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PRODUCTIVITY IN SCHOOLS

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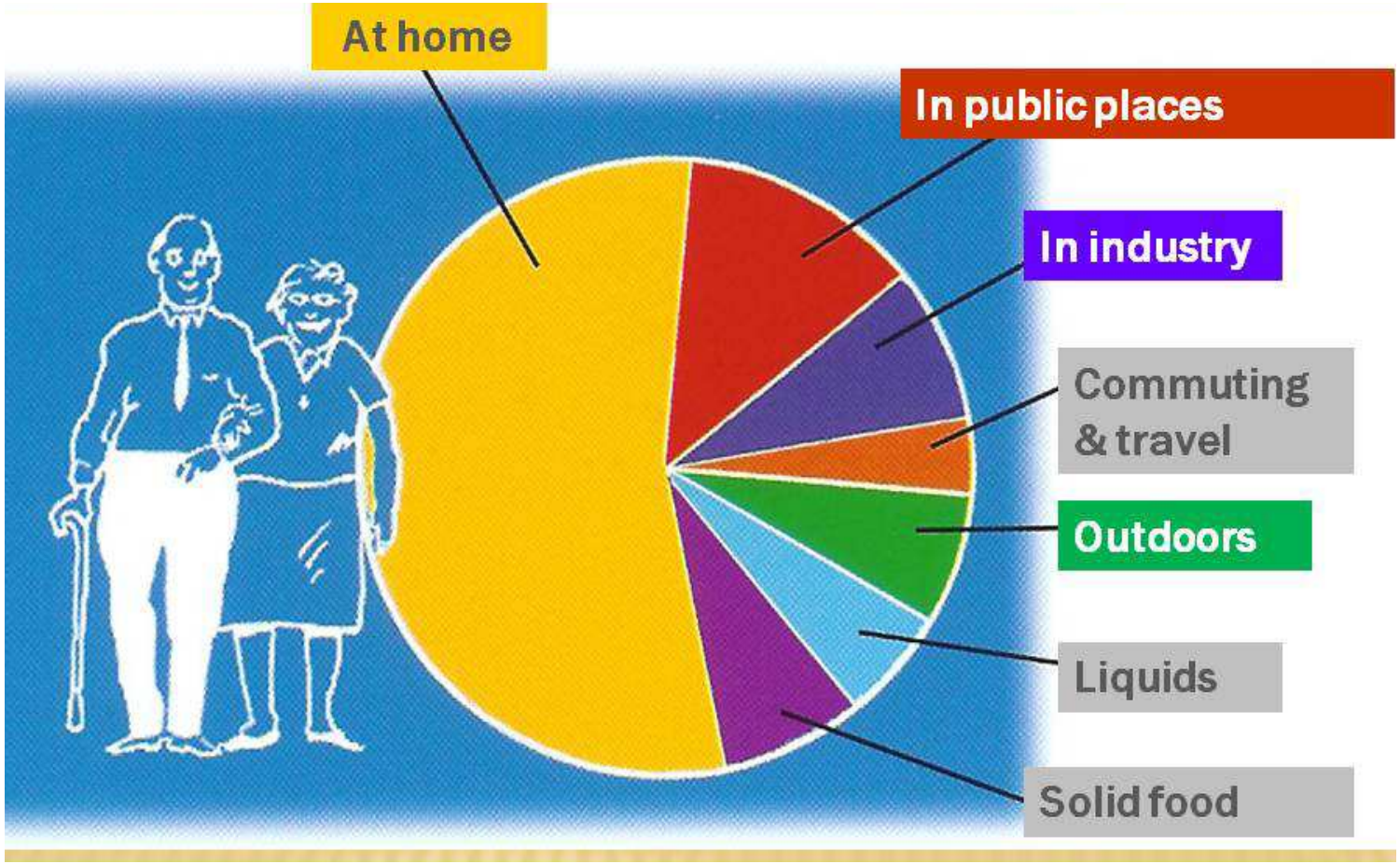
EFFECTS OF INDOOR CLIMATE (AIR QUALITY) IN SCHOOLS ON LEARNING ABILITIES AND ACADEMIC ACHIEVEMENTS

INDOOR AIR IS SIGNIFICANT CONTRIBUTOR TO LIFE-TIME EXPOSURES



IAQ IN SCHOOLS IS IMPORTANT

- 20% of EU's population
- 20% of time in schools
- Children must attend school; they can not absent themselves or find another school
- The work that children are obliged to perform in schools is not optional and almost always new
- Children have far fewer ways of registering complaints
- The effects of IAQ/IEQ on children are likely to be more marked than for adults as children are more vulnerable and their bodies are still growing

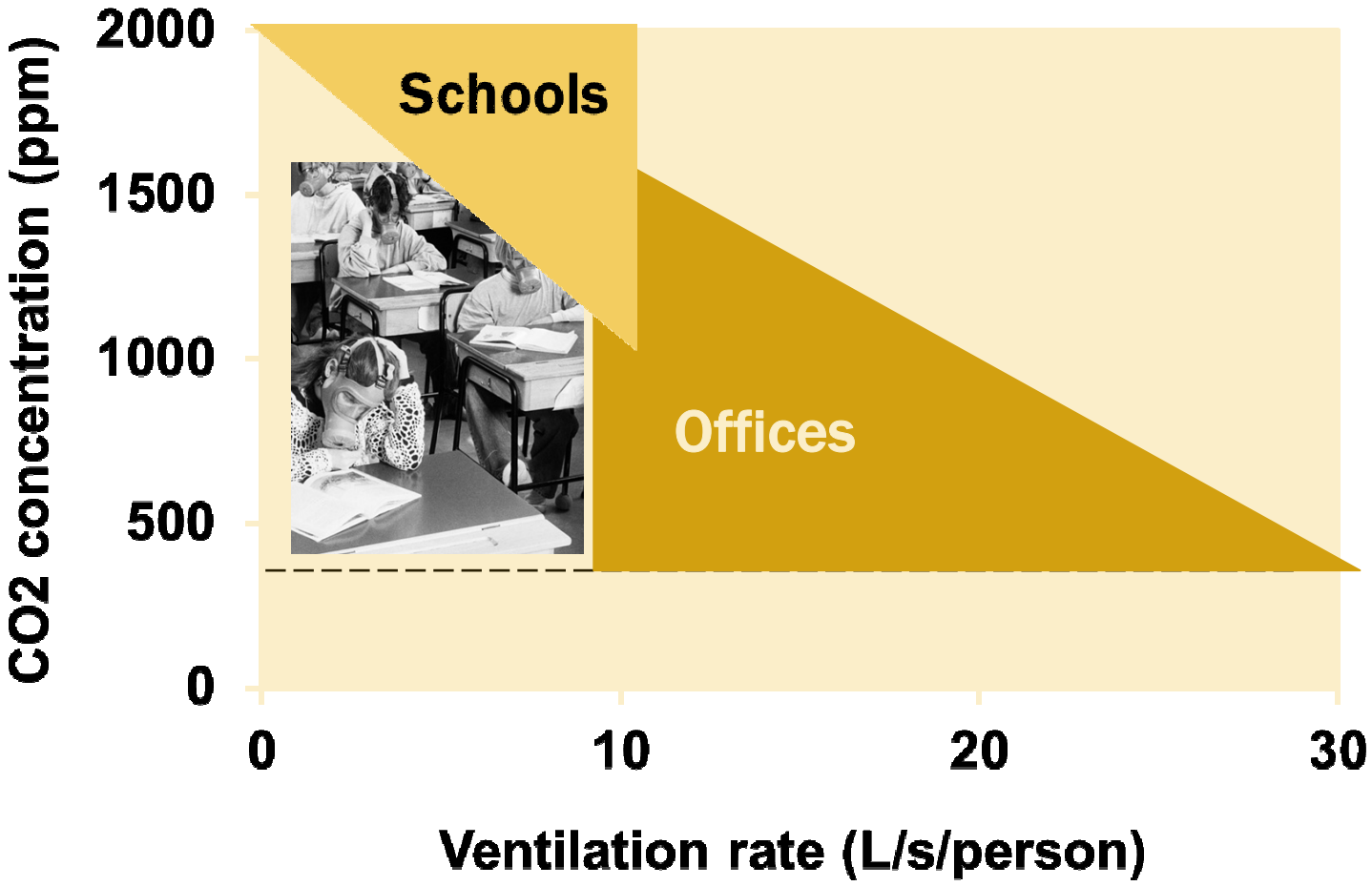
SCHOOL ENVIRONMENT IS SPECIAL

- Children (pupils) and adults (teachers and other personnel)
- Occupancy is higher in classrooms than in other buildings (offices/dwellings)
- Teaching is carried out in groups (classes) with low area/volume per person
- There should be as least as possible distraction during teaching

