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THE FIRST DUTCH NEARLY ZERO ENERGY SCHOOLS: THEIR INDOOR AIR QUALITY

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ABSTRACT

During the last decade different types of sustainable schools were built. However, there is danger that the focus on energy reduction leads to less attention towards the quality of the indoor environment and the thermal comfort as was found out from earlier research. This paper presents recent results of ongoing research towards IAQ of the first series of 6 nearly Zero Energy schools in the Netherlands. To be able to draw conclusions about the IAQ and thermal comfort in these schools during one week the most important parameters related to Indoor Air Quality and thermal comfort were measured and questionnaires were held. It proved that although in most situations the schools did meet most of the performance levels as defined by the design criteria, the perceived IAQ and thermal comfort was not according to the required quality level. So when applying sustainable design strategies for schools especially the aspects related to IAQ should be given more attention to make sure that there will be a comfortable, healthy and optimal learning environment.

KEY WORDS: net Zero Energy Schools, case studies, Indoor Air Quality, thermal comfort

1. INTRODUCTION

In Europe, more than 64 million students and almost 4.5 million teachers work inside a school in pre-primary, primary and secondary schools (EU 2015). School buildings represent a significant part of the building stock, and also noteworthy part of total energy use. In existing school buildings there are very often non optimized systems in term of energy consumption [1]. To reduce the high energy demand and pollution of greenhouse gasses the performance of the buildings has to be improved. Building performance in the Netherlands is expressed in Energy Performance Coefficient (EPC): a policy tool according to Dutch standard [8] providing a calculation method for building energy performance. It gives an indication of the primary energy demand, one of the fixed input values in the EPC calculation is the building use. The future policy timeline for nearly Zero Energy Buildings and their EPC-demand is shown in the table 1 [2].

Table 1 Future policy timeline [2]

	***EPC-demand* Future policy**				
Year:	**2014**	**2015**	**2021**	**2030**	**2050**
Residential buildings	0.6	0.4	≈ 0 All new buildings nZEB Governmental buildings should be nZEB in 2019 5% of the existing buildings nZEB	30% of all buildings renovated (after 2015) have to be nZEB	80% decreased primary energy consumption compared to 1990
Offices	1.1	0.8			
Educational	1.3	0.7			

It clearly shows that especially at schools there is a need for a strong reduction of the energy use. This led to a development trying to reduce the energy demand of schools as much as possible. The first Dutch net Zero Energy school was already built in 2000 [6], see Fig. 1. The school's electricity

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consumption of around 14.650 kWh is supplied by 145 m² PV-panels on the roof while its heating needs around 4000m³ gas ~ 16.000 kWh was covered by participation in a wind turbine park. After this the development of low energy schools came temporarily to a stop due to lack of funding by the government.

Fig. 1 First Dutch NZEB school [12]

In 2009 the Dutch government started their so called UKP NESK program to stimulate innovation for energy neutral buildings. UKP means unique chances projects and NESK means 'Towards energy neutral schools and offices' (Naar Energie neutrale Scholen en Kantoren). In the NESK from 2009 program there were 8 new school buildings additionally funded of which 6 were really built and one renovation school, see table 3. Unfortunately it took for some project quite a long time to get finished. For example the school 1 was officially opened December 2015. All the NESK schools were intended as energy neutral concepts. Recently the Rijksdienst voor Ondernemend Nederland (RVO) published their results on the Top 15 most energy conscious schools in the Netherlands 2016 [7], see Fig. 2. A special case is the school 16, it was the only renovation project within the NESK program. It was listed no.6 in the top-fifteen RVO list of 2014 but was not mentioned any more in the RVO top-fifteen list of 2016 and therefore it was left out in the further presented comparisons.

