NATIONAL CALCULATION TOOL FOR EPBD ENERGY PERFORMANCE CERTIFICATION

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ABSTRACT

Paper is focused on description of Czech national methodology and tool for energy performance calculation according to EPBD (Energy performance building directive 91/2002). Energy performance calculation is expressed by total annual energy consumption, including heating, cooling, ventilation, auxiliary and other energy required for building operation. There is a simplified multizone model, loaded by typical day for each month in hourly time step. Climate data are synthetic data for 4 climate zones according to standards, used for building physics calculation. Zone operation profiles include occupation, lighting, indoor environment requirements and auxiliary energy. Zone operation profiles are standardized for typical zones as offices, schools, dwellings etc. Building energy systems including heating, cooling, hot water generation and ventilation are incorporated as zone assigned systems, while energy sources (e.g. boilers, co-generation unit, solar collectors etc) are in the model assigned to the energy delivery systems. Result of energy performance calculation for assessed building is compared with existing average level of similar buildings and required level to obtain energy performance certificate according to EPBD requirements.

KEYWORDS

Energy performance calculation, EPBD, zone energy model, heating energy, cooling energy

INTRODUCTION

The Directive 2002/91/EC of the European Parliament and Council on energy efficiency of buildings (Energy Performance Building Directive EPBD) was adopted, after a lively discussion at all levels and with overwhelming support from Member States and the European Parliament, on 16th December 2002 and entered into force on 4th January 2003. It is considered as a very important legislative component of energy efficiency activities of the European Union designed to meet the Kyoto commitment and responds to issues raised in the recent debate on the Green Paper on energy supply security. The EPBD provides the general framework for the calculation procedures. A mandate has been given to the CEN committee to develop appropriate calculation procedures to support Member States in the national application of this article. This theme includes the assessment of the relevant EN (CEN) and EN ISO standards the way they are or will be implemented at national level, options for quality assurance of calculation methods, differences between methods or data input for new versus existing buildings, legal aspects (e.g. national versus CEN options), practicability (as "simple" as possible and yet sufficiently accurate and distinctive), methodologies for innovative technologies, further needs and possibilities for further harmonization and more.

TOOL DESCRIPTION

There are many ways of calculating building energy consumption and energy demand for whole building, especially energy demand for heating and cooling. The calculation method presented in this article is based on the delivered energy needed under standard indoor and outdoor conditions. Energy consumption of a building is an amount of the actually consumed energy or the expected amount of energy for the fulfilment of various demands related to the standard use of a building. In particular - heating, hot water preparation, cooling, treatment of air by ventilation and parameters modification of the indoor environment by air condition system and lighting. The basic process of the calculation is commonly divided into two stages:

- calculation of the building energy demand, or its parts – zones demands; it means the calculation of heat losses, and heat gains, required in each space in order to maintain specified internal conditions;
- calculation of energy consumption (building, or parts – zones, according to the energy demands) ; it means the calculation of the energy required by the energy systems (boilers, AHU units, DHW systems, lighting, etc.) needed to provide the necessary heating or cooling, or humidity control, etc..

The energy demand is calculated on the standard use of the building. This is utilization according to standard conditions of the indoor and outdoor environment and operations stated in connection with energy systems of the building in the valid technical standards and other national regulations. The calculation method is based on the simplified dynamic calculation. The energy demand can be calculated from monthly, daily and hourly simplified values, but hourly calculations are better to represent the complexities of HVAC system (mainly because of cooling) performance.