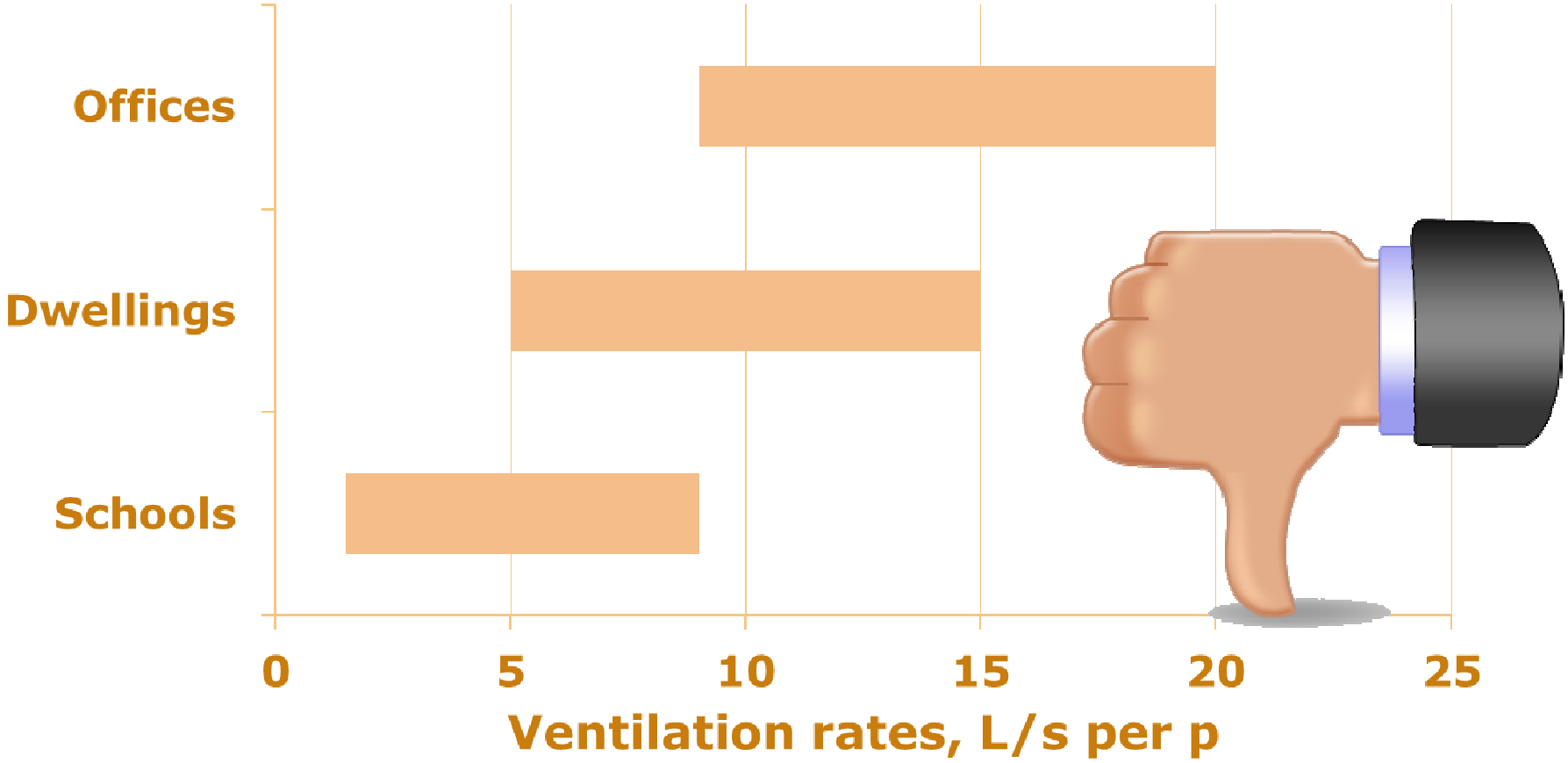
A good education system constitutes one of the fundaments of a modern society, because poor learning can have lifelong consequences for a student and for society

PURPOSE OF THE SCHOOL

VENTILATION REQUIREMENTS IN SCHOOLS



MEASURED VENTILATION RATES IN EU BUILDINGS

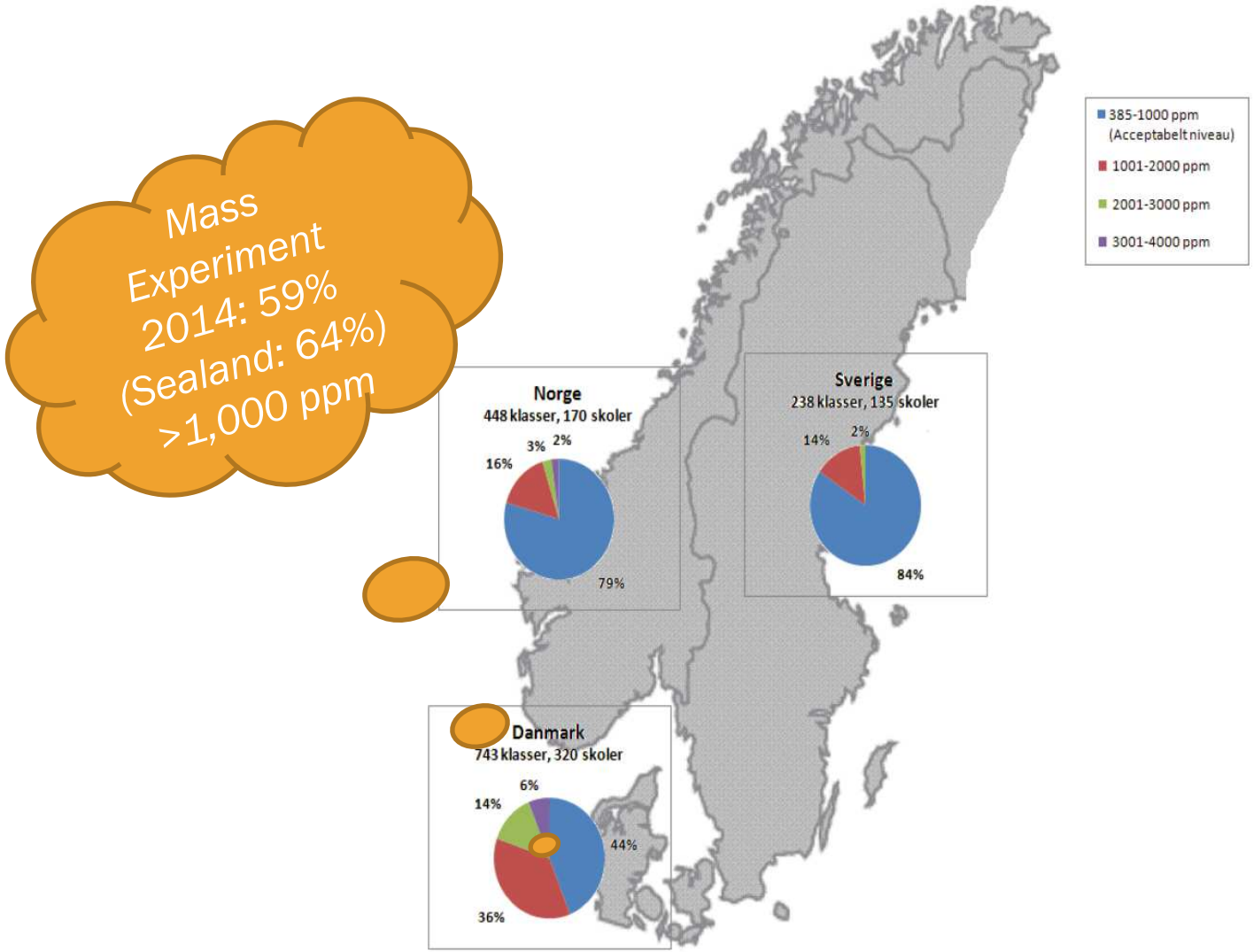


HEALTHVENT., 2013

Early childhood experiences impact behaviour later on in a life

Sigmund Freud

SCANDINAVIAN SCHOOLS



Report on Mass Experiment (2009)