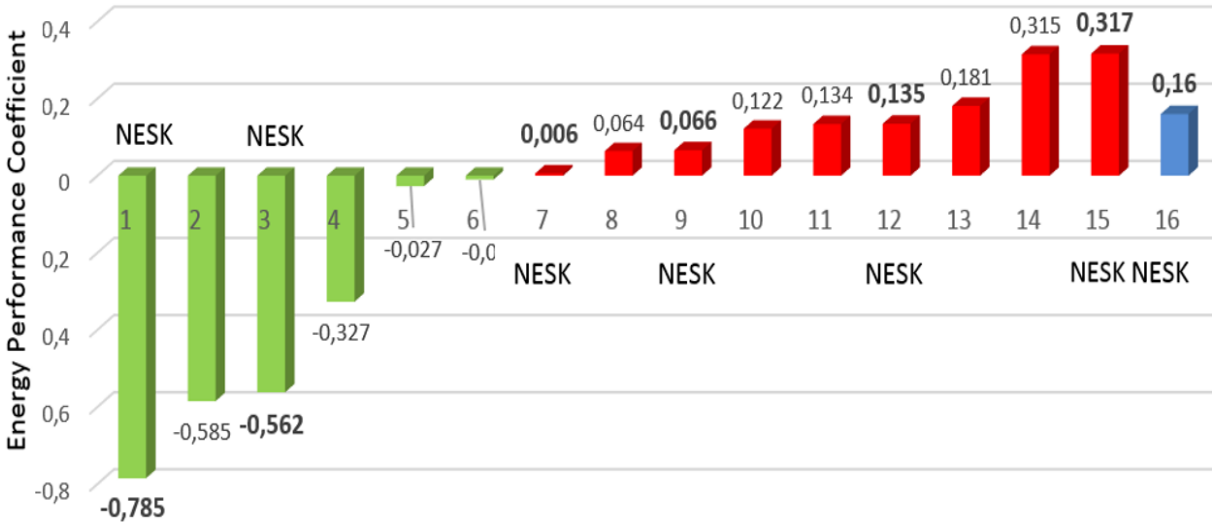

Fig. 2 Overview energy performance coefficient of the 7 NESK schools within the top 15 energy efficient schools [7]

Beside reducing the energy demand of schools, good ventilation of the classrooms is very important. The indoor air quality of classrooms has direct effect on the health [13, 14] and comfort of teachers and pupils and can reduce learning performance [15, 16, 17, 20, 21]. However, inadequate ventilation is a common problem in school classrooms all over the world [3, 4]. The performed measurements in the First Dutch NZEB school also showed that the CO2-concentrations were well above the recommended limits, see Fig. 3.