Calculation of heating energy demand is based on the following calculation method. The method calculates the building energy demand for each zone. Consequently for the energy system and related zone, is calculated energy consumption in terms of the energy demand. Energy demand for space heating $Q_{dem,H}$ and cooling $Q_{dem,C}$ is calculated according to CSN EN ISO 13 790 and CSN 73 0540. The basic calculation includes transmission losses Q_T and ventilation losses Q_V. The calculation method also includes heat gains $Q_{G,H}$ (internal Q_i and external Q_s) - internal heat gains from occupants $\Phi_{I,OCC}$, appliances $\Phi_{I,APP}$, lighting influences $\Phi_{I,LI}$ and final energy demands of the adjacent zones $Q_{i,u,n}$. Heat gains are determined by the heat production multiplied by fraction of the time t when the occupants/appliances are present in the zone. Energy demand is reduced by a constant value that is dependent on the external and internal gains. Calculation method is based on the method, described in Table1.

The domestic hot water demand $Q_{dem,DHW,n}$ is calculated according to CSN 060320. Annual domestic hot water consumption volume $V_{DHW,z}$ (at boiler temperature) per zone area is calculated according to the Regulation 428/2001 coll.

$$Q_{dem,H,n} = [V_{DHW,z} \bullet \rho_w \bullet c_w \bullet (\theta_{DHW,h} - \theta_{DHW,c})] / \eta_{DHW} \quad (20)$$

The lighting demand $Q_{dem,LI,n}$ is calculated using annual average reference specific demand $\Phi_{LI,n}$ for the particular types of buildings or by the total amount of electric power $P_{LI,n}$ installed in the zone for lighting. This dataset is generated according to the statistical data from several building types.

$$Q_{dem,LI,n} = \Phi_{LI,n} \bullet t_n \quad (21)$$

Calculation of energy consumption means the calculation of the energy Q_{gen} required by energy systems to provide the necessary heating $Q_{gen,H}$ or cooling $Q_{gen,c}$, humidity control $Q_{gen,Hum}$ and energy consumption for lighting $Q_{dem,LI,n}$, as well as DHW systems $Q_{gen,DHW}$. Calculation of energy consumption contains three basic steps ($_{XX}$ means kind of energy consumption):

- **Energy generation**

$$Q_{gen,XX} = Q_{distrXX} / \eta_{gen,XX} + Q_{auxXX} \quad (22)$$

$Q_{gen,XX}$ includes auxiliary energy $Q_{aux,XX}$ for energy systems.

- **Energy distribution**

$$Q_{distr,XX} = (\sum Q_{em,z,XX} + \sum Q_{AHU} - \sum Q_{SC}) / \eta_{distr,XX} \quad (23)$$

Q_{SC} is the energy from the renewable energy sources, or energy produced by the building (e.g. Photo Voltaic - systems $Q_{PV,n}$, Combined Heat and Power generation $Q_{CHP,n}$, Thermal solar systems $Q_{sc,n}$, Heat Pumps).

