CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 1

Heiselberg, Per Kvols

Roadmap to nZEB Hospital, a Case Study: Policlinic Building – VU Medical Center Amsterdam

R. Capperucci*[1], W.H. Maassen*[#2], W. Zeiler*[3]

[*]*Department of the Built Environment, Eindhoven University of Technology*
P.O. Box 513, 5600 MB Eindhoven, The Netherlands

[1]r.capperucci@student.tue.nl

[3]w.zeiler@tue.nl

[#]*Royal HaskoningDHV*
George Hintzenweg 85 - Postbus 8520 3009 AM Rotterdam, The Netherlands

[2]wim.maassen@rhdhv.com

Abstract

Hospitals need to achieve great reductions in energy consumptions and CO_2 emissions for existing as well as new buildings to fulfill upcoming requirements for the European Union directive on nearly Zero Energy Buildings (nZEB). This is a great challenge because realizing energy reduction within a hospital compared to an office has a by far lower priority. Consequently, in hospitals, less data about energy consumption and building services operation is available. The case study VU Medical Center (VUmc) Amsterdam was analyzed and the energy saving potential (achievable in the outpatient departments of the Policlinic) identified. A three-step methodology was used: (1) in-depth analysis of case study, (2) development of a nZEB-design approach and (3) energy simulations. The analysis revealed that little attention is directed on energy performance and monitoring activity of buildings. Application of the proposed approach resulted in a top five of energy saving measures. According to VABI Elements© building energy simulations, significant (27%) energy savings can be achieved and indoor comfort can be improved by upgrading building envelope, HVAC system and applying occupancy-dependent controls.

Keywords – Hospital energy demands; Building energy efficiency; nZEB; Energy savings; Matching Building-Services-User; Control systems; Building energy simulation.

1. Introduction

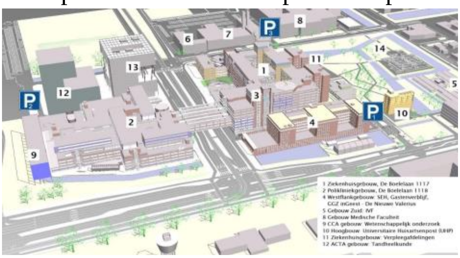
In the recast of the Energy Performance of Buildings Directive (EPBD) [1], the EU has set nZEB requirements to new buildings (2020) and all existing buildings (2050), which applies also to hospitals. Hereby, it is essential to guarantee appropriate and sometimes live saving functionality while saving energy. Therefore, achieving these requirements in hospitals is a greater challenge than, for example in office buildings.

Worldwide, circa 6% of the total energy consumption in the buildings sector is represented by energy usage in medical centers [2]. In the Netherlands, the healthcare sector consumes approximately 1.6 % of the energy consumption, of which 64% is consumed by academic medical centers (AMCs) [3,4]. The approaching EPBD requirements and the expected increase of energy costs have driven AMCs to review their energy policies. In light of these concerns, a multi-Year energy-efficiency covenant 2005-2020 (MJA3) [4]; organized by the Dutch Enterprise Agency (RVO), was signed by each Dutch AMC. The most relevant commitment of MJA3 to each hospital is the achievement of an average 2% energy efficiency per year, compared to consumptions of 2005.

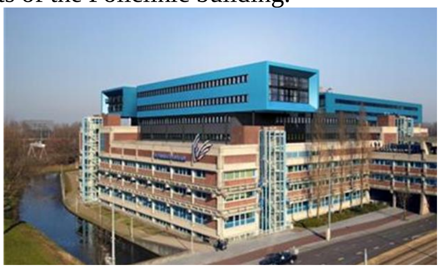
In order to determine if it is possible to reach the set goals for energy reduction, a case study was performed on VU Medisch Centrum (VUmc) (see Figure 1a); an academic hospital located in the southern part of Amsterdam, the Netherlands. The energy management coordination (CCE) is currently facing severe challenges to satisfy MJA3 requirements and increase the efficiency either at broad (campus) and at local (e.g. building, department) level. Preliminary research has shown several lacks in: monitoring activity, building energy performance and match between: building–user–services. For example, major issues in the optimization of HVAC systems are the difficulties in detecting inefficiencies and complex relations between the consumption and influencing parameters [5]. This study aims to indicate the potential of energy savings that can be achieved in the outpatient department of the VUmc Policlinic.