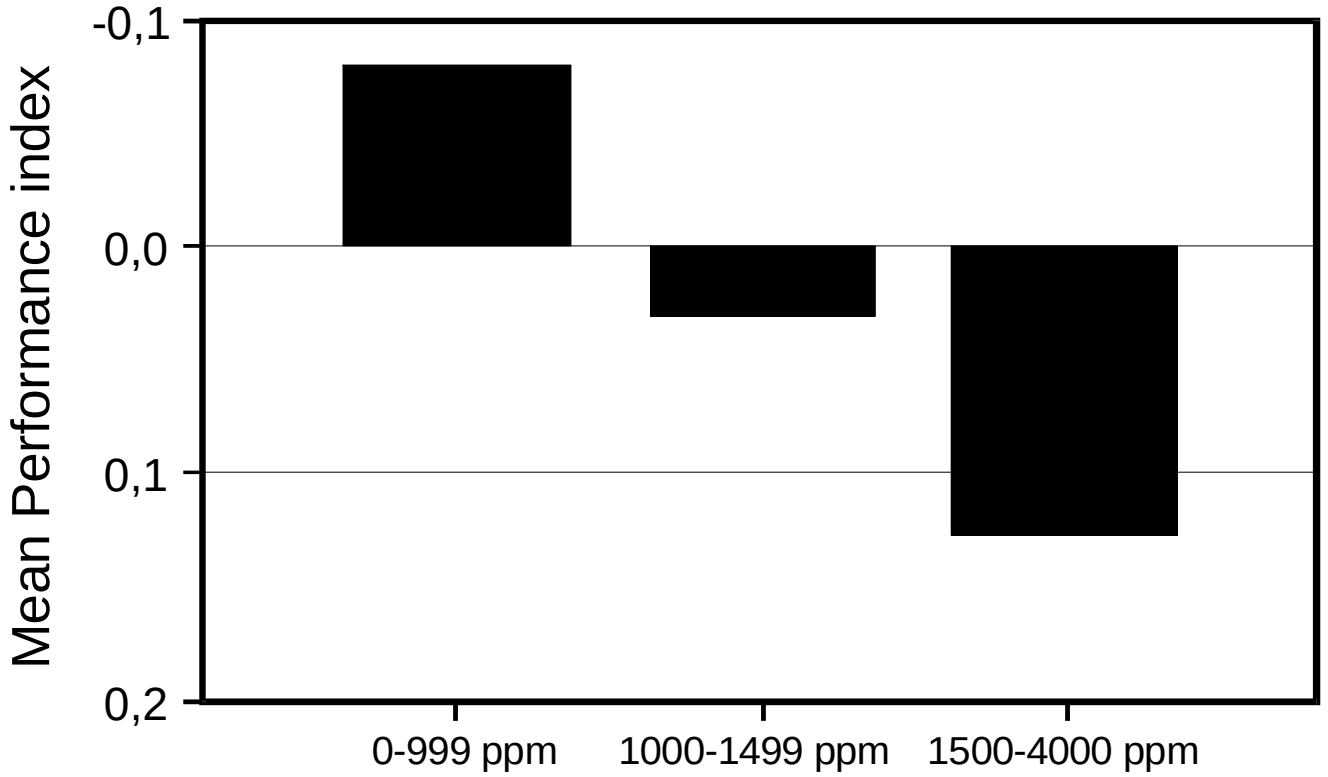
WHAT ARE CONSEQUENCES?

SCHOOLWORK (CHILDREN AND TEACHERS)

- Attitudes: cognitive skills
- Academic behaviours: typical school tasks and absence rate
- Academic achievements: standardized tests
- Usually 3rd to 6th grades (9-12 years old)

ATTITUDES: PSYCHOLOGICAL TESTS FOR MEASURING COGNITIVE SKILLS

(simple/choice reaction time, colour-word vigilance)



Myhrvold et al., 1997

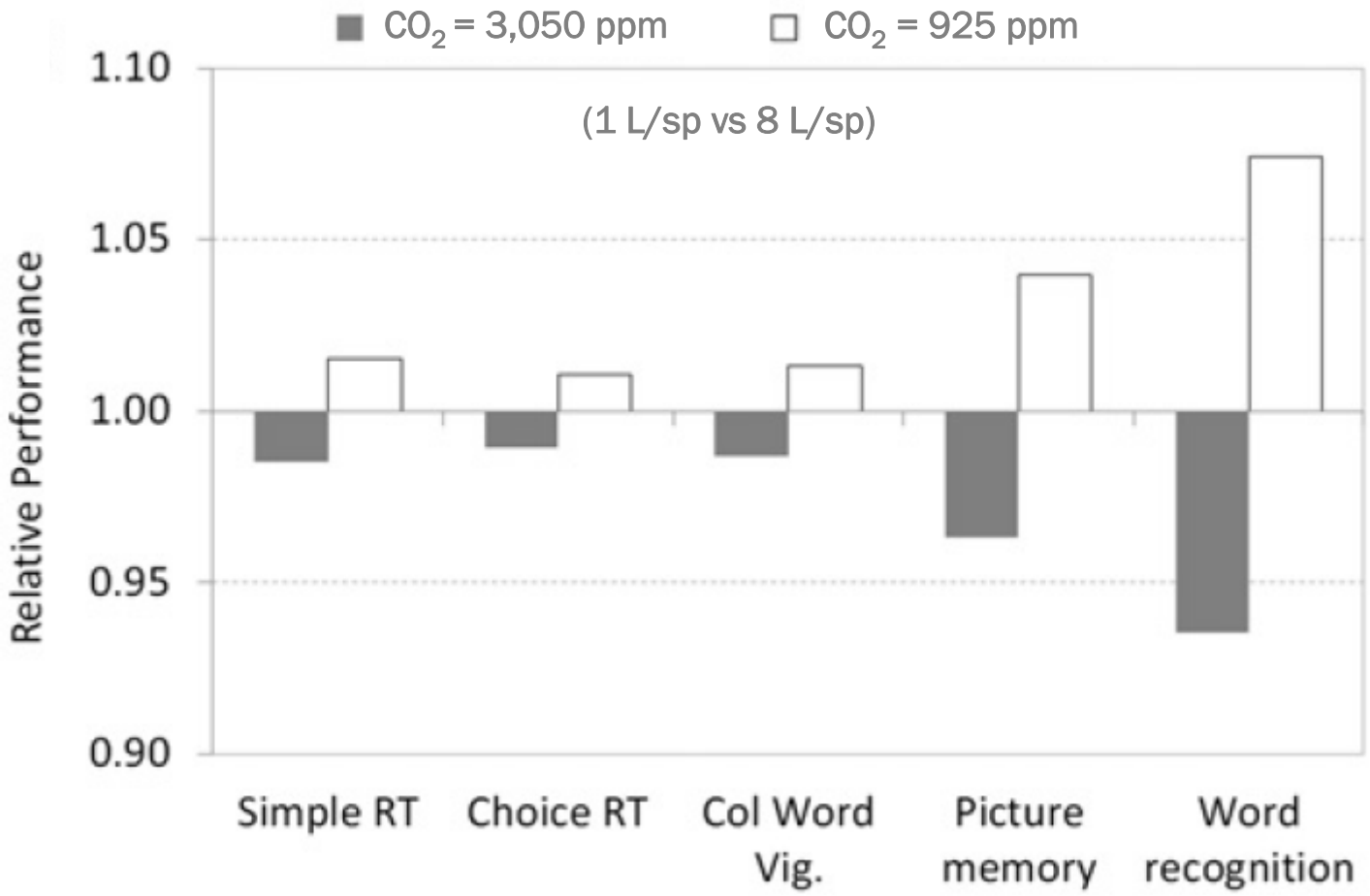
ATTITUDES: PSYCHOLOGICAL TESTS FOR MEASURING COGNITIVE SKILLS

- 18 schoolchildren, age 10-11
- 4 test sessions with range of cognitive tasks at CO_2 of 690±122 (501-983) ppm and 2909±474 (2096-4140) ppm
- Significant effects (better at lower CO_2): simple reaction time, power of attention and (close to significant) digit vigilance reaction time and choice reaction time
- Non significant effects: digit vigilance accuracy and false alarms, choice reaction time accuracy, picture recoognition response and accuracy.
- Pupils signficantly more calm at high CO_2 (self-assessed)

Coley and Greeves, 2004

ATTITUDES: PSYCHOLOGICAL TESTS FOR MEASURING COGNITIVE SKILLS -2

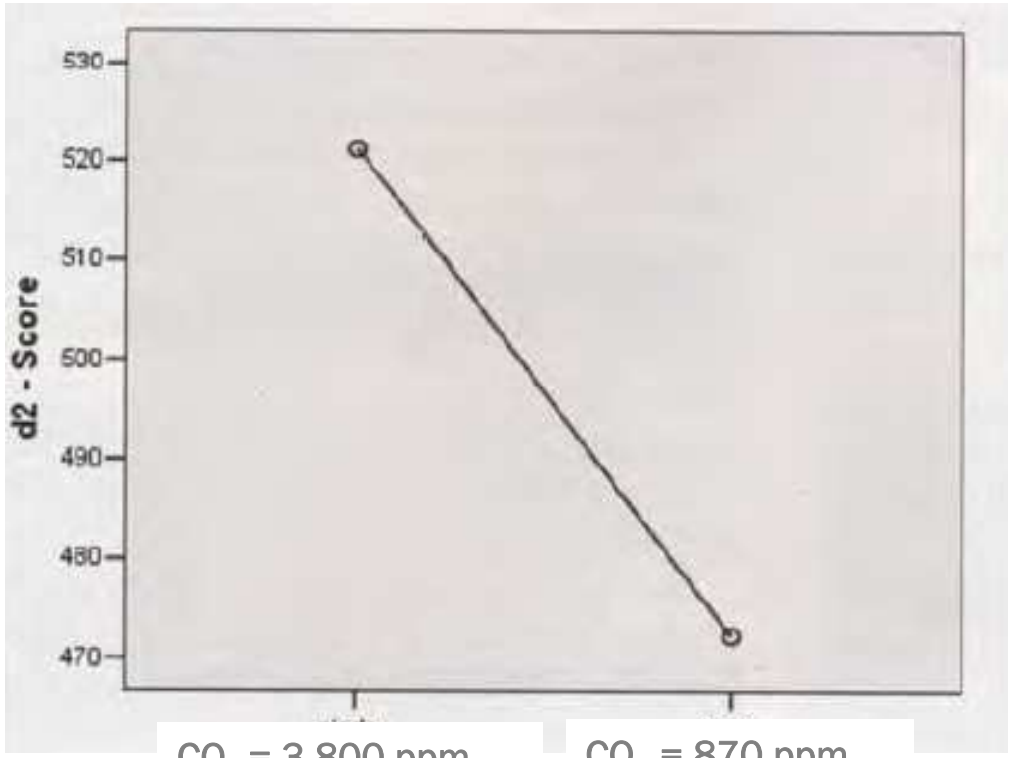
(reaction time, colour-word vigilance, memory, recognition)



