USE OF ENERGY PERFORMANCE SIMULATION FOR OPERATION COST DISTRIBUTION IN MULTIPURPOSE CONVENTIONAL CENTRE

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ABSTRACT

The paper describes case study of application of computer simulation in the field of operational energy costs distribution in the building with variable operation and no possibility of direct energy consumption measuring. The simulation is used to predict energy needs related to the climatic loads and to make a synergy with the internal loads. Presented results are in terms of average energy consumption related to floor area and operational case, divided into the heating, cooling and electric energy .

INTRODUCTION

Computer simulation tools are usually used in the early phase of building conceptual design to predict energy performance of the alternative solutions to support designer decision process (Clarke, Kabele 1996). Another utilization of simulation tools is in investigation of the operational breakdowns (Kabele 1998) and set-up of control systems (Hensen). This paper is focused on different period of building life - on the operation cost calculation and consequently cost distribution among users according to the results of simulation of different operational cases in large, conventional and congress centre in Prague (Fig.1). The paper is based on case study, solved recently at our department (Kabele 2000).

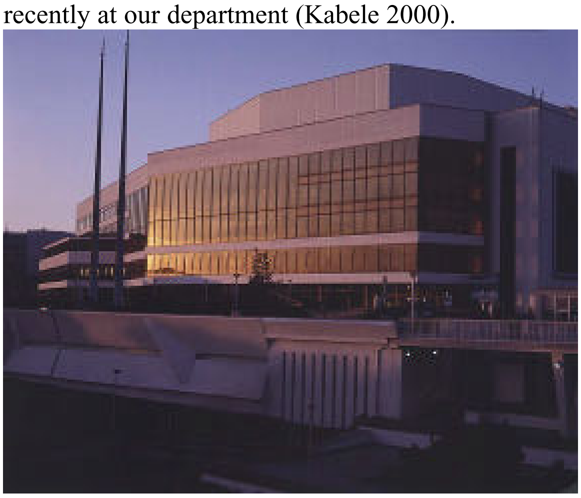


Fig. 1 Congress Centre Praha

PROBLEM DESCRIPTION AND ANALYSE

The building is located in Prague, Czech Republic with typical moderate continental climate, where outside design temperature for winter is -12°C, for summer +32°C. The centre was built without possibility of energy measuring (heating, cooling, and electric), distributed into specific building sections and since the design the building operational scheme has been many times changed. The basic question to be solved, was based on the owners request to evaluate energy consumption of the specific sections of the building complex during short- or long-term rooms leasing, described like operational cases. The example of the short-term operational case is night theatre performance, example of long-term operational case is office rooms lease. The entire problem was analysed and in co-operation with the owner of the complex we specified 15 typical operational cases, which were solved. The energy consumption is given by outside and inside energy gains, which are eliminated by the heating respectively cooling system. Electric energy consumption was calculated from the installed input and time utilisation of the electric appliances. The reason, why we used simulation, was to eliminate the influence of the year season and position of the space in the building (north vs. south facade) and simultaneously to cover the daytime impact of synergy of the external and internal loads. Those loads could be in different day/year time different (i.e. internal heat gains from people could help to heat up the space during winter evening, while during summer day is necessary to eliminate together this load by cooling system).

MODELLING AND SIMULATION

The building was modelled in ESP-r (ESRU) simulation environment. The plans of typical floors of the building are on the Fig.2. The main purpose of the model was to describe the building envelope thus this macro model, created without detailed description of the internal layout of the building, is describing thermal performance of the building from the viewpoint of external gains and losses(climate) and internal casual gains and losses, based on the operation of the entire building. In the model are included ventilation systems, occupants, lights and technology. Due to the complicated geometry shape of the building was the building modeled with 5 geometry thermal zones (Fig.3). All zones are virtually mutually ventilated by circulating air to keep uniform indoor environment in entire building.

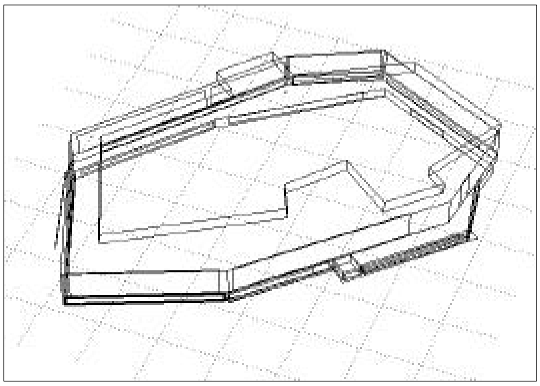


Fig. 3 ESP-r model of the building

For each of specified operational case was given the operation schedule, describing the internal energy gains and losses. Example of the schedule description for one operational case is on the Fig.4.5.