2. Methods

The project objectives were obtained through a three-step methodology: first, in-depth analysis of case study; second, development of a nZEB-design approach and; third, building energy simulations. The in-depth analysis of VUmc includes a literature study [6-9] on specific requirements for indoor environment and energy consumption in Hospitals as well as several interviews with the CCE technical staff and site visits. The approach has been applied on hospital building typology while the energy simulations were performed on the outpatient departments of the Policlinic building.



(a)



(b)

Fig. 1 – (a) Overview of VUmc district and healthcare buildings. (b)View of VUmc Policlinic building.

The existing Policlinic building (see Figure 1b) was chosen as an interesting case study according to preliminary analysis and indications from CCE coordinators; it was built in 1986 and has a gross floor area of 80000 square meters. The building is extensively used and although its lifetime has been extended (from 10 to 30 years, referred to 2014) any thorough re-commissioning has not been performed and maintenance is provided on a minimal level. These circumstances occur in many AMCs and their campuses, which are in continuous transition to upgrade primary processes according to the latest insights and developments.

2.1. In-Depth Analysis of Case Study

In the in-depth analysis the aim was to comprehend how VU, VUmc and Policlinic are organized and how they operate. Then the major features related to energy demands (for each type of supply), management and issues (e.g. Fig.2a) are examined. The investigation of the aforementioned points has been conducted through site visits (e.g. Fig.2b), interviews to CCE staff and analysis of data (e.g. MJA3 results, VU master plan, energy monitoring activity etc.).

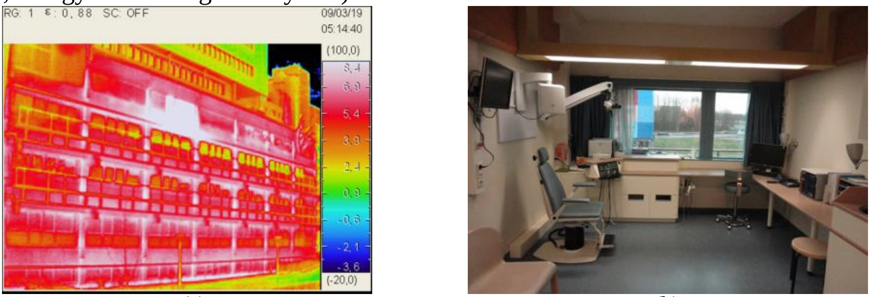


Fig. 2 – (a) A thermal picture of policlinic's West façade highlighting several thermal bridges on the external envelope. These can be identified by the bright patterns in the picture. (b) Typical room of Policlinic building.

2.2. nZEB-Design Approach

In the Netherlands, a commonly used approach for an energy-efficient building design is the three-step strategy called 'Trias Energetica' [10]. Due to increasing concern and evolution of techniques the 'Trias Energetica' has been upgraded to a 'Five-Step Method' [11], as can be seen in Figure 3.

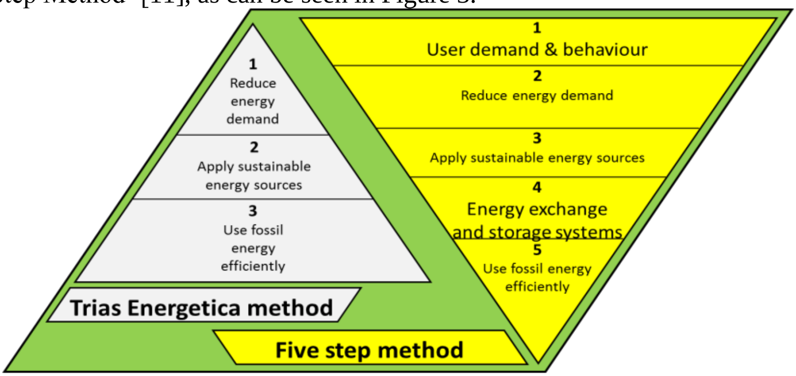


Fig. 3 – Building design approaches: 'Trias Energetica'[10] versus the upgraded 'Five Step Method'[11].