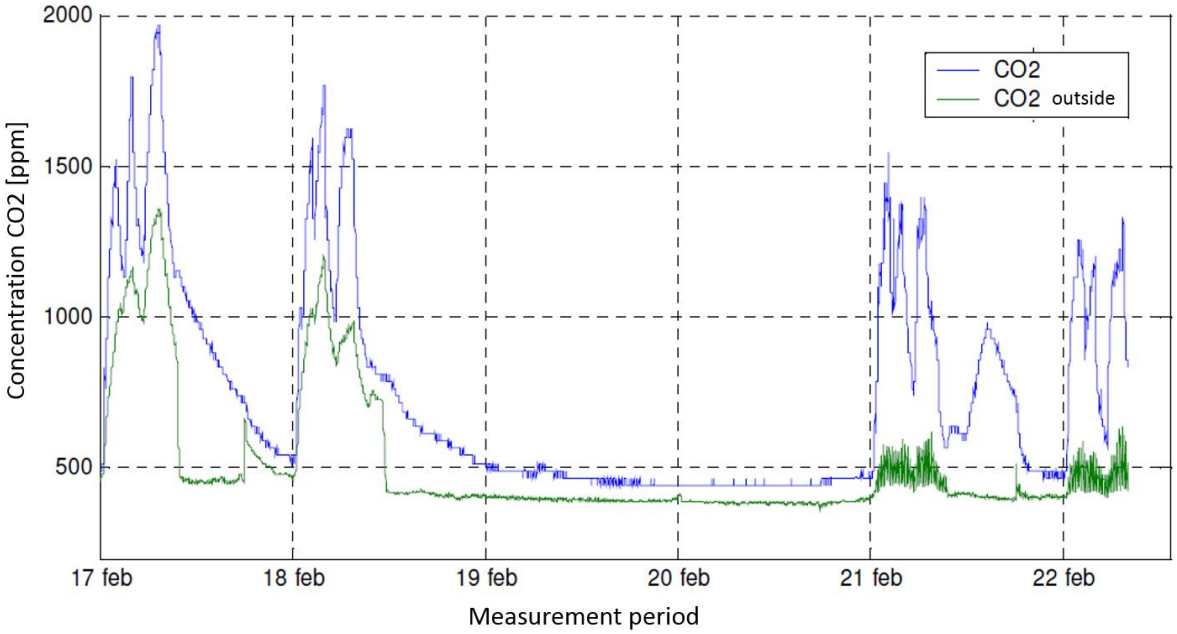

Fig. 3 Measured CO_2 concentrations in the First Dutch NEB school.

In the Netherlands the situation is that in around 70% of the classrooms the requirements for healthy ventilation are not met [18] although only in around 40% the ventilation is seriously insufficient in practice during the cold season. However, schools designed after 2012 show a significant improvement [18] because of the stricter regulation of the new Building Code of that year. To further improve this the Dutch government started a program Frisse scholen to define different quality classes which can be used to define design requirements. Indoor Air Quality in schools is primarily evaluated by CO_2-concentrations. The new guideline Frisse Scholen [5] therefore states the required CO_2 concentrations inside the classroom independ of the outside concentrations, see table 2.

Table 2 Frisse scholen [5] different classes for IAQ regarding CO_2-content in parts per million

Class C (acceptable)	Class B (good)	Class A (very good)
≤ 1200 PPM	≤ 950 PPM	≤ 800 PPM

Similarly, the European EN 13779 [19] standard provides ventilation rate values equal to 20, 12.5, 8, and 5 L s-1 per person when high, medium, moderate, and low air quality targets have to be reached. Class C corresponds with IDA3, class B with IDA2 and class A with IDA1. Next to the sustainable aspects, it is important and required to create a healthy and productive environment for education. In this article, both the energy performance and the IAQ performance of the first series of highly rated sustainable schools are provided in the subsequent sections.

2. METHODOLGY

2.1 IAQ aspects

The CO_2-concentration in classrooms is dependent on the indoor production depending on occupancy of the classroom and activity level of the attendees. However, there are more influencing factor like the air flow, functionality, effectiveness and capacity of the ventilation system, the use and operation of the ventilation system as well as opening windows and doors. According to the research of the Health Council of the Netherlands, 'Gezondheidsraad' [9] CO_2 is a weak indicator of indoor air quality in classrooms, because the

rate of production of CO_2 is hardly associated with other substances distributed by pupils, such as VOCs, plasticizers, moisture and mould or air from outside. In the recent research study MERMAID [10], they identified over 150 VOC species of which only a few are associated with occupancy and most with other indoor sources. Although CO_2 is less useful as an indicator for human scattered dust particles, allergens and pathogens, it is quite a good indicator of body odours. Despite the fact that there is no relationship between the concentration of CO_2 and other substances and small particles in the air, an increase of ventilation will lead to a decrease of both substances. The concentration of CO_2 is not immediately noticeable to people, only at concentrations above 1500 ppm a relation is demonstrated between CO_2-concentration and odour nuisance when entering a space. In 4 out of the 6 schools from the NESK project series, the CO_2 concentrations were measured during a period of a week during November/December. Their P95 value was determined which yields interesting results overall in table 5. In the other schools they gave no permission to perform the measurements because they had been part of a measuring process by RVO and therefore the values from RVO reports were then included. The CO_2 Concentration was measured by a SBA-5 CO_2 Analyzer with a range of 0 - 2000 [ppm] and an accuracy of ± 20.0 [ppm] and stored on a data logger Squirrel SQ2010 (Grant) and processed with a laptop Lenovo ThinkPad W541. Besides the CO_2 concentration, also the temperature and relative humidity and air speeds were measured. This to evaluate whether the possible problems associated with IAQ were related with e.g. too high humidity levels, which was not the case and therefore we concentrate in this paper on the CO^2 concentrations .In addition, a questionnaire among the personnel of the school was taken. This included questions about the indoor air quality and thermal comfort experiences in the winter and summer period. The answers of the questionnaire were in a 7-point scale from 1 to 7, the indicator (CO_2 concentration, temperature etc.).