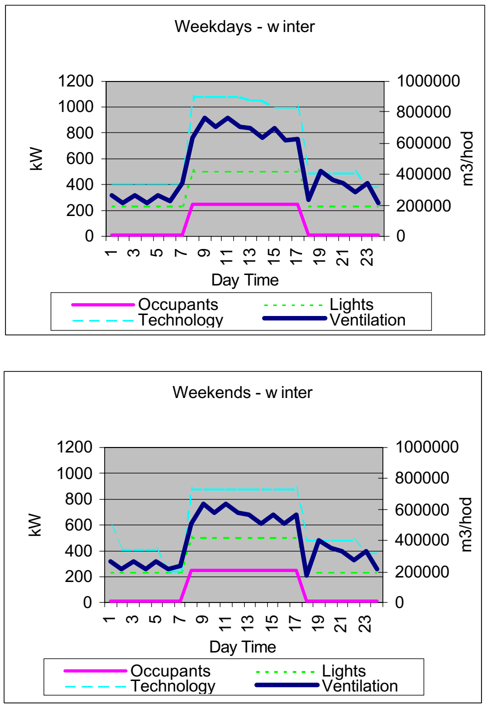


Fig. 4 Example of operation schedules - winter

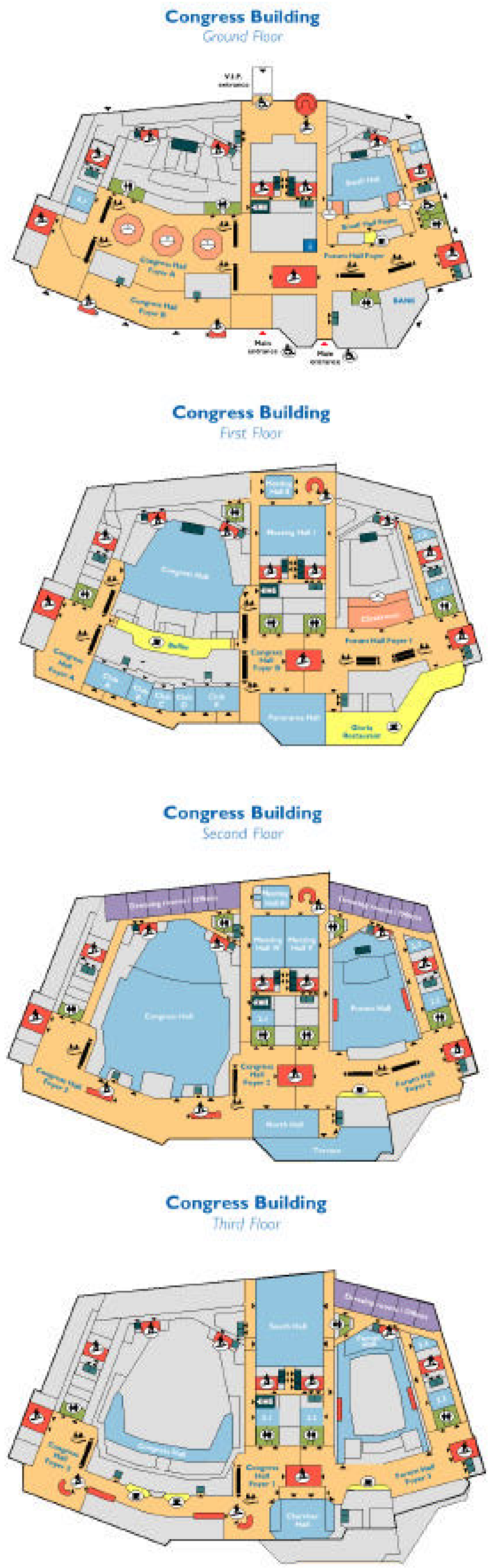


Fig. 2 Floor plans of the building

The step-by-step calculation process is in following paragraphs.

a) Each operational case was described by:

- volume of the fresh air distributed by AC units, $V_{CV,}$
- input of the pumps, fans and technology $Q_{è}$
- number of occupants N_{per}
- input of the lights Q_{osv}