As can be seen in the figure, the additional steps to the original approach are: user demand and behavior, and; energy exchange and storage systems. The former step implements the 'user-oriented' concept through smart building designs and controls. The focus on the user results in improvements of indoor climate as well as productivity; furthermore, it can substantially decrease energy wastage.

Both methodologies and their concepts should be considered in light of their congruence with nZEBs' features [1] and requirements of MJA3. However, the approach developed in this research focuses mainly on two principles:

1. Minimize the demand of energy, and;
2. User demand and behavior.

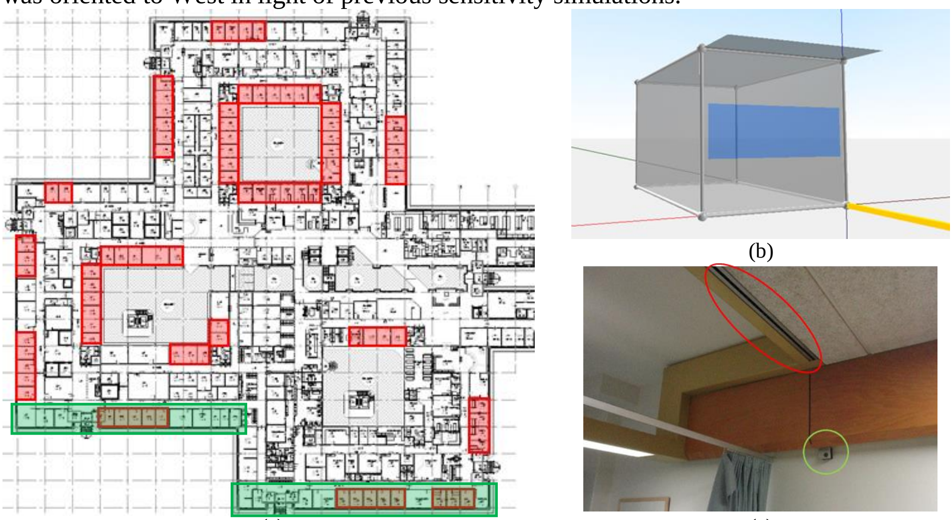
In addition, the methodology must consider a few aspects strictly related to the case study at hand: those having relevant impact over design success. With respect to our case study building (VUmc Policlinic) the following aspects are also considered:

3. Case study analysis (issues, requirements and potential), and;
4. Building life expectance and maintenance costs.

In light of these four aspects, a list of measures for upgrading the performance and the indoor comfort is determined; moreover, further steps of the project are made in their consideration.

2.3. Methods: Building Energy Simulations

A set of building energy simulations is determined in order to validate the aforementioned measures and to provide insights about energy flows and controls over the case study. VABI Elements© building simulation tool was chosen for the purpose of this study. The plan of the policlinic presents a variety of rooms designed based on a modular room, as can be seen in Figure 4a. This is identified as the most representative space of the building and adopted for the set of simulations. The room has a width of 3.25 m, a length of 4.55 m and a height of 2.80 m. The VABI model (see Figure 4b) was oriented to West in light of previous sensitivity simulations.



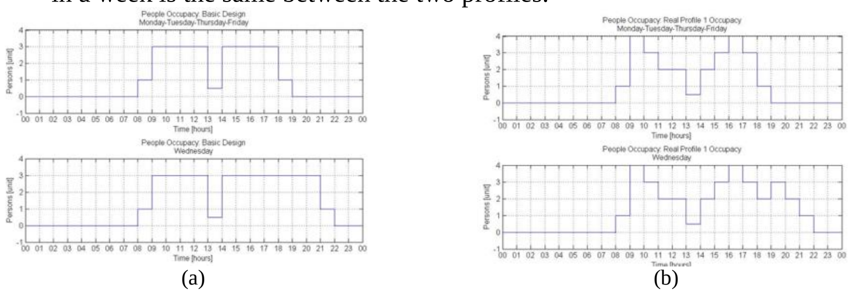
(a) (b) (c)

Fig. 4 – (a) Plan of policlinic building, in red are highlighted the room considered for the simulations while in green are circled the western oriented façades. (b) Policlinic room modeled in VABI Elements©. (c) Local re-heating system in case study room: air inlet (red) and temperature set-point control (green).

