between measured and simulated indoor air temperature (corridors where N=North and S=South) in the monitored floor. Summer weeks.

by another company in August) together with the vacation period.

Fig. 5 shows a comparison for electricity used by the supply and return air fans. The comparison concerning fan electricity (Fig. 5) does not show the same differences for July partly due to applied hourly night fan operation schedules. However, the importance of looking into periods when the night ventilation is used in more detail is discussed in the following.

DETAILED MODEL VALIDATION

Having carried out a basic calibration based on typical schedules for office equipment, lighting and fan operation, the next step is to carry out a more detailed validation of the summer period, i.e. when night ventilation is used.

A basic assumption here is that the monitored floor with more detailed measurements is representative for the reference building as a whole. However, as this is a tenant office building, the occupancy as well as the working circumstances, might not be the same for each floor. Fig. 6 shows the monitored specific hourly electrical energy usage (lighting and office equipment) for the monitored floor and the entire reference building.

Apart from the results shown in Fig. 6, the monitored specific monthly electricity usage is almost the same (See Fig. 4 and 5) and the specific electrical usage in the monitored floor is, thus, judged to be representative for the entire reference building.

By comparing and analysing the hourly simulations based on measured intensities and determined schedules with measured hourly values for fans, lighting and office equipment electricity use, possible errors in computer simulation (or measurements) can be detected. If the simulation results do not satisfy

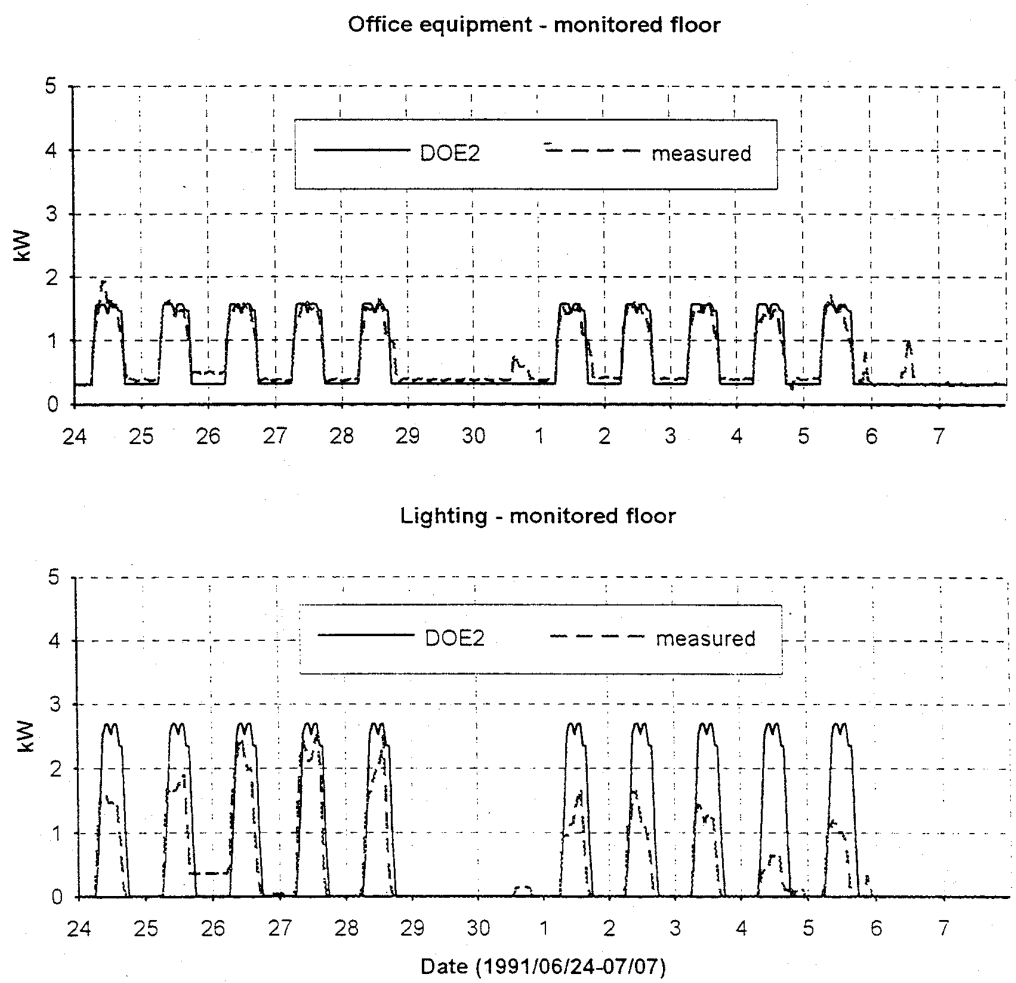

Fig. 8. Comparison between measured and simulated electricity usage for office equipment and lighting. Monitored floor. Summer weeks.