Table 1 Calculation of energy demand

Heat demand for each zone according to CSN EN ISO 13 790 and CSN 73 0540		
Basic figure	1st step figure	2nd step figure, ..xnd step figure
$Q_{dem,z,H} = Q_{L,H} - \eta_{G,H} \bullet Q_{G,H}$ (1)		
$Q_{L,H} = Q_T + Q_V$ (2) $Q_T = \sum_k\{H_{T,k} \bullet (\theta_i - \theta_{e,k})\} \bullet t$ (3)		$H_D = \sum_i A_i \bullet U_{i,corr}$ (4) $H_T = H_D + H_g + H_U$
$Q_V = \sum_k \{H_{V,k} \bullet (\theta_{i,z} - \theta_{s,k})\} \bullet t$ (7)		$H_{V,k} = b \bullet f_V \bullet \rho_a \bullet c_a \bullet V_{V,k}$ (6)
rem: Q_V depends on the three types of ventilation (natural ventilation, hybrid ventilation or mech. ventilation)		
$Q_{G,H} = Q_i + Q_S$ (8) $Q_i = \sum_k Q_{i,k} + \sum_l (1 - b_l) \bullet Q_{i,u,l}$ (9)		$Q_{i,k} = \Phi_{i,mean,k} \bullet t$ (11) $Q_{i,u,l} = \Phi_{i,mean,u,l} \bullet t$ (12) $\Phi_i = \Phi_{I,OCC} + \Phi_{I,APP} + \Phi_{I,LI}$ (13) $\Phi_{I,OCC} = f_{OCC} \bullet q_{OCC} \bullet A_{gross}$ (14) $\Phi_{I,APP} = f_{APP} \bullet q_{APP} \bullet A_{gross}$ (15) $\Phi_{I,LI} = f_{e,r,LI} \bullet \Phi_{LI}$ (16)
$Q_s = Q_{s,c} + \sum_j [(1 - b_j) \bullet Q_{s,u,j}]$ (10)		$Q_{s,c} = \sum_k [I_{s,k} \bullet F_{s,o,k} \bullet A_{s,k}]$ (17) $Q_{s,u,j} = \sum_j [I_{s,j} \bullet F_{s,o,j} \bullet A_{s,j}]_u$ (18)
$\eta_{G,H}$	Intensity of utilization heat gain depends on the thermal capacity of the buildings and of the ratio $Q_{G,H} / Q_{L,H}$	
Cooling demand for each zone according to CSN EN ISO 13 790 and to CSN 73 0540		
$Q_{dem,z,C} = Q_{G,C} - \eta_{L,C} \bullet Q_{L,C}$ (19) rem: the calculation is paralleled by the heat demand		

- **Energy emission**

$$Q_{e,z,XX} = Q_{de,z,XX} / \eta_{em,z,XX} \quad (24)$$

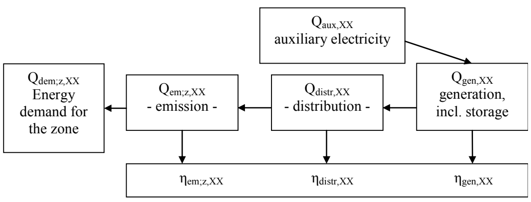

Figure 1 A principle of the calculation energy consumption

For example heating system - the heat generator is provided by the demand and the losses from the individual heating systems. When a heat pump is used, COP value depends on the type of a heat pump and the type of a heat source. Systems without a heat pump have a $COP_{gen,H,i} = 1$.

$$Q_{gen,H,c,n,i} = Q_{distr,H,n} / (\eta_{gen,H,c,i} \bullet COP_{gen,H,c,i}) \qquad (25)$$

The heat distribution describes required energy quantity generated and transported to the heat emission system - heating system energy consumption per heating system ***s*** is summarized for all the zones ***z*** and all air handling units ***AHU***, if they are included. $Q_{SC,distr,H,sc,n}$ represent the energy from the renewable energy sources (e.g. energy from the thermal solar systems) used for space heating.

$$Q_{distr,H,n,s} = \frac{\sum_{z_s} Q_{em,H,z,n} + \sum_{AHU} Q_{AHU,H,n,s}}{\eta_{distr,H,s}} - Q_{SC,distr,H,sc,n} \qquad (26)$$

Energy demand for space heating of the zone ***z*** is covered by the heating system ***s***, thus energy $Q_{em,H,z,n}$ is emitted, e.g. into the room space – zone.

$$Q_{em,H,zs,n} = Q_{dem,H,zs,n} / \eta_{em,H,zs} \qquad (27)$$

Losses represent efficiency $\eta_{(em,distr,gen),H,(z)s}$ (heat emission, heat distribution) in the process steps between the energy demand and the energy generation, i.e. in the emission, distribution, storage and generation. It is the fraction of the heat flow rate from the system part x (emission, distribution and generation) that is recovered in the zone. The auxiliary electricity (i.e. fans, pumps) used for heating generation in the zone of the building depends on the installed power and total heating area.

$$Q_{aux,H,n} = t_n \bullet f_{H,n} \bullet p_{pump,H} \bullet A_{tot,H} \bullet f_{c,H} \qquad (28)$$

In the method was not used degree-day method, which is well-established and easily used method for heating and cooling energy calculations, especially for relatively simple buildings. But if the cooling demand is calculated by degree-day methods, there is a problem with average monthly temperatures. Empirically, it is found that there are extensive correlations between cooling energy use and cooling degree-days for some buildings and systems, but not for all. For cooling demand it is not possible to use average month temperatures because average temperatures are lower in summer months than the indoor temperature - it does means no cooling requirements.