Air-conditioning in the modelled space resembles current system organization: it receives conditioned air from the central system (central heating and cooling) and occupants can adjust temperature by a local re-heater (local heating), as can be seen in Figure 4c. The adjacent spaces are assumed to have equal temperature set-points while the back wall neighboring with the corridor has lower set-points. Differently, the external environment (air temperature, relative humidity and solar irradiation) is modelled with a climate file for the year 1965-1965 at De Bilt (Royal Dutch Meteorological Institute, KNMI). Building simulations were done in consideration of an entire year period for various parameters. However, in light of the research' goals, the focus is oriented on consumptions (either central and local system) and indoor thermal comfort.

The set of simulations is composed of a total number of eight scenarios involving the variation of three major systems, which are based on the results of the design approach (see section 3.3). Each aspect consists of two elements, the first resembles the current conditions of the system in the policlinic while the second models an improvement to the system as defined in section 3.3. The aspects involved are:

1. HVAC: The systems taken into account are a Constant Air Volume (CAV) and a Variable Air Volume (VAV) system. In both systems the heating profile relates the external air to the target inlet air and the systems generating heating and cooling are assumed to have no power limits. The CAV has only a 'On-Off' modality with a constant airflow rate. Differently, the VAV has a high-low ventilation rate controlled by CO_2 set-points.
2. Occupancy profile: The profiles are based the opening times of the building, on which the internal heat gains schedules of devices (not medical) and lighting are based. First profile (see Fig.5a) considers a constant presence of three people in the room while the second (see Fig.5b) has a random occupancy of maximum four people. The average number of people per hour in a week is the same between the two profiles.



(a) (b)

Fig. 5 – Occupancy profiles employed in the simulations: (a) 'Constant' and (b) 'Random' profile.

3. Building envelope: The current building shell is based on Dutch standards [8], which have defined lump-sum values for R_c (opaque elements) and U (transparent elements) related to limits at policlinic's time of construction. The improved systems are designed to satisfy current Dutch standards [9].

The set of simulations is presented as a scheme in Table 1.

Table 1 – Simulation set scheme.

SIMULATION NUMBER	HVAC		OCCUPANCY		ENVELOPE	
	Type	I – CAV II – VAV	Type	0 – Constant 1 – Random	Type	0 – Current 1 – Improved
I.0.0	I		0		0	
I.1.0	I		1		0	
I.0.1	I		0		1	
I.1.1	I		1		1	
II.0.0	II		0		0	
II.1.0	II		1		0	
II.0.1	II		0		1	
II.1.1	II		1		1	

3. Results

3.1. In-Depth Analyses of Case Study

The research on VUmc and case study has provided a clear picture on how buildings are currently managed. Moreover, it showed that little attention is directed on inefficient energy systems in buildings. Some of the structures are old and their building and services design are obsolete for current standards. Current services are not user-oriented, hence, in the energy management small attention is directed toward occupants (e.g. indoor comfort) and occupancy.

The outcomes of the investigation through interviews and visits, which have been supported by a study of current activity reports and monitoring, are:

In typical hospital buildings:

- Energy consumers, energy flows and energy wasting components are often unknown, resulting in uncertain parameters for sustainable energy reduction investments.
- Medical personnel have little awareness of energy consumption, therefore of its costs: great waste of money and resources (energy) due to poor management.

In case study hospital building (Policlinic):

- Current energy management method is not producing the necessary savings to fulfil MJA3 requirements in both short and long periods. Therefore, additional measures have to be implemented also to address issues related to energy demands and indoor comfort at policlinic
- The extended life of policlinic strengthens the necessity to increase the efficiency of both components and services of the building. This aspect might have a great relevance in light of constantly increasing costs of energy and demands of new and more specialized healthcare treatments.
- Coarse monitoring activity and the poor quality of measured data (not calibrated or approximated amounts) give a hard time to CCE for determining the magnitude of inefficient processes.
- Severe issues were identified at essential building components such as the envelope, the HVACs and their distribution systems.