Bako-Biro et al., 2011

ATTITUDES: PSYCHOLOGICAL TESTS FOR MEASURING COGNITIVE SKILLS

(d2-test for concentration)



Ribic, 2008

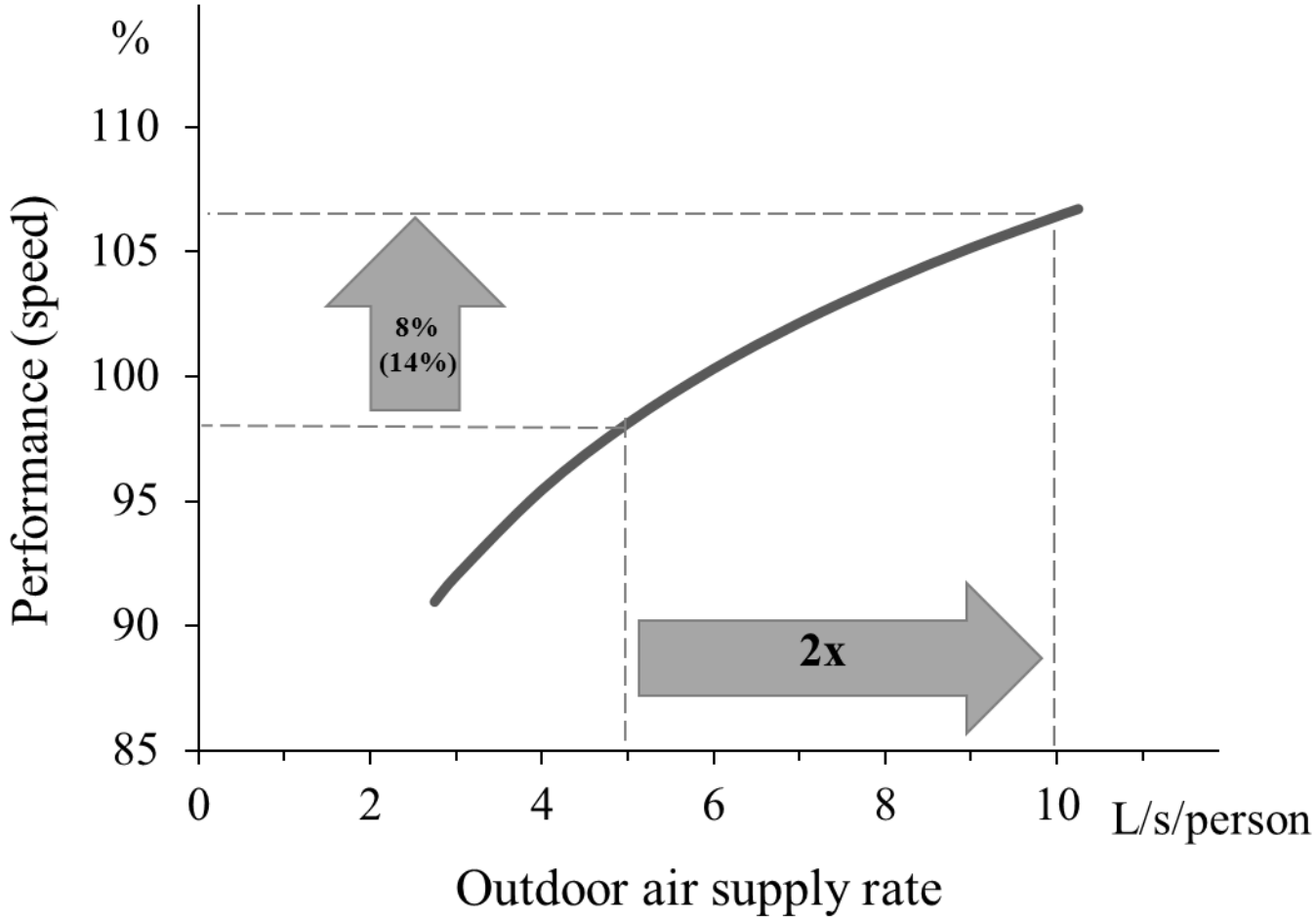
COGNITIVE SKILLS ARE AFFECTED BY POOR CLASSROOM AIR QUALITY

- Reaction time
- Memory
- Concentration
- Attention

Important component skills securing proper education progress

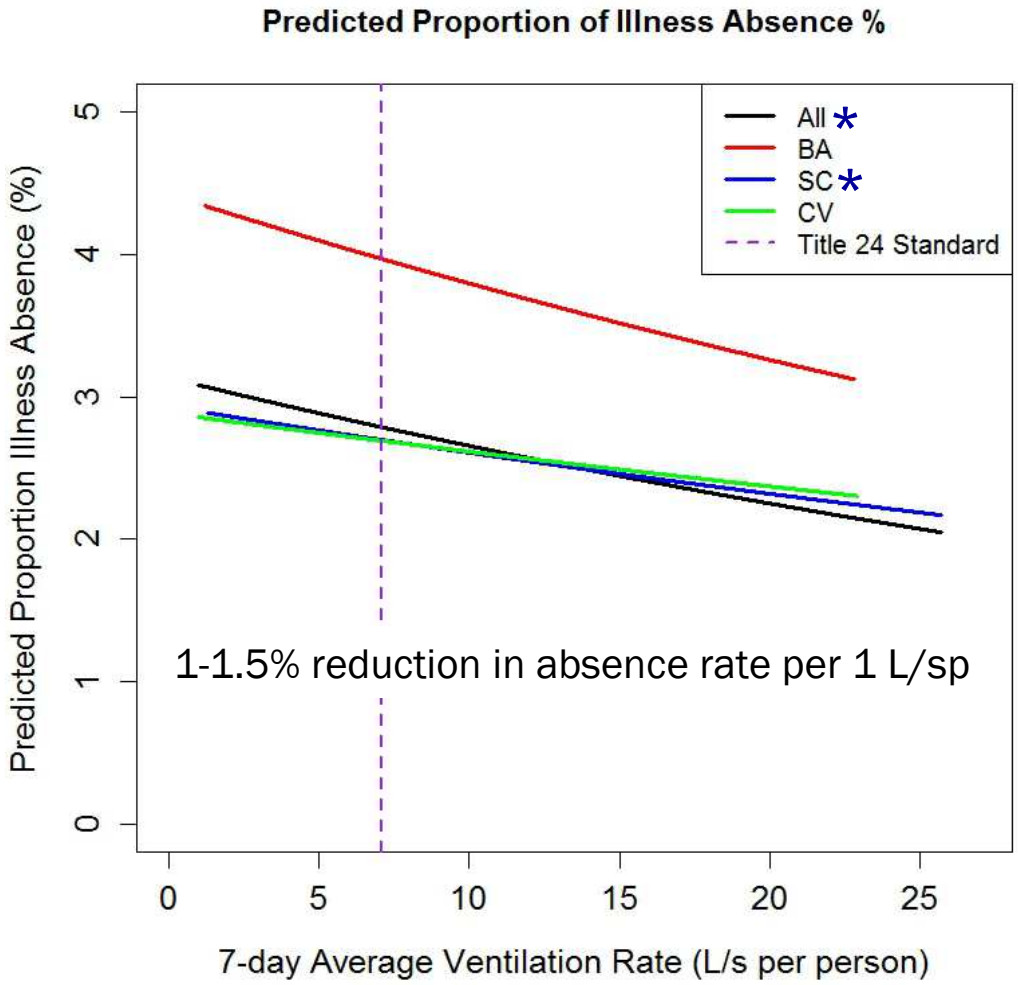
ACADEMIC BEHAVIOURS: EFFECTS FOR TYPICAL SCHOOL TASKS

(math & language based)