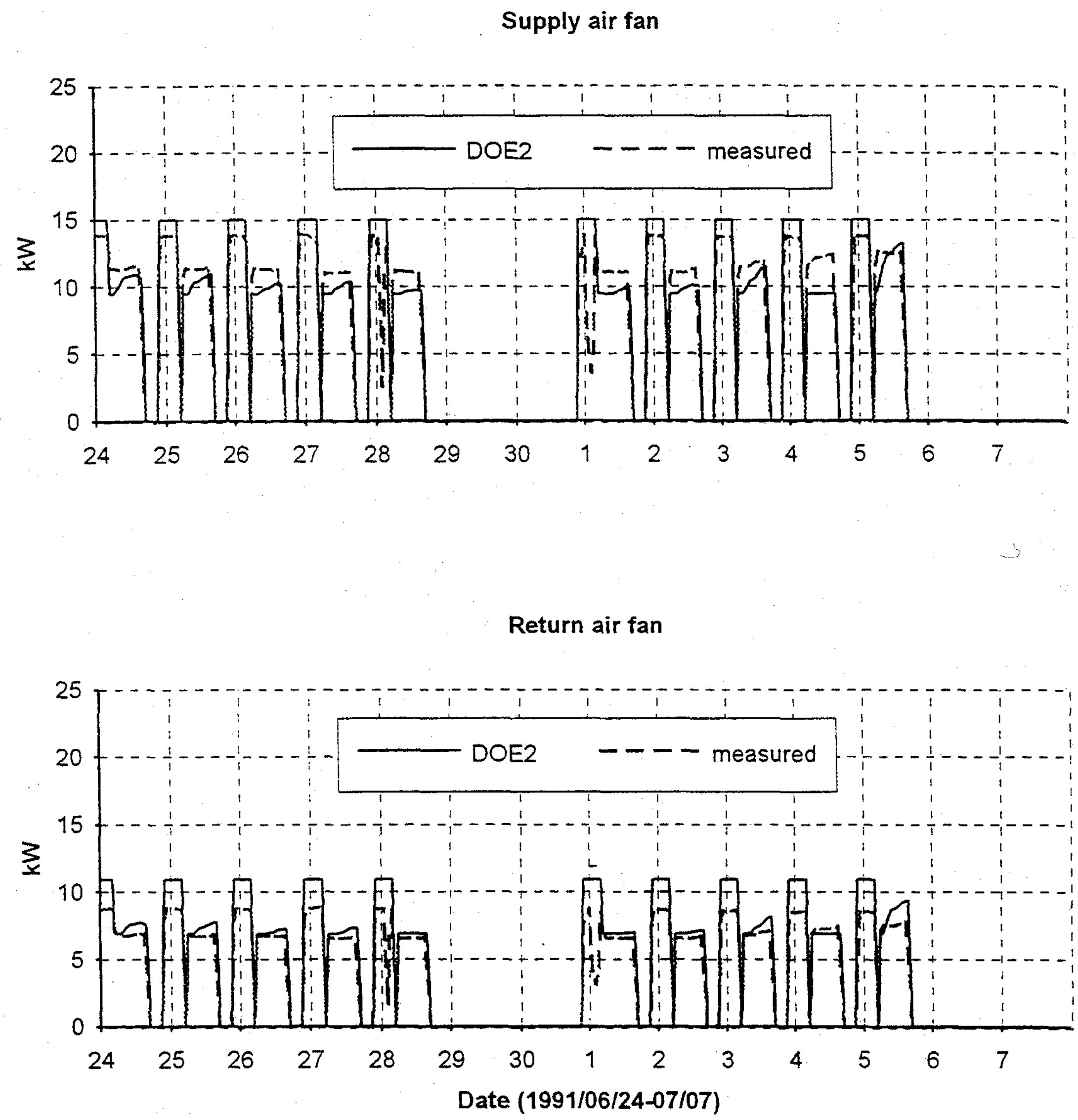

Fig. 9. Comparison between measured and simulated electricity usage for the supply and return air fans. Summer weeks.

the monitored results (within a given tolerance), input data have to be adjusted, in order to get simulation results within acceptable tolerances [3].