3.2. nZEB-Design Approach

The application of the approach resulted in list of energy saving measures suitable to typical hospital and to case study. The identification of measures was done in consideration of:

- Current energy demands per type: total amount, total cost and cost per unit.
- Positive outcomes for indoor environment: improvement of comfort (thermal and visual) and healing conditions.
- Current condition and performance of the system and its components.

Next, a further selection based on these criteria was done to prioritize solutions and resulting in the top five measures. The selection of the five high-potential solutions was supported by a solid literature review on related previous research [12-21]. In particular, it was found that typically in hospitals the ventilation load, because of the processing of outdoor air in the AHUs, is the greatest cause of energy requests [2,12,21]. In conclusion, the top five solutions for hospital buildings are:

1. Upgrade of the HVAC system (e.g. from CAV to VAV system);
2. Application of occupancy-based smart controls to HVAC system (ventilation, heating and cooling);
3. Upgrade of the building envelope (opaque and transparent components);
4. Upgrade of the lighting system and elements;
5. Application of occupancy-based smart controls to lighting system and devices.

The first three measures are chosen to be implemented in the building simulation models to evaluate their effect on energy consumption and indoor comfort.

3.3. Building Energy Simulations

The building simulations over an entire year results in yearly amounts of energy consumptions (kWh) and GTO (h) index [22] values. Energy demands are presented in Figure 6 and are presented separately for each component: central heating, central cooling and local heating. The results for both aspects are presented in comparison to the simulated current situation (I.0.0).

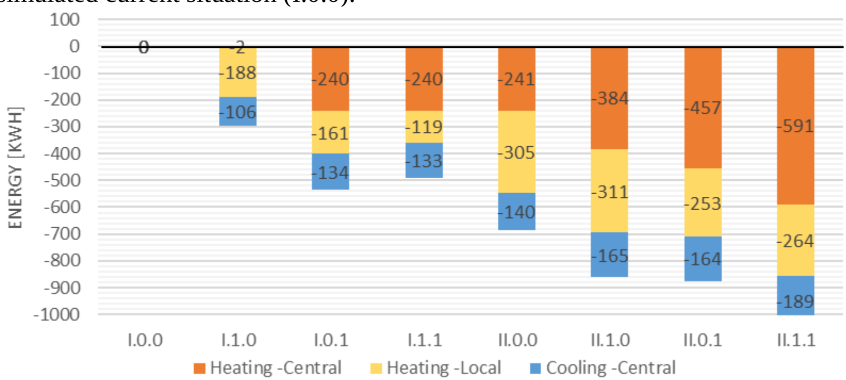


Fig. 6 – Energy reductions for one year simulation compared to simulated current conditions for a single room.

In Figure 6 are displayed the reduction of consumptions divided by type that can be achieved in the case study room at VUmc policlinic. Each column represents the implemented energy saving measure. The greater savings are obtained for the central heating, which is the most demanding; but significant reductions are achieved also for cooling and local heating. As can be seen, significant savings (up to 535 kWh, 14% saving from I.0.0) can be achieved without upgrading the HVAC system. However, reductions rise easily with the implementation of VAV system as can be observed for the results of set II of simulations. In set II.1.1, savings reach 1044 kWh (considering central heating and cooling but also local heating) which is 27 % less compared to current conditions. In order to choose the best solution, it is essential to consider the magnitude of possible installation costs. In light of the previous consideration, the II.1.1 and II.0.1 are the most demanding (VAV and envelope); therefore, the most convenient seems to be the implementation of the VAV with controls on the occupancy (configuration II.1.0).

GTO (Weighted Overheating Hours) [22] is a performance index which relates the hours with a PMV (Predicted Mean Vote) exceeding comfort boundaries with a weighting criteria based on the PPD (Predicted Percentage of Dissatisfied). The 'weighted' hours of a year will be summed up, resulting in the GTO index. It is necessary to say that the whole set of simulations was done to meet the BREEAM temperature comfort requirement of 150 overheating hours. Last, the results for the indoor comfort index are displayed in Figure 7.