Wargocki et al., 2012

ACADEMIC BEHAVIOURS: SCHOOL ATTENDANCE



Mendell et al., 2013

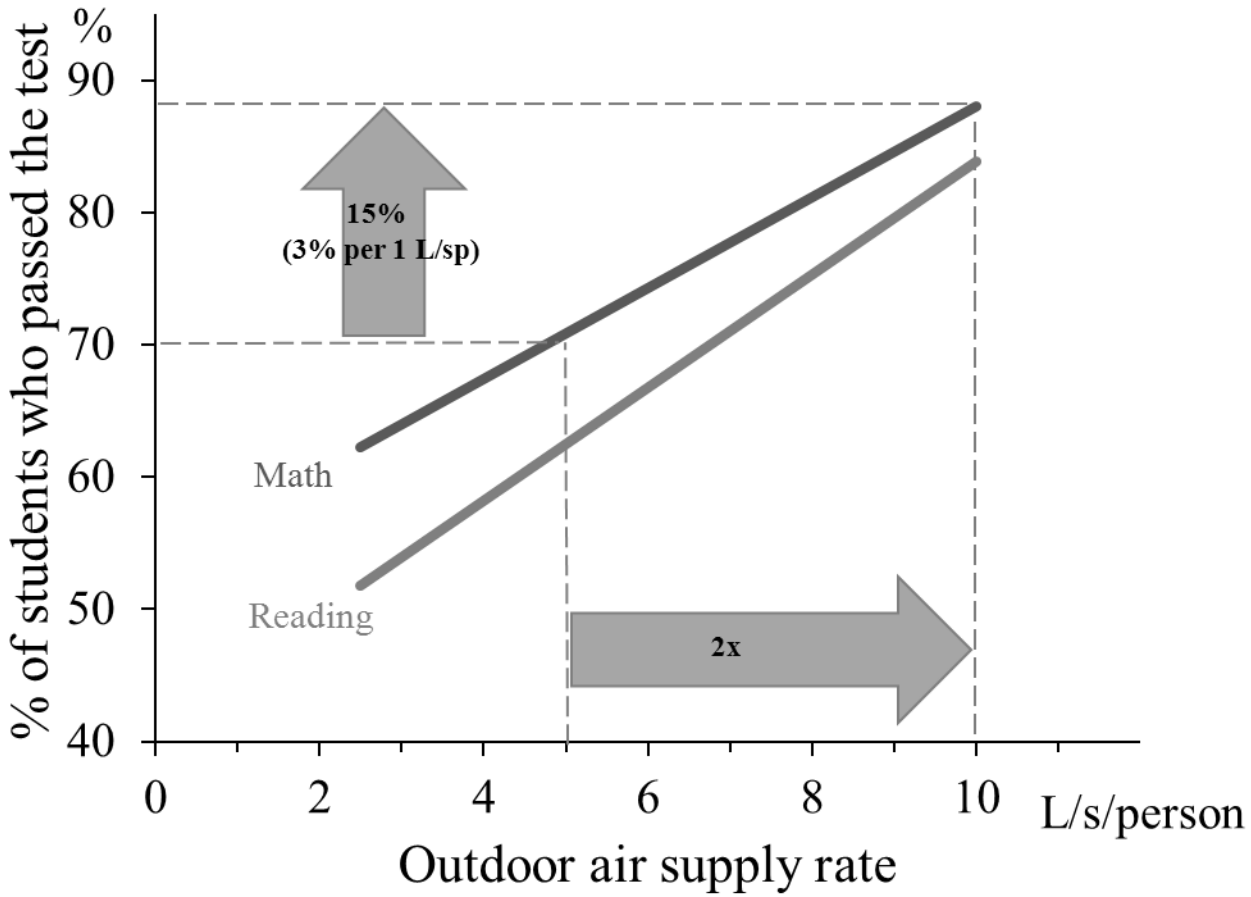
CO_2, SCHOOL ATTENDANCE, EDUCATIONAL ATTAINMENT

- 60 classrooms in 32 primary schools in Aberdeen
- Each school 2 classrooms (6-7 and 10-11 years old)
- 1 week measurements of CO2 (temp rh) in early summer months: median 1086 ppm IQR 922-1310 ppm
- Absence rates for the whole school year
- Educational attainment (% of class attaining the average level expected for this group)
- Models adjusted for socieconomic indicators (free school meals)
- **An increase of 100 ppm corresponded to 0.2% increase in absence rates** (0.04-0.4) corresponding roughly to ½ day a year (in 190 days school year); average absence rate in Scotish schools 5.1%
- No effects on attainment

Gaihre et al., 2014

ACADEMIC ACHIEVEMENTS: STANDARDIZED TESTS

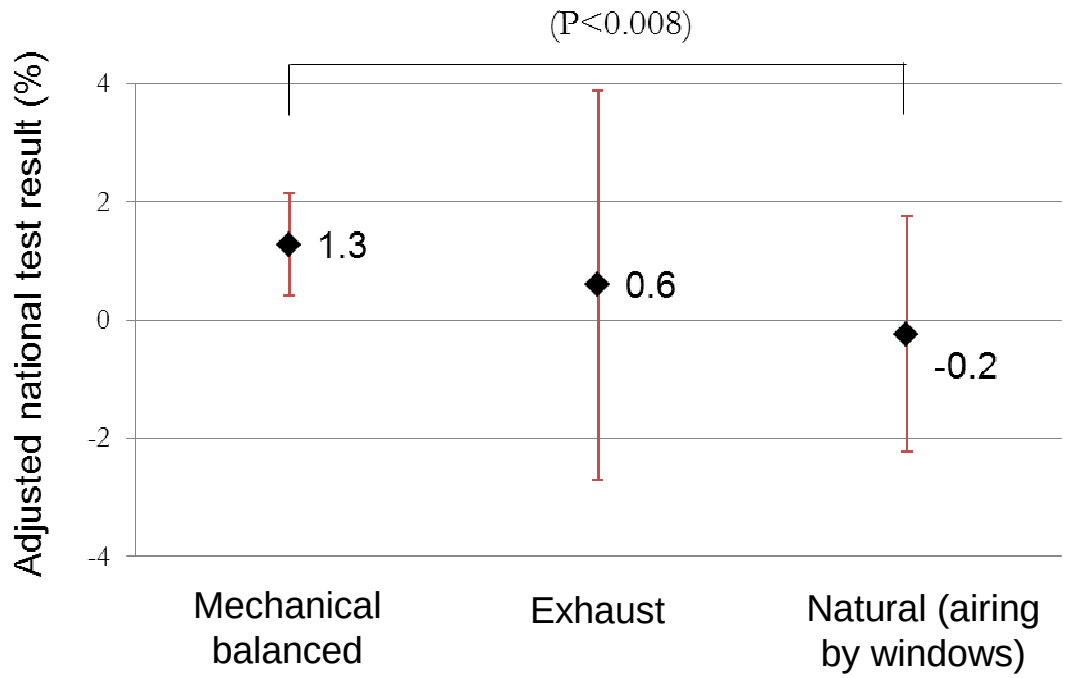
(number of pupils who passed)



Haverinen-Shaughnessy et al., 2013

NATIONAL STANDARD EDUCATIONAL TESTS

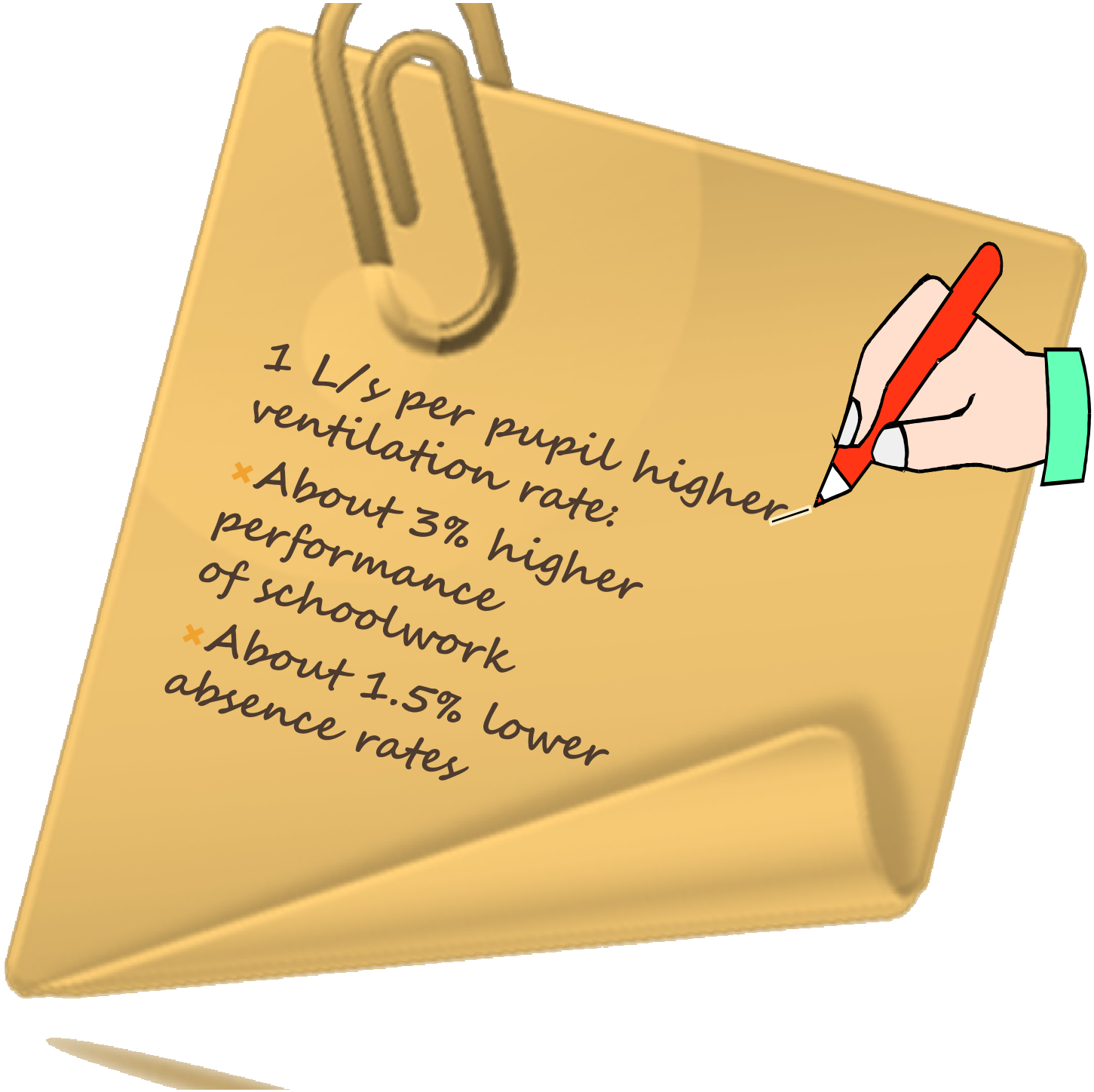
(math, language-based,science (chemistry/physics, geography, biology), foreign language)