National calculation tool (NCT)

Based on the described method is provided the calculation tool. The calculation tool is created in spreadsheet on the base of the calculation method to combine compact structure of the method and to give access to easy test the calculation method. The national calculation tool calculates the energy demands (heating, cooling, domestic hot water systems, lighting, etc.) of each space in the building or zone according to the activity within. NCT includes different standardized profiles of the use that may have different temperatures, operating periods, lighting standards, etc. It calculates the heating and cooling energy demands by carrying out an energy balance based on the climatic location. This is combined with information about system efficiencies to determine energy consumption. Energy used for lighting is calculated for each zone and domestic hot water. It is calculated for whole building – it depends on the type of DHW system. Input data to NCT require information from the following sources:

Table 2 Input to the NCT

INFORMATION	SOURCE
Building geometry, areas, orientation, etc.	Reads from drawings or direct measurement
Climatic data	From internal database of calculation tool
Selection of occupancy profiles for activity areas assigned to each space	For consistency, these come from an internal database – selects by choosing building type and activity for each zone
Building envelope constructions	Inputs parameters directly (“Inference” procedures may be used for energy certification of existing buildings)
HVAC systems	Selects from internal databases or inputs parameters directly
Lighting	Selects from internal databases or inputs parameters directly

Setting a building in NCT contains the following steps:

- to enter general information about the building, owner, certifier, and select the appropriate weather data (Figure 2);
- to build up a database of the different forms of constructions and glazing types;
- to create the zones in the interface and enter their basic dimensions;
- to define the envelopes of each zone – walls, floors, ceilings, etc. their dimension, orientations, the conditions in the adjacent spaces, and the constructions used to be defined along with the air permeability of the space;
- to define the HVAC (heating, ventilation, and air conditioning) systems, the DHW (domestic hot water) systems, and any SES (solar energy systems), PVS (photovoltaic systems), wind generators or CHP (combined heat and power) generators used in the building;
- to define the lighting system and ventilation characteristics of each zone and assign them to the appropriate HVAC and DHW systems.

- And the last step – to see the class of the energy performance of the building and the energy consumption.

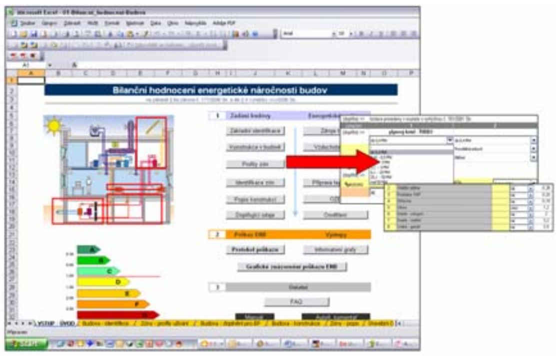

Figure 2 NCT user interface in MS Excel

The annual energy consumption is calculated for the following items:

- space heating systems;
- domestic hot water heating;
- electricity for pumps and fans (including mechanical ventilation if present);
- electricity for lighting.

The energy performance and the class of the building energy performance are calculated from energy consumption in compliance with the data of the reference (notional) building. The notional building has the same geometry, orientation, and usage as the evaluated building. It is exposed to the same weather conditions as the evaluated building; it is in the same location. The class of the energy performance depends on the classification index CI. It shows range of the energy performance resulting class of entire building, or certain HVAC system (heating system, cooling system, domestic hot water system, lighting of the building). Figure 3 shows graphical part of building energy performance certificate. It does express building’s energy consumption level in range of seven classes A – G according to CI index. Required level of a building is C, if building falls under C class – it does not pass. Every class above C is strongly recommended for newly build or refurbished buildings. The best A class matches to low energy and passive buildings.