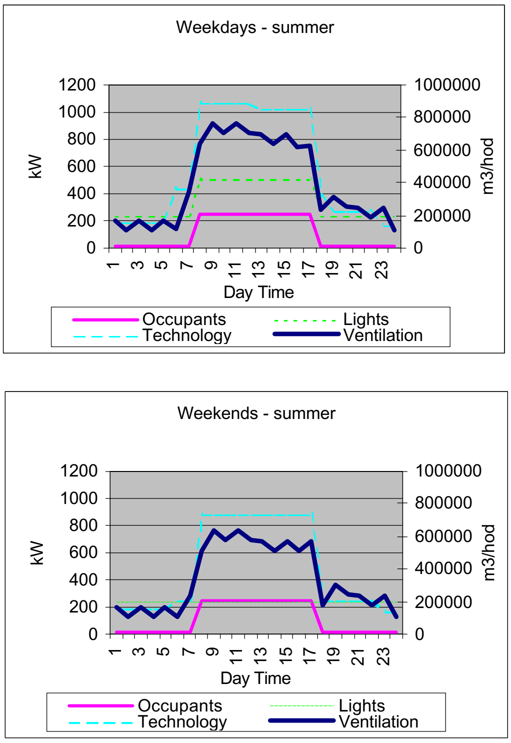
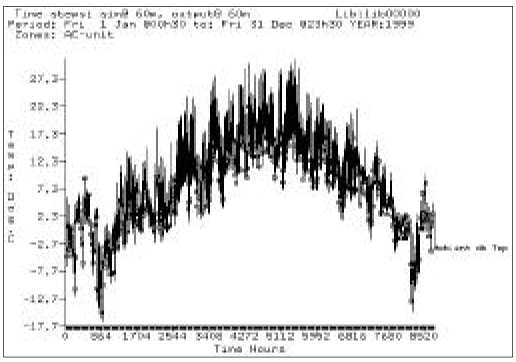


Fig. 5 Example of operation schedules - summer

b) The simulation of the energy performance has been run during whole year period under the climate



condition of Test reference year for Prague (Fig.6).

Fig. 6 Ambient db temperature – TRY Praha

The first run of the simulation has been done for the operational state called "Empty building", which is describing energy performance of the building with no rented spaces and the building is in "stand-by" state with basic occupancy of the personnel, basic lights and continuously operating AC units. Next runs of the simulation were focused on specific operation states, where was simulated annual energy consumption during the specific usage of the building. To avoid impact of the year season (Hensen 2001) the operation of the building was simulated on daily schedule during operational state within whole year period. The operation schedule of the heat gains has been done with superposition of the operational state "Empty building" and specific operation state (i.e. "Evening theatre performance") The outputs of the simulation were annual heating energy $Q^{N}_{R,T}$, cooling energy $Q^{N}_{R,C}$ and electricity $Q^{N}_{R,E}$ for each operational state. (Tab. 1)

Tab. 1 Total annual energy consumption during the operational case

No.	Operational case	Total energy consumption: Heat $Q^{N}_{R,T}$ kWh.a^{-1}	Cold $Q^{N}_{R,C}$ kWh.a^{-1}	Electricity $Q^{N}_{R,E}$ kWh.a^{-1}
0	*Empty building*	1940322	840790	12784130
1	*Club (day-time)*	516449	1886734	13499531
2	*Club (night-time)*	265984	2112936	13857231
3	*Halls no. 3 (day)*	1755051	1743430	16045408
4	*Halls no. 3 (night)*	2281255	1226509	17676047
5	*Congress hall (day)*	963215	2221997	15415052
6	*Congress hall (night)*	942633	2025807	16730513
7	*Cinema hall (day)*	423566	1825362	12842530
8	*Cinema hall (night)*	159020	2264857	12871730
9	*Restaurant (day)*	823835	1847335	14025131
10	*Restaurant (night)*	599767	1796621	14645632
11	*Assembly room (day)*	687783	2311064	15083632
12	*Assembly room (night)*	459552	2330770	16233383
13	*Halls no. 8*	197222	3439981	13780143
14	*Congress foyer*	792613	3155158	21491577
15	*Party foyer*	110409	3463355	16669193
16	*Full building*	2707628	2888534	51888911

c) Each operational state was described by volume ratio $\boldsymbol{k_N}$, related to entire volume of rented spaces in the building. $\boldsymbol{V_N}$ is volume of rooms of individual operational case and $\boldsymbol{i}$ is total number of the operational cases.