Uldahl Kjeldsen et al., 2013

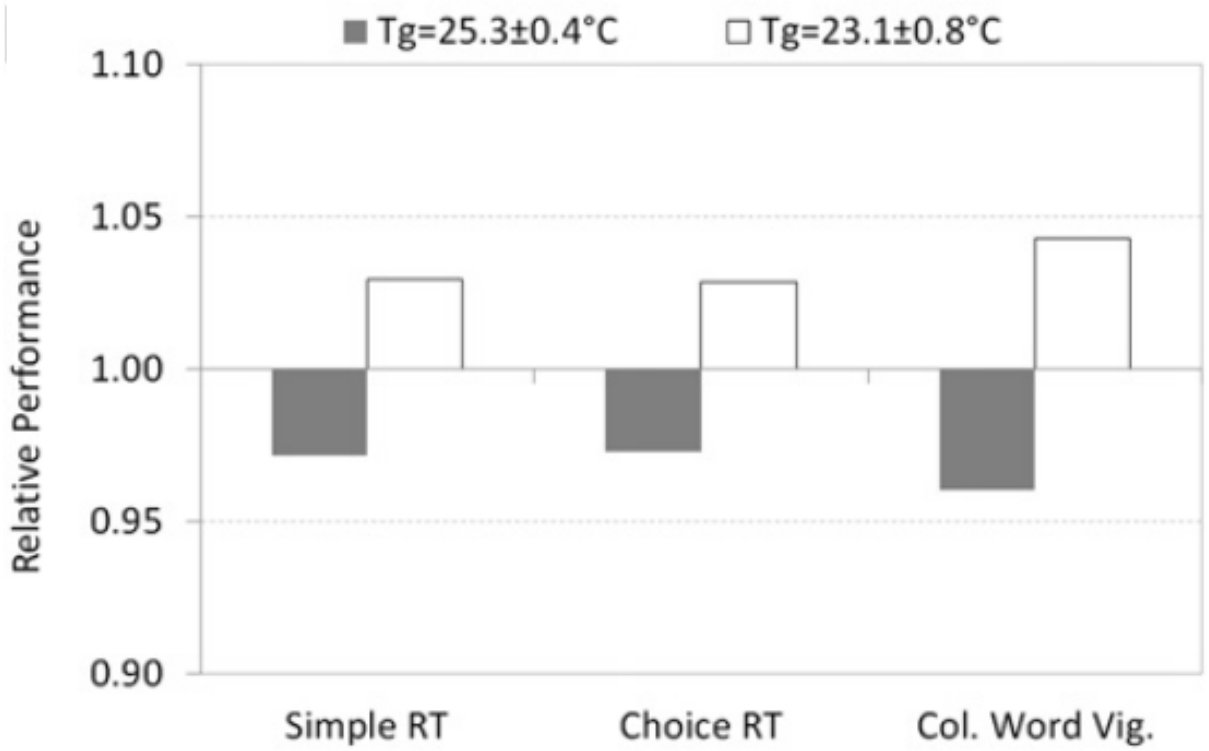
OECD: COUNTRIES WITH BETTER TEST SCHOOL RESULTS HAVE HIGHER GROWTH RATE

The OECD new survey of Adults Skills finds that foundation skills in mathematics have a major impact on indivividual's life chances. The survey shows that poor mathematics skills severely limit people's access to better-paying and more rewarding jobs; at the aggregate level, inequality in the distribution of mathematics skills across populations is closely related to how wealth is shared within nations. Beyond that, the survey shows that people with strong skills in mathematics are also more likely to volunteer, see themselves as actors rather than objects of political processes, and are even more likely to trust others.


1 L/s per pupil higher ventilation rate:
About 3% higher performance of schoolwork
About 1.5% lower absence rates

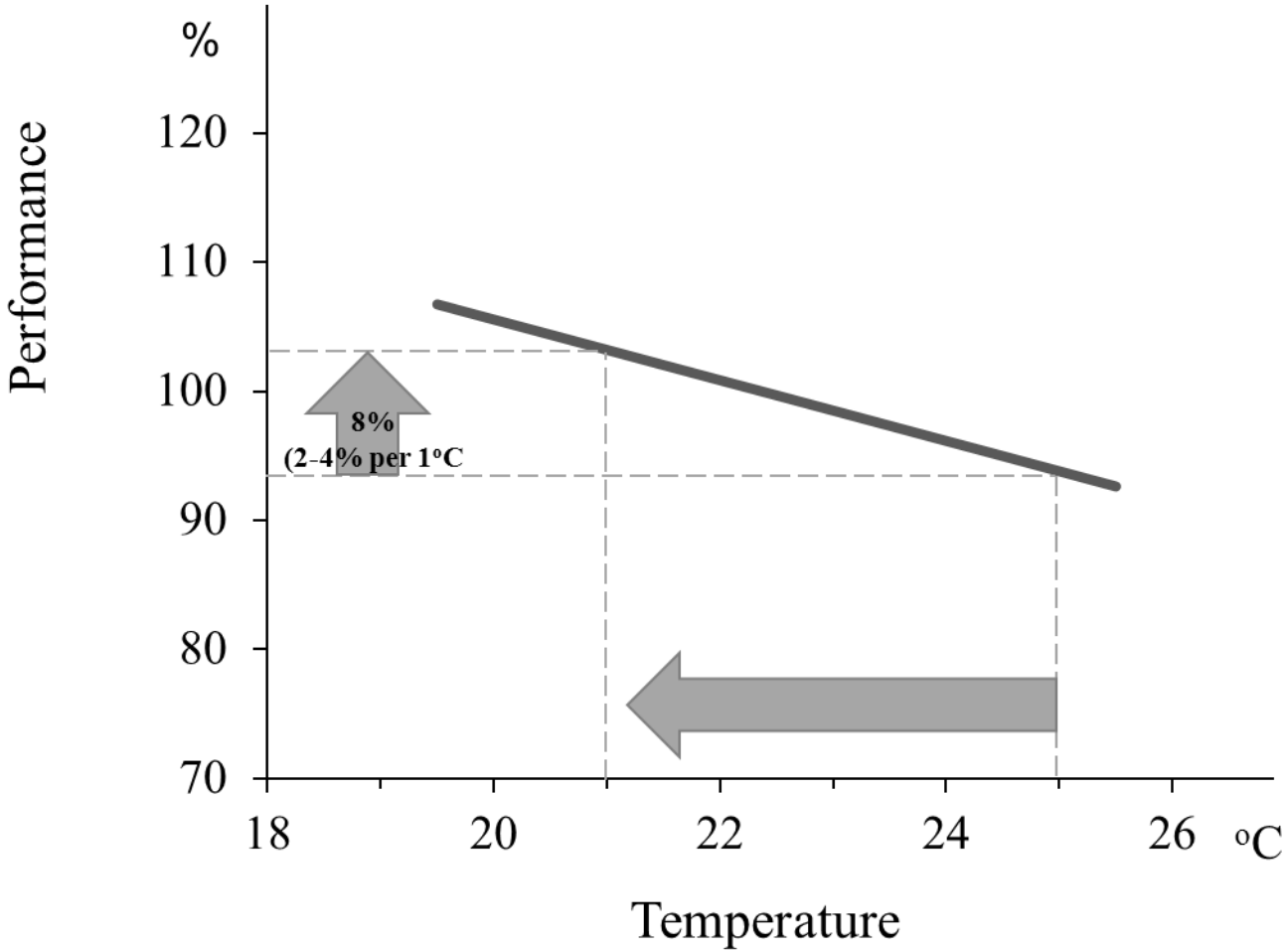
HOW ABOUT OTHER INDOOR CLIMATE PARAMETERS?