2.2 Case studies

In table 3 a short overview is given of the investigated 6 NESK schools.

Table 3. List of UKP NESK school projects and the their number in the Top 15 list


School 1


School 3


School 7


School 9


School 12


School 15

School	Year	m²	HP	ATES	Pellet boiler	District heating	HR boiler	Mechanical supply & exhaust ventilation system
1	2015	1575	X	X	X			Textile displacement duct, CO_2 controlled
3	2012	1524	X				X	Textile displacement duct, CO_2 controlled
7	2014	2521	X	X				CO_2 controlled
9	2012	4803	X	X	X			CO_2 controlled
12	2011	2137	X					CO_2 controlled
15	2013	2868				X		Time controlled

From table 3 clearly follows that the use of heat pumps is an essential step towards a net Zero Energy school if you do not have a connection to district heating. Furthermore the application of Aquifer Thermal Energy Systems (ATES) in combination with a heat pump offers a large potential in the Netherlands and as a result almost all sustainable offices and also some schools applies geothermal ATES systems for seasonal heat and cold storage. For offices the number operating hours is higher than for schools so that the return on investment is often quicker.

3. RESULTS

3.1 Energy performance

As can be seen from Fig. 3 there is quite a difference between the different schools according to their energy performance coefficient, ranging from -0.785 towards 0.317. Quite remarkable is that the most energy conscious school is one of the original NESK projects: Hart van Oijen It is still the best performing school concerning net energy consonsumption, it produces more energy than it uses.
However, if we only look at the total energy use, see Fig. 4 the situation changes and the differences are reduced due to the fact that the energy production of the PV-panels of the projects is no longer taken into account. Quite remarkable, that beside one school which is connected to a district heating systems, all other schools are using a heat pump, see table 4. As can be seen clearly there is a preference to use HP in the highly energy efficient schools. Most in combination with an ATES system.

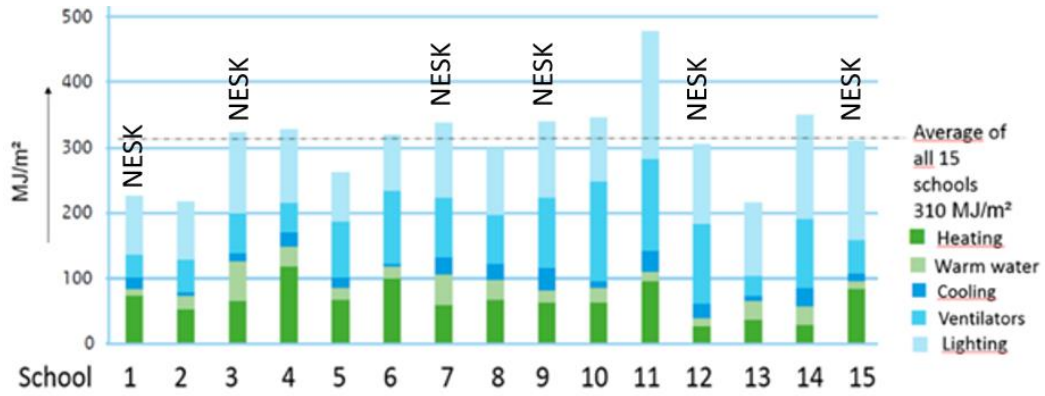

Fig. 4 Overview total energy use of the top 15 efficient Dutch schools 2016 [7]

3.2 Indoor Air Quality aspect CO_2

In schools the CO2 concentrations in one classroom was measured, as an example the results of school 1 are presented in Fig. 5.