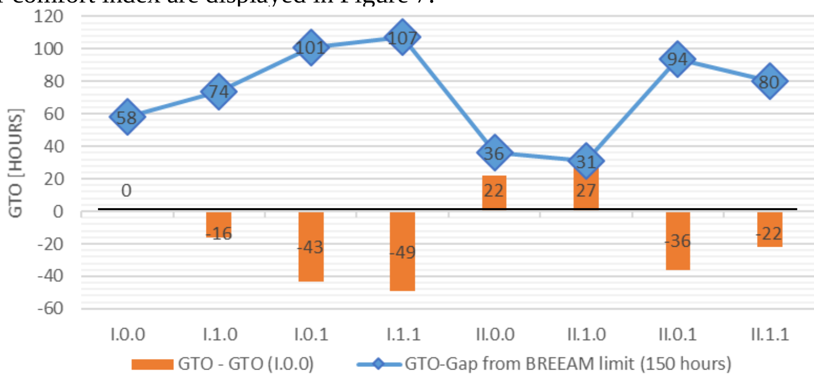


Fig. 7 – GTO index amount for one year simulation compared to simulated current conditions for a single room and to BREEAM temperature comfort requirement.

Differently from the previous results, the GTO index has a different trend in light of the two sets of simulations. As can be seen in Figure 7, all the simulations have GTO index below the BREEAM limit (GTO=150 h) this is highlighted by the blue line representing the gap from this limit. The best results are achieved in the set I of simulations, in which are realized the highest reduction of GTO hours compared to I.0.0. Differently, in the set II an increase is obtained in the first two configurations but still far from the design limit. Last, in configuration II.0.1 and II.1.1 the index decreases again demonstrating improvement of the temperature conditions realized in the room.

4. Discussion

This research is about identifying possible reductions in energy consumption and CO_2 emissions of hospital buildings. As a case study, the VUmc hospital, especially the outpatient departments of the policlinic, was used. The study on an existing AMC Policlinic has shown that:

- In light of approaching energy performance requirements (i.e. nZEB), CCE has set very ambitious goals for future energy distribution and generation at campus level. However, at local level (i.e. building, room) the performances are still inadequate as highlighted by MJA3 results and current research. Interviews have shown how the hospital is providing a great effort for improving the actual situation at building and room level. However, realizing effective reductions are quite a challenge due to strict budgets. In addition, life expectation of buildings and their influence on hospital's incomes are aspects that must be considered in the choice of energy saving measures.
- Expertise in the primary processes (e.g. user profiles, requirements) and the relations with supporting services is required to achieve nZEB performance in hospital buildings. In hospitals (including AMCs) the primary process of healing patients, is leading, more than primary processes in other markets and type of buildings. Important aspects that must be considered are the optimal functioning of the buildings as well as their life-cycle and maintenance related to the future.
- Energy consumers, flows and wasting components are often unknown; resulting in uncertain parameters for sustainable energy reduction investments in the sector.
- Building energy performance and indoor comfort can be significantly improved (more than 25%) by upgrading the building envelope, the HVAC system and applying occupancy-dependent smart controls, as indicated by simulations.

5. Conclusions

A three-step methodology was used to identify possibilities to reach towards nZEB requirements for AMCs. This approach consisted of three steps: (1) in-depth analysis of case study, (2) development of a nZEB-design approach and (3) energy simulations. The in-depth analysis revealed that little attention is directed on energy performance and monitoring activity of buildings. Application of the proposed nZEB-Design method resulted in a top five of energy saving measures. The case study VU Medical Center (VUmc) Amsterdam was analyzed and the energy saving potential (achievable in the outpatient departments of the Policlinic) identified. It showed that the approach is adequate and showed important potential for application to identify energy reduction.

Acknowledgments

The authors would like to thank VU Medical Centre Amsterdam who allowed this research to focus on a case study at its policlinic. Special thanks goes to the CCE coordinator R.W. (Rooske) Gaal MSc, A. (Annemarie) Brouwer BSc and all CCE staff who provided necessary information, energy data about VU, VUmc and Policlinic.