STANDARDIZED PROFILES OF USE

Whatever type of building during its utilization period is operated differently and likewise while the main day period is over and all systems decrease its performance. It is obvious for various building types, but the same come out in case of similar or the same types of buildings. In compare of completely equal buildings, when the first one is heated to the set point temperature 20 °C and the second one meets temperature 22 °C. Evidently are received dissimilar values of annual heating energy consumption.

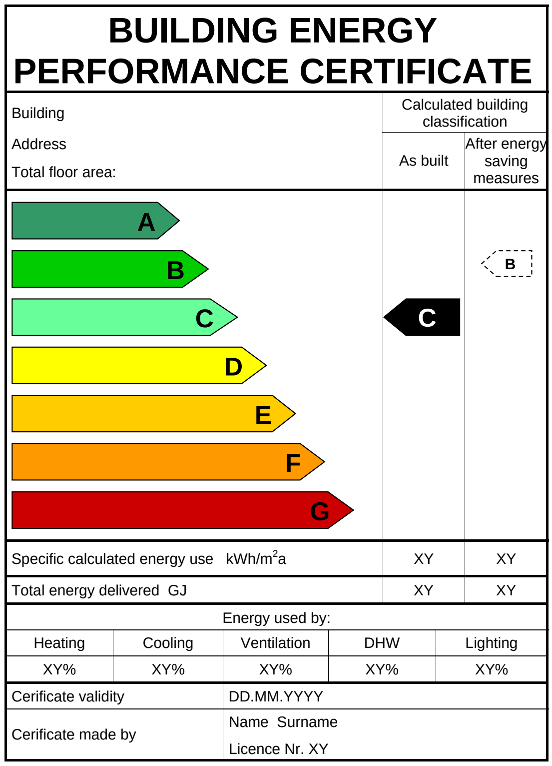

Figure 3 Czech energy performance certificate

These circumstances provides serious problem for general assessment of building performance even in the case that is required comparison of different buildings. The only solutions are standardized profiles of use.

While our performance assessment tool NCT was composed was decided to create certain profiles for major building types. The target of each profile is to set indoor conditions that meet desired quality level of zone environment. Basically the zone environment level setup fulfils requirements of thermal comfort (Fanger, 1970), ventilation, lighting and also effects related to activity such as heat gains. This choice of constant profiles serves to certain advantages, especially identical parameters for same zone type in different buildings, it does helps also to avoid underestimating of some energy consumers in a building, for example low lighting intensity. Finally is lower possibility to intentional affection of energy consumption results.

Generally it does mean large amount of data in each profile. These values serve as one of boundary conditions for energy building performance calculation of any zone or any building. For calculation purposes user just choose particular profile related to assessed zone.

Concretely each zone standardized profile of use include data’s groups defining operation time in a day and year, heating and cooling set point temperatures, ventilation air flow and supply air temperatures, indoor heat gains and artificial lighting in zone.

Collecting necessary microenvironmental data took complex search primary through national technical and law standards. However those sources include many relevant numbers, due to heterogeneous building types were some data missed. Purposefully was utilized values from some foreign standards e.g. DIN 4799 (1990) and ASHRAE (1999) for supply air in surgery zone definition. Unique part of gathered data was indoor heat gains caused by occupants and equipment, reasonable source that came in sight were databases of energy simulation programs, especially DesignBuilder (2006).

Presently are available 9 groups containing totally 49 standardized profiles of use. These nine groups cover main types of buildings as dwelling houses, apartment buildings, office buildings, educational buildings, health and care institutions, hotels and restaurants, sports facilities, commercial buildings and finally theatres.