$$k_N = \frac{V_N}{\sum_{N=1}^{i} V_N} \quad [Eq.\ 1]$$

d) To split basic energy consumption of the empty building and energy consumption during operational state, we numerically calculated increment of the average hour energy consumption for heating, ΔQ^N_T, cooling ΔQ^N_C and electricity ΔQ^N_E for each operational case, where N = 0 for "Empty building" and N = 1 to i for specific operational cases; t^N_{prov} is number of the operational hours during annual period of the operational case. (Tab.2)

$$\Delta Q^N_T = \frac{Q^N_{R,T}}{t^N_{prov}} - \frac{Q^O_{R,T}}{t^N_{prov}} \quad \text{[Eq. 2]}$$

$$\Delta Q^N_C = \frac{Q^N_{R,C}}{t^N_{prov}} - \frac{Q^O_{R,C}}{t^N_{prov}} \quad \text{[Eq. 3]}$$

$$\Delta Q^N_E = \frac{Q^N_{R,E}}{t^N_{prov}} - \frac{Q^O_{R,E}}{t^N_{prov}} \quad \textit{[Eq. 4]}$$

Tab. 2 Energy increment during operational cases related to the case 0 "Empty building"

No	Operational case	Energy increment		
		Heat ΔQ^N_T kWh.h^{-1}	Cold ΔQ^N_C kWh.h^{-1}	Electricity ΔQ^N_E kWh.h^{-1}
0	*Empty building*	**0**	**0**	**0**
1	*Club (day-time)*	**-390**	**287**	**196**
2	*Club (night-time)*	**-328**	**249**	**210**
3	*Halls no. 3 (day)*	**-51**	**247**	**894**
4	*Halls no. 3 (night)*	**67**	**75**	**957**
5	*Congress hall (day)*	**-268**	**378**	**721**
6	*Congress hall (night)*	**-195**	**232**	**772**
7	*Cinema hall (day)*	**-416**	**270**	**16**
8	*Cinema hall (night)*	**-349**	**279**	**17**
9	*Restaurant (day)*	**-306**	**276**	**340**
10	*Restaurant (night)*	**-262**	**187**	**364**
11	*Assembly room (day)*	**-343**	**403**	**630**
12	*Assembly room (night)*	**-290**	**292**	**675**
13	*Halls no. 8*	**-199**	**297**	**114**
14	*Congress foyer*	**-131**	**264**	**994**
15	*Party foyer*	**-209**	**299**	**444**
16	*Full building*	**88**	**234**	**4464**

e) The total average hour energy consumption was calculated as the sum of the increments of average hour energy consumption for heating ΔQ^N_T, cooling ΔQ^N_C and electricity ΔQ^N_E and $\boldsymbol{k_N}$ ratio of the average hour energy consumption for heating Q^O_T, cooling Q^0_C and electricity Q^O_E during the operational state "Empty building" (Tab.3)

$$Q^N_T = \Delta Q^N_T + k_N \cdot \frac{Q^O_{R,T}}{t^N_{prov}} \quad \text{[Eq. 5]}$$

$$Q^N_C = \Delta Q^N_C + k_N \cdot \frac{Q^O_{R,C}}{t^N_{prov}} \quad \text{[Eq. 6]}$$

$$Q^N_E = \Delta Q^N_E + k_N \cdot \frac{Q^O_{R,E}}{t^N_{prov}} \quad \text{[Eq. 7]}$$

Tab. 3 Total average hour energy consumption during the operation cases

No.	Operational case	Energy		
		Heat Q^N_T kWh.h^{-1}	Cold Q^N_C kWh.h^{-1}	Electricity Q^N_E kWh.h^{-1}
0	*Empty building*	**221**	**96**	**1459**
1	*Club (day-time)*	**-383**	**289**	**241**
2	*Club (night-time)*	**-323**	**251**	**242**
3	*Halls no. 3 (day)*	**-7**	**266**	**1179**
4	*Halls no. 3 (night)*	**98**	**89**	**1161**
5	*Congress hall (day)*	**-137**	**435**	**1584**
6	*Congress hall (night)*	**-102**	**272**	**1389**
7	*Cinema hall (day)*	**-411**	**272**	**46**
8	*Cinema hall (night)*	**-345**	**280**	**39**
9	*Restaurant (day)*	**-290**	**283**	**444**
10	*Restaurant (night)*	**-251**	**192**	**439**
11	*Assembly room (day)*	**-219**	**456**	**1446**
12	*Assembly room (night)*	**-201**	**330**	**1258**
13	*Halls no. 8*	**-194**	**299**	**144**
14	*Congress foyer*	**-73**	**289**	**1375**
15	*Party foyer*	**-185**	**310**	**599**
16	*Full building*	**309**	**330**	**5923**

f) From the average hour energy consumption was calculated average hour energy consumption, related to the floor area and space volume. (Tab.4)