CLASSROOM TEMPERATURE, PSYCHOLOGICAL TESTS



Bako-Biro et al., 2012

CLASSROOM TEMPERATURE, TYPICAL SCHOOL TASKS



Wargocki et al., 2012

STUDIES ON TEMPERATURE AND LEARNING

- Mayo (1955): no effect of air conditioning on learning measured by performance on end of month examinations (students in a naval electronics school)
- Nolan (1960): physical discomfort resulting from high temperature conditions does have an adverse influence on academic learning (grades of students at Air Force Base tested in winter in heated classrooms better than in non-air-conditioned classrooms in the summer)
- Peccolo (1962): fourth grade students scored higher on special tasks (clerical, reasoning, etc.) in a classroom where climate was controlled compared with classroom where climate varied normally
- Stuart and Curtis (1964): gains in maths, science, social studies and language arts were superior in climate controlled classrooms with those in schools where no climate control was present but McNall and Nevins (1967) concluded that also due to better teachers and better supervisions
- Pepler and Warner (1968): **at temperature which was comfortable and caused pupil to exert least effort (27C) more time was needed to work through programmed text compared with less comfortable temperature where self estimated effort was higher (20C)**
- Schoer and Shaffran (1973): 10-12 year old pupils worked in a class with 22.5 and 26C; Nineteen different tests were applied,ranging from very simple and repetitive tests (such as crossing out certain letters in a text) toschool exercises stated to be current at the time (such as coding numbers onto machine-readablepunched cards), **and the students' performance was significantly better in the classroom that was always cool, on average by 5.7%**
- Wyon studies (1960s and 1970s): elevated temperatures resulted in negative performance and behavioral changes; **least able to perform the test were affected more**

TEMPERATURE, EFFORT AND TIME TO LEARN

Pepler and Warner, 1968

STUDIES ON TEMPERATURE AND LEARNING, WYON 1970

- Wyon studies (1960s and 1970s): elevated temperatures resulted in negative performance and behavioral changes; least able to perform the test were affected more

Wyon, 1970

ENERGY SAVING MEASURES AND PERFORMANCE (CAN WE USE ADAPTIVE THERMAL COMFORT APPROACH WITH NO NEGATIVE EFFECTS?)

- Elevated indoor temperatures should not be adopted to conserve energy in buildings because negative effects on performance will increase progressively even if some subjective habituation takes place and because people can often avoid discomfort by working less
- Acceptance (psychological) of undesirably warm thermal conditions should not be equated with achieving thermal comfort => physiological and mental changes occur in response to warmth: headache, fatigue, difficulty in thinking clearly, dry eyes, reduced oxygen saturation and increased CO2 levels in blood, and decreased tear film quality all affecting performance
- Objective adaptation due to behavioral changes may not always occur: inconveniently high velocities, dress code, etc..
- One of the most reported behavioral adjustments is to 'take a break' or to slow down work speed that definitely leads to decreased performance at high temperatures.

Lan et al., 2013

NOISE IN CLASSROOMS

- Text comprehension and memory were negatively affected by increased noise from airplanes; the effect was linear
- There were no strong effects of traffic noise (cars) on the performance of schoolwork – cognitive tasks, only episodic memory was slightly affected

Stansfeld et al., 2005

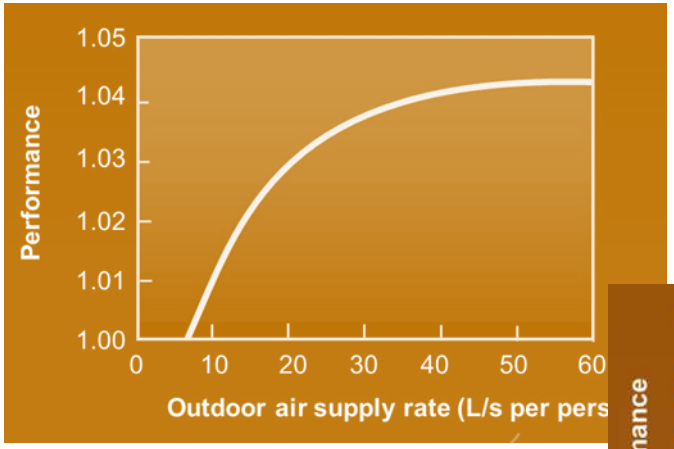
DAYLIGHT IN CLASSROOMS

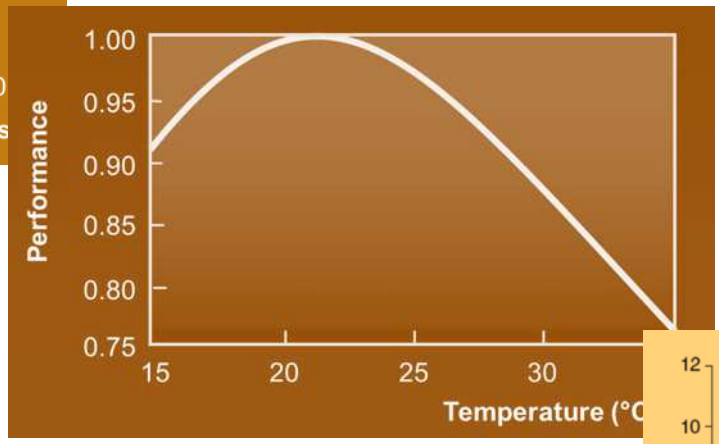
- School grades in elementary schools were improved by 21% for pupils in classes with much daylight compared with classes with least daylight

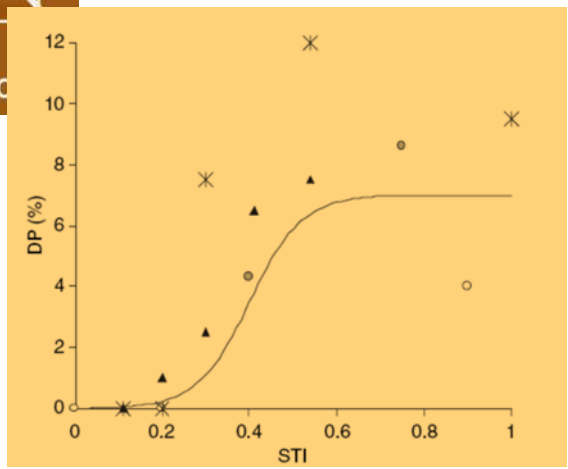
Heschong-Mahone, 2003

HOW ABOUT TEACHERS?