The indoor air temperature is an important parameter which reflects the performance of the HVAC system, as well as system control. The purpose of these systems is to maintain the required indoor air temperature within an acceptable range.

A comparison between simulated and measured indoor temperatures (here corridors in the monitored floor) shows a poor agreement for a couple of weeks in the summer (See Fig. 7). The simulations indicate that internal heat gains as well as air-handling (i.e. the VAV system) is treated differently in the model and in reality.

A more detailed analysis of the internal heat gains shows that the use of office equipment is close to the typical usage, while the use of lighting is far from typical (See Fig. 8). The differences between simulated and measured indoor temperatures is, thus, partly due to more regular occupancy schedules being applied than the real ones (less lighting use).

Another reason for the differences in indoor temperature is that the default fan part load curves applied (default curve in DOE-2) do not describe the actual characteristics of the supply and return air fans. Comparisons between measured and simulated electricity used by the supply and return air fans are shown in Fig. 9.

DISCUSSION

Night ventilation is judged to present an interesting alternative to refrigerant water chillers or air conditioners for cooling purposes in office buildings in temperate climates, e.g. northern Europe. The possibility to use a detailed building simulation model, e.g. DOE-2, to analyse the influence of building design, internal heat gains and control strategies on the potential use of night ventilation would be of great help. However, a major experience from simulation studies is that simulation results obtained depend very much on the assumptions made and the input parameters used. Thus, this study is based on measurements in an existing modern office building with night ventilation.

A basic model calibration using measurements in an occupied office building (reference) shows quite acceptable agreement between measurements and simulations on a monthly basis. However, irregular occupancy during the summer period, fan part load curves not described in the DOE-2 model (variable inlet vanes with two-speed motors), and a VAV system operated to a large extent by manual control, makes a more detailed calibration necessary in order to achieve acceptable tolerances concerning studies of night ventilation.

The continuation of the analyses will contain more detailed lighting schedules, complementary air flow measurements and the implementation of more suitable fan part load curves in the DOE-2 model.

ACKNOWLEDGMENT

The support by BFR (Swedish Council for Building Research), which has financed the research work related to this paper, is gratefully acknowledged. Our thanks are also due to: A. Nilson and C. Hjalmarsson, Bengt Dahlgren AB, who provided us with their material; and our colleagues in the Department of Building Services Engineering, for their valuable help in presentation of our work.

REFERENCES

[1] Holtz, M. (1990). *Electrical Energy Savings in Office Buildings.* Document D17:1990. Swedish Council for Building Research, Stockholm.

[2] *DOE-2 Reference Manual.* LBL Report LBL-8706, Rev. 3, Berkeley CA: Lawrence Berkeley Laboratory, USA.

[3] Kaplan, M.B., J. McFerran, J. Jansen, and R. Pratt. (1990). Reconciliation of a DOE-2.1C Model with Monitored End-use Data for a Small Office Building. *ASHRAE Transactions 96(1).*

[4] Diamond, S. C., B. D. Hunn, and C. C. Cappello. (1985). Computer Modelling the DOE-2 Validation. *ASHRAE Journal*, Nov. 1985.

[5] Nilson, A. and C. Hjalmarsson (1993). *Elanvändning i fyra kontorsbyggnader. Mätningar, anayser och erfarenheter.* (The end-use electricity in four office buildings: Measurements, analyses and experiences) Report R56: 1993, Swedish Council for Building Research, Stockholm.

[6] Kaplan, M. and P. Caber. (1992). *Guidelines for Energy Simulation of Commercial Buildings.* Bonneville Power Administration, Oregon, USA.

[7] Nilsson, P-E. (1994). *Heating and Cooling Requirements in Commercial Buildings: A Duration Curve Model Including Building Dynamics.* Document D27:1994, Department of Building Services Engineering, Chalmers University of Technology, Göteborg.

[8] *Energy End-Use Intensities in Commercial Buildings.* DOE/EIA-0555(94)/2, Energy Consumption Series, Energy Information Administration, U.S. DOE, Washington DC.

[9] Jagemar, L. (1995). *Learning from experiences with Energy Efficient HVAC Systems in Office Buildings.* Draft report. CADDET Analysis Support Unit, CIT Energiteknisk Analys, Göteborg, Sweden.

[10] Baker, M.S. and J.S. Reynolds. (1994). Overall and Zonal Energy End Use in an Energy Conscious Office Building. *Solar Energy. Vol. 52, No. 1, 1994.*