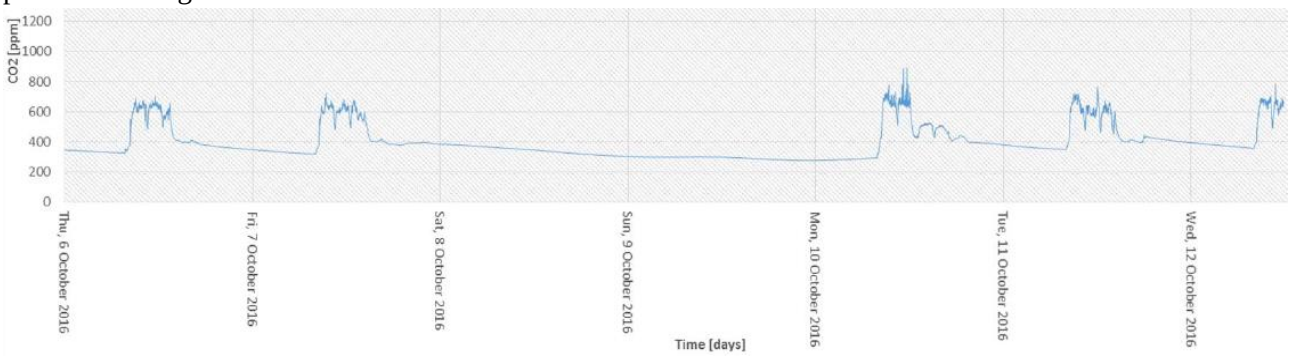

Fig. 5 Results CO2 measurements in school 1 during one week

Table 5 presents the highest recorded CO_2 concentration during class in the 6 schools. Another helpful characteristic parameters are P95 and P50 during class shown in table 5, P50 which is the median value of CO_2 concentration over a duration of time in class and P95 represents the concentration which is not passed during 95% of the time in class.

Table 5 CO_2 concentrations of the NESK schools

CO_2 con	School 1	School 3*	School 7	School 9	School 12	School 15*
Peak	820	980	1200	1200	1290	1600
P95	654	N/A	1074	1044	1207	N/A
P50	393	880	889	759	936	900

* RVO report data

3.3 Questionnaires Perceived IAQ

Series of questions have been provided for the students to find out what was their experience during the measurements. The scoring system was based on 7 scores, 1 represents the best case scenario and 7 is the worst in whatever scale they are inserted in. Teachers, on average around 5 for each school, have been questioned about various factors that could lead us to finding out the roots of the problems associating with IAQ. For example, insufficient ventilation rate could lead to "stuffy" air and increment in humidity levels. These issues could have several causing going hand in hand and furthering research in perceived IAQ is as important as evaluating the measurement values from different factors. Table 6 presents the survey results of the schools and difference is quite noticeable, the situation in school 9 and 12 is far from optimal.

Table 6 Survey results from the 6 NESK schools (scale 1 very good - 7 very poor*)*

School	1	3*	7	9	12	15*
Freshness	2	n/a	3	5	4	n/a
Smell	2	n/a	2	4	3	n/a
Satisfaction	2	1	3	5	4	3
Respiration	3	n/a	1	4	1	n/a
Humidity	2	2	1	5	4	2
Drowsiness	1	n/a	1	5	1	n/a