CONCLUSION AND RESULTS

In terms of the presented study. There is average, time scaled annual energy consumption for each operational state (Fig.7), which could be used for calculation of operation costs for specific part of the building.

This method is describing distribution model of the overheads operational energy costs such, that each renter pays average operational energy costs, used in the rented part of the building and proportional part of the overheads operational energy costs. During rental period of the part of the building the number of users and heat loads are increasing. Therefore in most operational states the heating energy need is smaller than in the basic state – "Empty building"- while the cooling and electric energy are higher.

Tab. 4 Average hour energy consumption related to the floor area of the leased space

No	Operational case	Leased area m^2	Energy		
			Heat $Q^N{}_T$ kWh.h^{-1}m^{-2}	Cold $Q^N{}_C$ kWh.h^{-1}m^{-2}	Electricity $Q^N{}_E$ kWh.h^{-1}m^{-2}
0	*Empty building*	0	-	-	-
1	*Club (day-time)*	600	**-0,639**	**0,482**	**0,401**
2	*Club (night-time)*	600	**-0,538**	**0,418**	**0,403**
3	*Halls no. 3 (day)*	3662	**-0,002**	**0,073**	**0,322**
4	*Halls no. 3 (night)*	3662	**0,027**	**0,024**	**0,317**
5	*Congress hall (day)*	3003	**-0,046**	**0,145**	**0,527**
6	*Congress hall (night)*	3003	**-0,034**	**0,091**	**0,462**
7	*Cinema hall (day)*	324	**-1,268**	**0,839**	**0,143**
8	*Cinema hall (night)*	324	**-1,066**	**0,865**	**0,120**
9	*Restaurant (day)*	1350	**-0,215**	**0,209**	**0,329**
10	*Restaurant (night)*	1350	**-0,186**	**0,142**	**0,325**
11	*Assembly room (day)*	2284	**-0,096**	**0,200**	**0,633**
12	*Assemblyroom (night)*	2284	**-0,088**	**0,144**	**0,551**
13	*Halls no. 8*	1074	**-0,181**	**0,278**	**0,134**
14	*Congress foyer*	11464	**-0,006**	**0,025**	**0,120**
15	*Party foyer*	5395	**-0,034**	**0,057**	**0,111**
16	*Full building*	29156	**0,011**	**0,011**	**0,203**

The total operational energy costs C^N of 1 m^2 leased area for the operational case *N* is given by the following eq.8:

$$C^N = Q_T^N \cdot C_T + Q_C^N \cdot C_C + Q_E^N \cdot C_E \text{ [Eq. 8]},$$

where C_T is price of the heat energy, C_C is price of the cooling energy and C_C is price of the electricity.

Conclusion in terms of the used method.
This method eliminates orientation of the rented spaces to the cardinal points and year season of the lease so, that all renters are sharing proportional operating energy costs, related to climate conditions. This method could be used for distribution of the operational energy costs in the buildings, where is no possibility of measuring of the primary energies and where are known the operational schedules of heat gains and usage of the building.