References

[1] European Union Parliament. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. Official Journal of the European Union, (2010), p. 13-35.
[2] Teke A., Timur O. Assessing the energy efficiency improvement potentials of HVAC systems considering economic and environmental aspects at the hospitals. Renewable and Sustainable Energy Reviews, Volume 33, (2014) 224 – 235.
[3] Compendium leefomgeving, Compendium Leefomgeving Energieverbruik per sector 1990–2012. (2014)
[4] Agentschap NL Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer. Energiebesparing in de zorg, Congreskrant zorg, 2. (2010) .
[5] Korolija I., Marjanovic-Halburd L., Zhang Y., Hanby V.I. Influence of building parameters and HVAC systems coupling on building energy performance. Energy and Buildings, Volume 43 (2011), 1247 – 1253.
[6] ASHRAE. Handbook Fundamentals. SI Edition (2009).
[7] ASHRAE. Advanced Energy Design Guide for Large Hospitals. SI Edition (2012).
[8] NEN 7210 (2011); Energieprestatie van gebouwen – Bepalingsmethode.
[9] Ministerie van volkshuisvesting, ruimtelijke ordening en milieubeheer. Technische bouwvoorschriften uit het oogpunt van gezondheid. (2015).
[10] Entrop A., Brouwers H. Assessing the sustainability of buildings using a framework of triad approaches. Journal of Building Appraisal Vol. 5, 4, (2009) 293–310.
[11]RHDHV 'In 5 stappen naar Bijna EnergieNeutrale gebouwen', http://www.royalhaskoningdhv.com/nl-nl/nederland/diensten/diensten-van-a-tot-z/bijna-energieneutrale-gebouwen-toelichting/3424 .
[12] Ascione F., Bianco N., De Masi R.F., Vanoli G.P. Rehabilitation of the building envelope of hospitals: Achievable energy savings and microclimatic control on varying the HVAC systems in Mediterranean climates. Energy and Buildings, Volume 60, (2012) 125 – 138.
[13] Čongradac V., Prebiracevic B., Jorgonanovic N.,`Stanisic D. Assessing the energy consumption for heating and cooling in hospitals, Energy and Buildings, Volume 48, (2012) 146 – 154.
[14] Yang K., Ting M. An innovative analysis and experimental investigation on energy savings of a VAV system in hot and humid climates, Building and Environment, Volume 35, (2000) 27-31.
[15] Timilehin L., Zeiler W., Boxem G., Yang Z. Occupancy Measurement In Commercial Office Buildings For Demand-Driven Control Applications- A Survey And Detection System Evaluation. Energy and Buildings, Volume 93, (2015) 303-314.
[16] M. Mysen, J.P. Rydock, P.O. Tjelflaat, Demand controlled ventilation for office cubicles—can it be profitable?. Energy and Building, Volume 35, (2003) 657–662.
[17] Gentile N., Laike T., Dubois M. Lighting control systems in peripheral offices rooms at high latitude: measurements of electricity savings and users preferences. Energy Procedia, Volume 57, (2014) 1988-1996.
[18] Roisin B., Bodart M., Deneyer A., D'Herdt P. Lighting energy savings in offices using different control systems and their real consumption.Energy and Buildings,Volume 50, (2008) 514-23.
[19] Principi P., Fioretti R. A comparative life cycle assessment of luminaires for general lighting for the office - compact fluorescent (CFL) vs Light Emitting Diode (LED) - a case study. Journal of Cleaner Production, Volume 83, (2014) 96-107.
[20] Anderson R. and Roberts D. Maximizing Residential Energy Savings: Net Zero Energy Home Technology Pathways. National Renewable Energy Laboratory Colorado, USA. (2008)
[21] Perez-Lombard L., Oritz J., Pout C. A review on buildings energy consumption information. Energy and Buildings, Volume 40, (2007) 394-398.
[22] Raue A.K., Kurvers S.R., van der Linden A.C., Boerstra A.C., Plokker W. . Dutch thermal comfort guidelines: from weighted temperature exceeding hours towards adaptive temperature limits. Network for Comfort and Energy Use in Buildings, (2006), 1–16.