* RVO report data

4. DISCUSSION

The measurements at the schools were done in one classroom during one week in the winter season. Therefore they represent only a typical situation and more measurements are needed to get a good overall insight in the effects of the ventilation during the whole year. However, the measurements showed the most critical situation for classroom ventilation. That is during the cold season when the windows cannot be open because of possible cold draft problems and the IAQ is the direct effect of the installed ventilation system.
The results from the questionnaires have limited significance because of the limited number of teachers that participated, but in practice it is difficult to reach them as they are not always present or willing to cooperate.
As such the NESK school projects played, as inspiring examples of low energy schools, an important role in stimulating others and the mainstream in commercial and industrial building in The Netherlands. As a result this first series of new schools led to an intensive development in energy conscious schools and now there are even net positive energy schools. To see if progress has been made on the quality of the IAQ we compare

the outcome of our CO_2 concentration measurements with the outcome of an former Dutch research of schools from 2007 in which they measured in 120 classrooms [11, see Fig. 6. As can been seen clearly a big step forward was made with now all P_{50} CO_2 concentrations well below 1000 ppm.

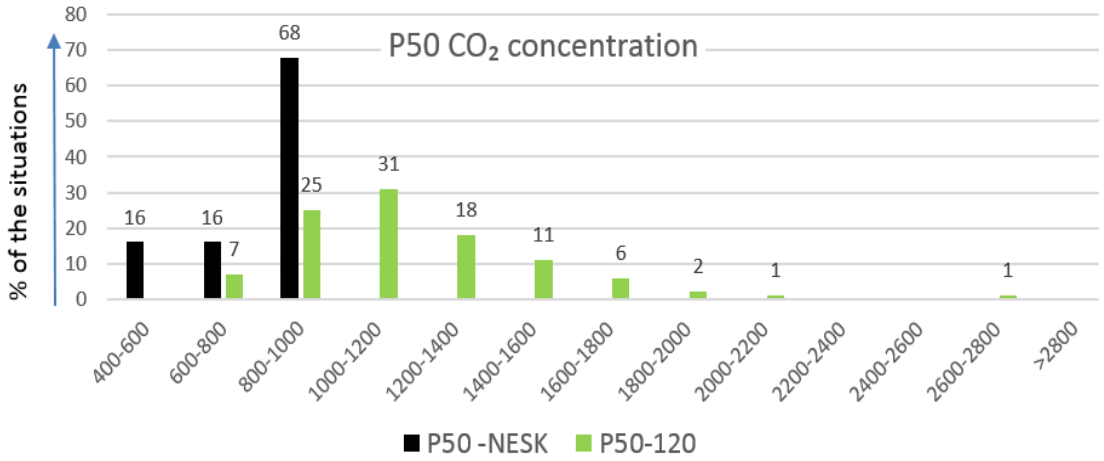

Fig. 6 Comparison outcome this research with that of 2007 with results of 120 class rooms [11].

5. CONCLUSIONS

Part of evaluating of the NESK schools was to see whether these schools did meet the designed requirements for ventilation according to the Frisse Scholen program of requirements classifications of A, B and C. However, the measurements proved that two of the schools exceeded the design limit, see table 7.

Table 7 Designed vs measured fresh schools classification comparison

School	1	3*	7	9	12	15*
Designed	A	A	B	B	B	A
Measured	A	A	B	B	C	B

* RVO report data

Although there is a difficult relation between energy consumption and IAQ it is possible to come up with a good solution and satisfy both in principle conflicting demands, applying more ventilation and using less energy. School 1 for example, it is the most efficient of the 6 schools and has the lowest P95 CO_2 value of all schools as well. The results of our research showed that in general still more attention is needed for aspects related to ventilation to be able to design and built, not only highly sustainable and energy efficient schools, but also schools which will have an optimal learning environment with a high level of IAQ and freshness.

REFERENCES

[1] Menezes C., Cripps A., Bouchlaghem D. and Buswell R., Predicted vs. actual energy performance of non-domestic buildings: using post occupancy evaluation data to reduce the performance gap. Applied Energy 97 (2012) 355-364.
[2] Gvozdenović K., Maassen W.H., Zeiler W., Besselink H., 2015, Roadmap to nearly Zero Energy Buildings in 2020, REHVA Journal, March.
[3] Mydlarz C.A., Conetta R., Connolly D., Cox T.J., Dockrell J.E., Shield B.M., 2013, Comparison of environmental and acoustic factors in occupied school classrooms for 11-16 year old students, Building and Environment 60: 265-271
[4] Hou Y., Liu J., Li J., 2015, Investigation of Indoor Air Quallity in Primary School Classrooms, Proceedings 9th ISHVAC & 3rd COBEE conference, Tianjin, China
[5] RVO, 2015a, Programma van Eisen Frisse scholen 2015, Publicatienummer: RVO-039-1401/BR-DUZA, http://www.rvo.nl/sites/default/files/2014/12/Programma%20van%20Eisen%20Frisse%20Scholen%202015..pdf