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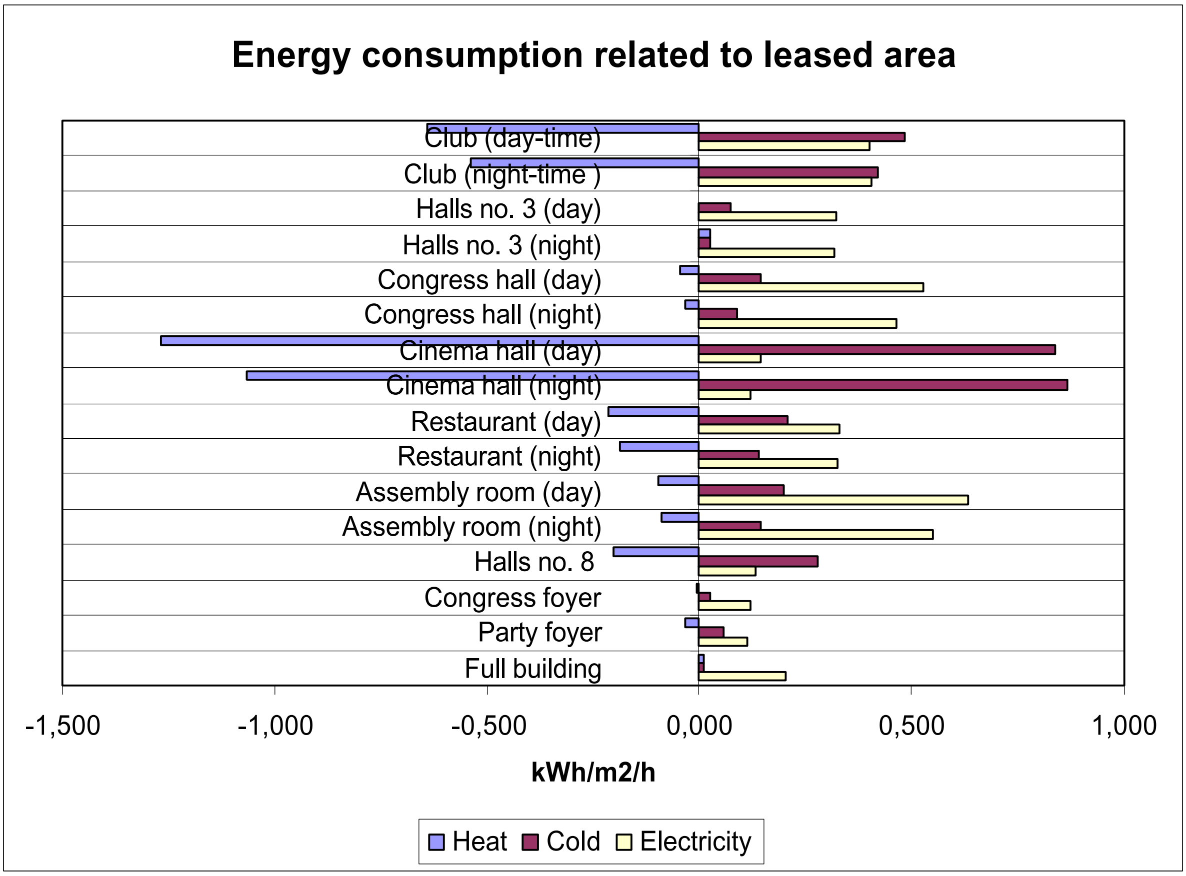

Fig. 7 Hour specific energy consumption during the operational cases

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NOMENCLATURE

V_{CV} ....volume of the fresh air distributed by AC units [$m^3.s^{-1}$]

$Q_{è}$ ....input of the pumps, fans and technology [kW]

N_{per} ....number of occupants [-]

N............operational case index [-]

Q_{osv} ....input of the lights [kW]

$Q^N_{R,T}$ ....annual heating energy [$kWh.a^{-1}$]

$Q^N_{R,C}$ ..... cooling energy [$kWh.a^{-1}$]

$Q^N_{R,E}$ ......annual electricity consumption[$kWh.a^{-1}$]

$\boldsymbol{k_N}$**...........** volume ratio index [-]

$\boldsymbol{V_N}$ .... volume of the rooms adjacent to the operational cases N [m^3]

i **.............** total number of the operational cases[-]

ΔQ^N_T ......increment of the average hour energy consumption for heating [$kWh.h^{-1}$]

ΔQ^N_C ...... increment of the average hour energy consumption for cooling [$kWh.h^{-1}$]

ΔQ^N_E....... increment of the average hour energy consumption of electricity [$kWh.h^{-1}$]

Q^N_T..........average hour heating energy consumption [$kWh.h^{-1}$]

Q^N_C.........average hour heating energy consumption [$kWh.h^{-1}$]

Q^N_E.........average hour electricity consumption [$kWh.h^{-1}$]

C_T ....market price of the heat energy [EUR/kWh, CZK/kWh]

C_C ....market price of the cooling energy [EUR/kWh, CZK/kWh]

C_C ....market price of the electricity [EUR/kWh, CZK/kWh]

C^N........... market price of the energy per m^2 of leased space for lease, classified according to operational cases[EUR/m^2, CZK/m^2]