CLIMATE DATA

Ambient temperature

There are used climate dates for four climate areas (according to ČSN 730540, supplement H1) in National Methodology climate database. Twelve synthetic reference days in hourly time-step temperature values, was created for every climate area. Each representative day cover certain month. Creation of reference days was done utilizing climate dates in format TM2 (TRNsys 16 Climate Database) for following localities:

- area 1 : Prague
- area 2 : Ostrava – Poruba
- area 3 : Churáňov
- area 4 : is classified as mountain location for which wasn't accessible climate dates during the year. Simplified height interpolation was done for this reason.

$$\Delta\Phi_e = \Phi_{e,0} \cdot \frac{\Delta h}{100} \quad \text{(ČSN 730540-3)} \qquad (29)$$

Source data are in hourly temperature values format during the year, which does in sum 8760 values. Climate dates for methodology was processed in typical day format where every month represents just one typical day. Typical day for winter temperature is average of all separated values in month and in given time-step interval. For summer season, it was necessary to take into account increased temperature in summer months, which is being expressively higher than mere average value. Temperature for months from June to August was determined using monthly values but with regard to amplitude temperature in summer season.

Solar radiation

It was necessary to create file with radiation dates for various slope insulation surfaces and world's direction orientation for needs of National methodology. Input values are solar constant I_0 = 1366 W/m^2, geographical latitude for Czech Republic (CR) 50,08°, average altitude for CR 300 alt. and atmosphere pollution coefficient (Cihelka 1994), which is considered for calculation as urban area.

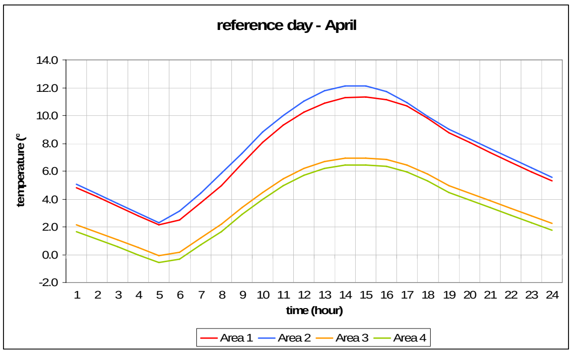

Figure 4 – Example of reference day for month April

Further, it was on the base of values (declination (30), angle determining sequence for certain day in year (31), hourly angle (32), sun high above horizon (33), azimuth (34)) determining the sun position on the sky.

$$\delta = 23{,}45°\, sin(T - 109°) \qquad (30)$$

$$T = 0{,}98° D + 29{,}7° M \qquad (31)$$

$$\tau = 15 \cdot (PSČ - 12) \qquad (32)$$

$$h = arcsin(sin(\delta)sin(\varphi) + cos(\delta)cos(\varphi)cos(\tau)) \qquad (33)$$

$$a = arcsin(\frac{cos(\delta)}{cos(h)} sin(\tau)) \qquad (34)$$

Direct normal radiation (35), which takes into account coefficient of sun high above horizon and sea level altitude in a given place (36) was determined on the base of these values. In the next step, solar radiation intensity impacted on universal laid surface (37) and diffuse solar radiation (38) was calculated.

$$I_{pn} = I_0 \cdot exp\left(-\frac{Z}{\varepsilon}\right) \qquad (35)$$

$$\varepsilon = 4{,}83182 \,.\, [sin(h) + (0{,}003 + sin^2 h)^{0,5}] + 0{,}91018 \qquad (36)$$

$$I_P = I_{Pn} \cdot cos\,\gamma \qquad (37)$$

$$I_D = 0{,}5(1+cos(\alpha))I_{Dh} + 0{,}5r(1 - cos(\alpha)).(I_{Ph} + I_{Dh}) \qquad (38)$$

$$I_{Ph} = I_{Pn} \cdot sin(h) \qquad (39)$$

$$I_{Dh} = 0{,}33(I_0 - I_{Pn})\, sin(h) \qquad (40)$$

The total solar radiation I is sum of direct and diffuse radiation (38). Radiation values were calculated for every day in the year in hourly time-step intervals. Average values for every day of particular month in the year are used in the NCT calculation method. Sun shine duration from long-term (30 years) Czech Hydro meteorological institute observation was assumed for every four climate areas. The measurement was realized by heliograph which records sun shine duration during month. Result value of sun shine is average of this climate area. In these values is taken into account real sun shine duration.