[6] Weenen, J.C. van, Dettmers, W.J.M., Overtoom, M.S.J., Poldermans, H.G.J.M., 2000, Development of the First Sustainable Elementary School of The Netherlands, Proceedings International Conference Sustainable Building 2000, 22-25 October, Maastricht, the Netherlands, pp. 651-653
[7] RVO, 2016, Top 15 energiezuinige scholen onderzoeksrapport 2016, Rijksdienst voor Ondernemend Nederland
[8] NEN, 2012, NEN 7120 - Energieprestatie van gebouwen - Bepalingsmethode.
[9] Gezondheidsraad, 2010, Binnenluchtkwaliteit in basisscholenen de waarde van kooldioxide als indicator voor luchtkwaliteit, Rapport Nr. 2010/06
[10] Verriele M., Schoenmaecker C., Hanoune B., Leclerc N., Germain S., Gaudion V., Locoge N., 2016, The MERMAID study: indoor and outdoor average pollutant concentrations in 10 low-energy school buildings in France, Indoor Air 26: 702-713
[11] Versteeg H.,2007, Onderzoek naar de kwaliteit van het binnenmilieu in basisscholen, Min. VROM, reportno. 8055
[12] AgentschapNL, 2011, Eerste duurzame school Nederland nog steeds fris, Publicatienummer: 2EGOU1103
[13] Sundell J., Levin H., Nazaroff W.W., Cain W.S., Fisk W.J., Grimsrud D.T., Gyntelberg F., li Y., Persily A.K., Pickering A.C., Samet J.M., Spengler J.D., Taylor S.T., Weschler C.J., 2011, Ventilation rates and health: multidisciplinary review of the scientific literature, IndoorAir 21(3); 191-204
[14] Shendel D.G., Prill R., Fisk W.J., Apte M.G., Blake D., Faulkner D., 2004, Associations between classroom CO2 concnetrations and student attendance in Washington and Idaho, InoorAir 14(50: 333-342
[15] Bakó-Biró Z., Clements-Croome D.J., Kochhar N., Awbi H.B., Williams M.J., 2012, Ventilation rates in schools and pupils'performance, Building and Environment 48: 215-223
[16] Mendell M.J., Heath G.A., 2005, Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature, IndoorAir 15(1); 27-52
[17] Wargocki P., Wyoun D.P., 2007, The effects of moderately raised classroom temperatures and classroom ventilation rate on the performance of schoolwork, HVAC&R Research 13(2): 192-220
[18] Dijken F. van, Gelderblom A., Performance of mechanical ventilation systems in primary schools in Rotterdam, the Netherlands, Proceeding Indoor Air, 2016, Gent, Belgium
[19] European Committee for Standardisation, 2007, EN 13779 - Ventilation for non-residential buildings – Performance requirements for ventilation and room conditioning systems, in, European Committee for Standardisation, Brussels, Belgium
[20] Dorizas P., Assimakopoulos M., Santamouris M., 2015, A holistic approach for the assessment of the indoor environmental quality, student productivity, and energy consumption in primary schools. Environ Monit Assess, 187-259.
[21] Chatzidiakou L., Mumovic D., Dockrell J., 2014, The Effects of Thermal Conditions and Indoor Air Quality on Health, Comfort and Cognitive Performance of Students. London The Bartlett, UCL Faculty of the Built Environment UCL Institute for Environmental Design and Engineering London.