Air humidity

Specific air humidity is determined as average value of separate monthly values. Relative humidity computation comes out from specific air humidity according to equation 41.

$$\varphi_e = \frac{p}{p_v''} \cdot \frac{x}{(0{,}622 + x)} \qquad (41)$$

NOMENCLATURE

Symbols

a - sun azimuth (°)
a_s - azimuth angle of normal insulated surface measured from south (°)
A - area (m^2)
b - correction factor for an unconditioned adjacent space (-)
c - specific heat capacity (J/(kg.K))
D - number of day in month (-)
f - operation constant (-)
h - sun high above horizon (°)
$_\Delta h$ - see level altitude difference (m)
H - heat transfer koeficient (W/K)
I_s - final solar iradiance (W/m^2)
I_D - diffuse solar radiation intensity (W/m^2)
I_p - solar radiation intensity impacted on universally laid surface (W/m^2)
I_{PH} - direct solar radiation intensity on horizontal surface (W/m^2)
I_{DH} - diffuse solar radiation intensity on horizontal surface (W/m^2)
I_{pn} - direct solar radiation intensity (W/m^2)
I_0 - solar constant (W/m^2)
M - number of month (-)
p - total air pressure (Pa)
p_v'' - partial saturated vapour pressure (Pa)
PSČ - real sun time (h)
Q - quantity of heat or energy (J)
t - time, period of time (s)
T - angle determined day sequence in given year (°)
U - thermal transmittance (W/m^2K)
V - volume of tranfered medium (air, water) (m^3)
x - specific air humidity (g/kg)
Z - atmosphere pollution coefficient (-)
α - insulated surface slope from horizontal surface (°)
γ - angle of sun beam impact on insulated surface (°)
ε - coefficient of depend sun high above horizon and see level altitude (-)
φ_e - relative air humidity (-)
φ - latitude (°)
Φ - heat flow rate (W)
Φ_e - height temperature gradient (K)
$\Phi_{e,0}$ - basic temperature gradient (K)
η - efficiency, utilisation factor for gais or losses (-)
Θ - celsius temperature (°C)
ρ - density (kg/m^3)
τ - hourly angle value (°)

Subscripts

a - air
aux - auxiliary
APP - appliances
corr - correction
C - cooling
D - direct
e - exterior, external
g - ground
G - gains
H - heating
Hum - humimidifacition
i - internal
L - loss
LI - light
o - overall
OCC - occupancy
s - solar, sunspace
SC - renewable energy sources
T - transmission
U - unconditioned
V - ventilation
Z - zone number
i,j,n,u - dummy integers

TOOL TESTING AND VALIDATION

National model was validated with BESTEST methodology and with new multizone models. The climatic data set was transformed to new design conditions which corresponded to Czech Republic conditions. Simulation results were compared with national tool results. Simulation was done with esp-r and Designbuilder (Energyplus core) software and with the degreeday calculation method. Detailed validation results will be available in April 2007.

CONCLUSION

The presented method for EPBD calculation will be used according to Czech law for all new buildings with floor area above $50m^2$ except temporary buildings to calculate building certificate, describing building energy performance. Presented approach for problem solution is result of professionals groups together with experts from the Czech Ministry of Industry consensus, fulfilling European Commission requirements on EPBD implementation.

ACKNOWLEDGMENT

This paper was supported by Research Plan CEZ MSM 6840770003.

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