TEACHERS ALSO PERFORM LESS WELL

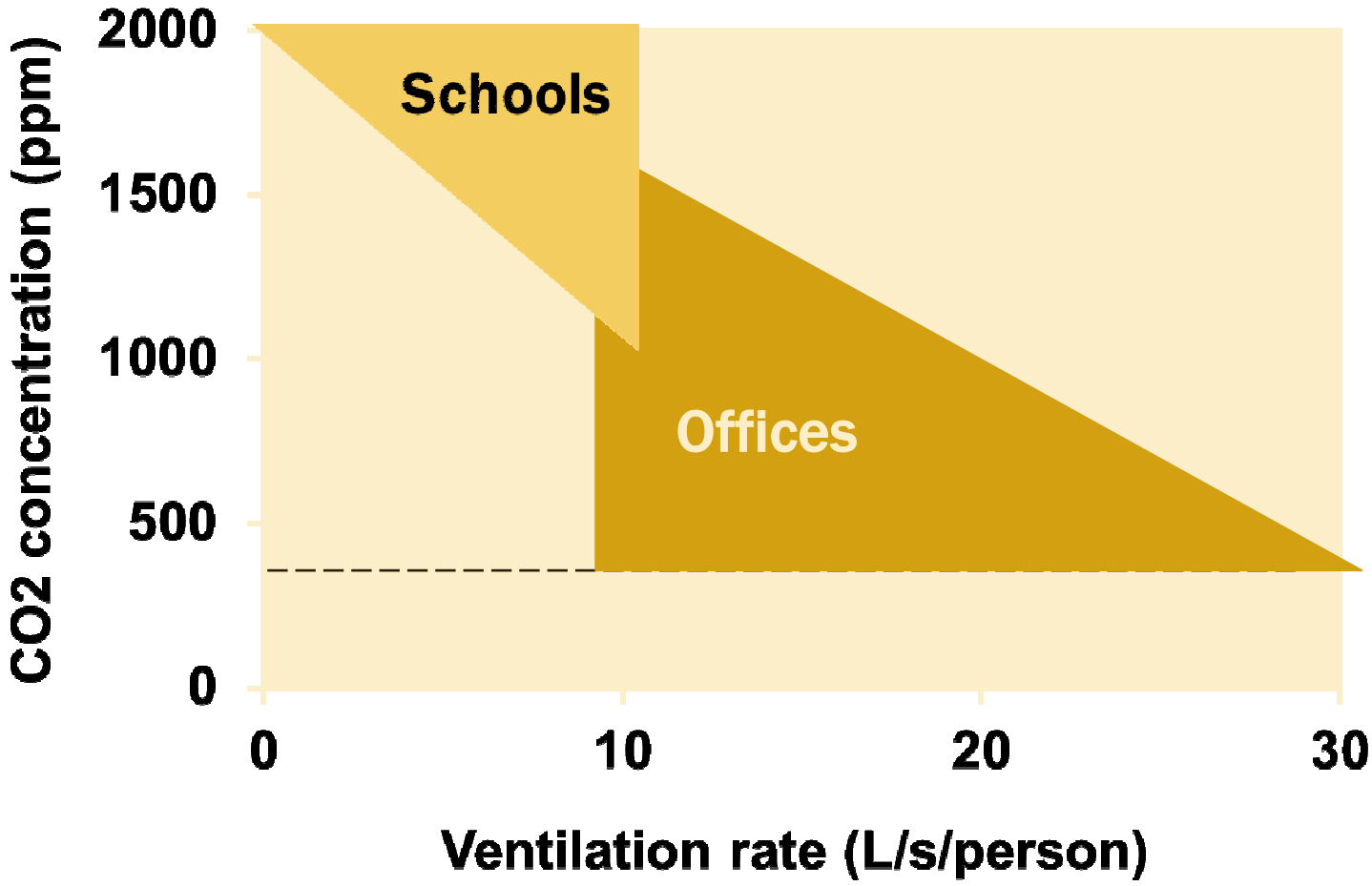


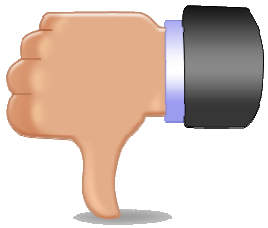




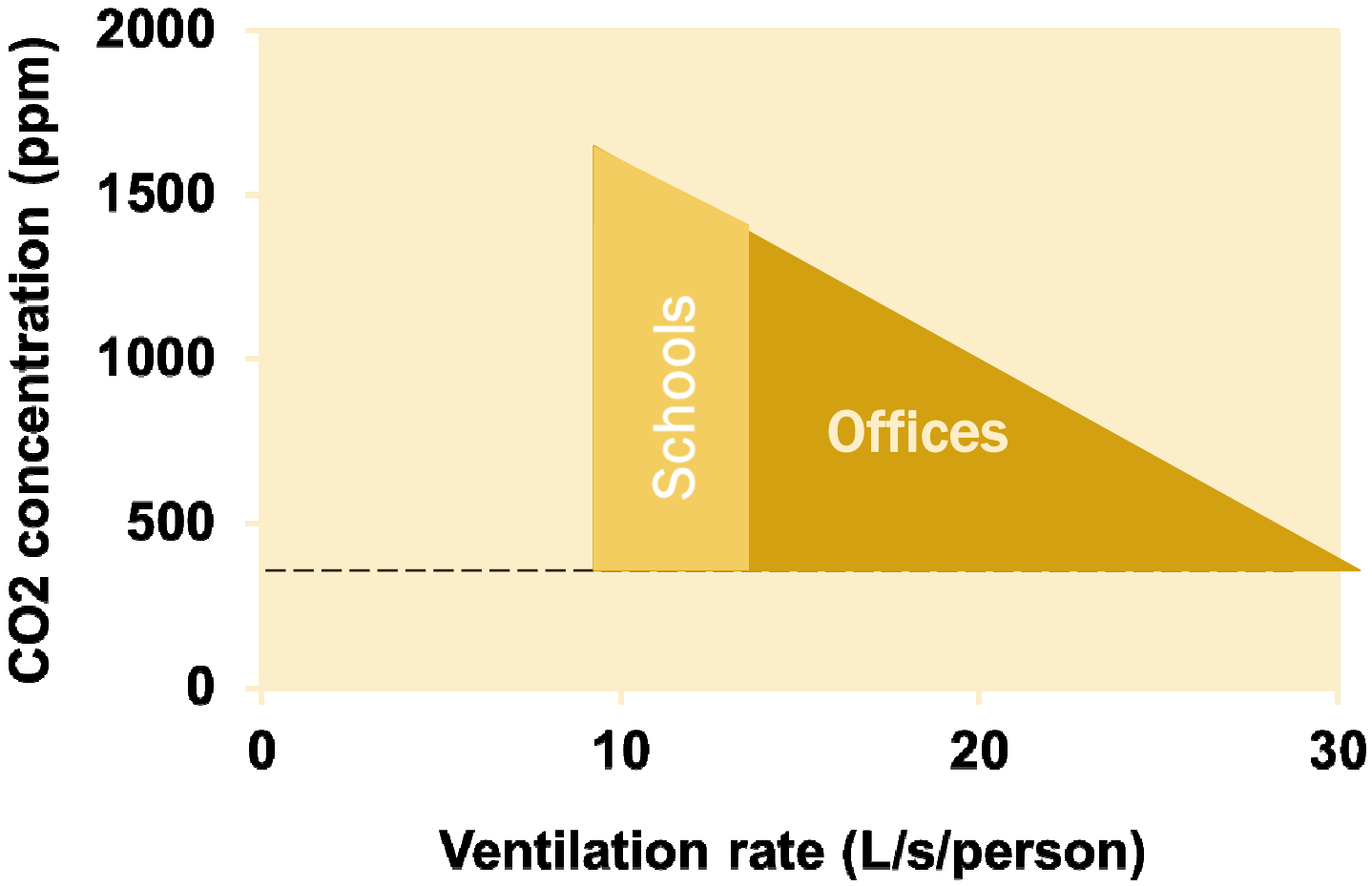
Hongisto, 2005; REHVA, Wargocki et al., 2006

VENTILATION REQUIREMENTS IN SCHOOLS

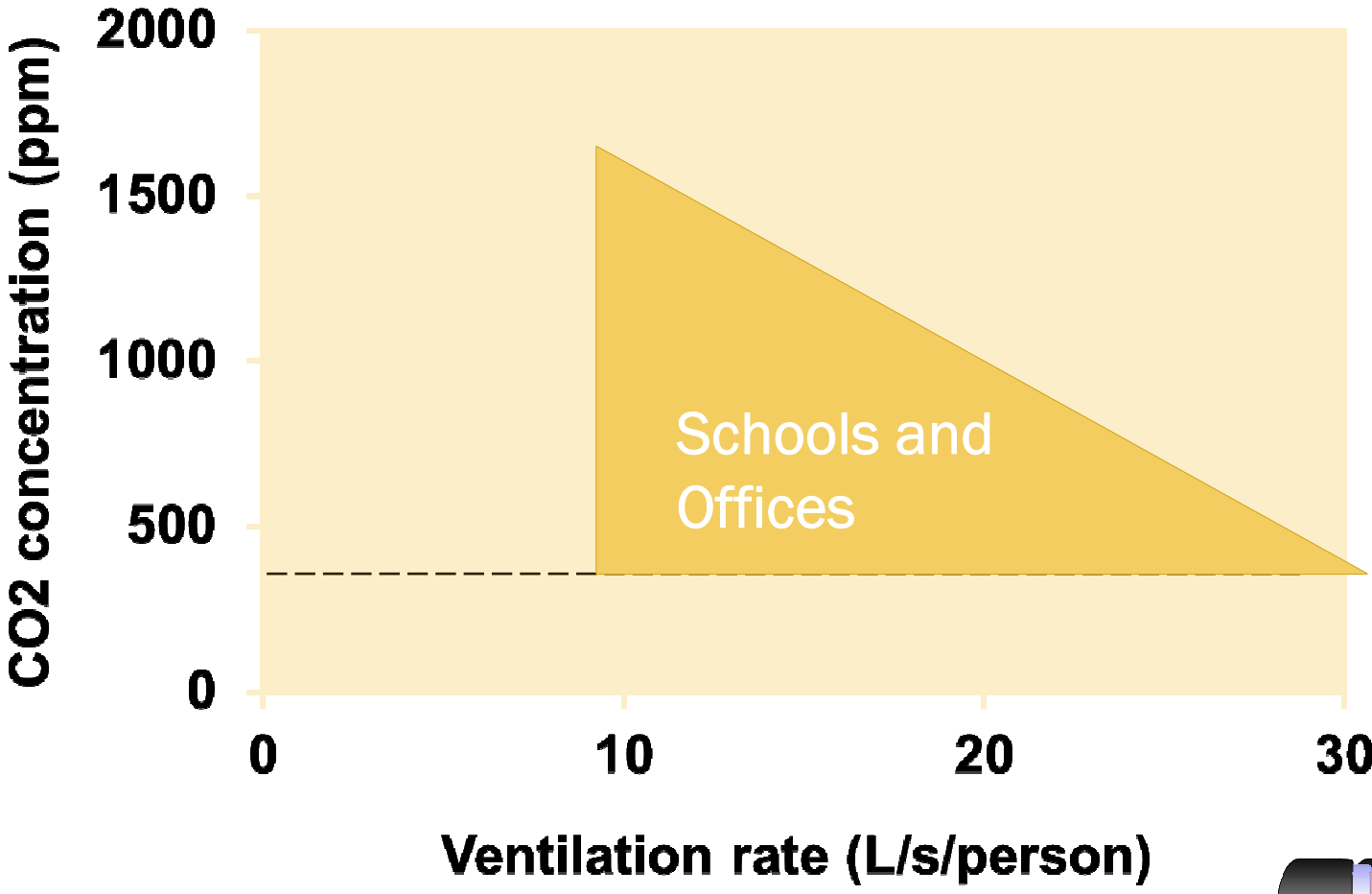




VENTILATION REQUIREMENTS IN SCHOOLS



VENTILATION REQUIREMENTS IN SCHOOLS



“It is certain that the additional expenses per pupil of the best ventilation needed not exceed the price of one or two cheap lunches.”

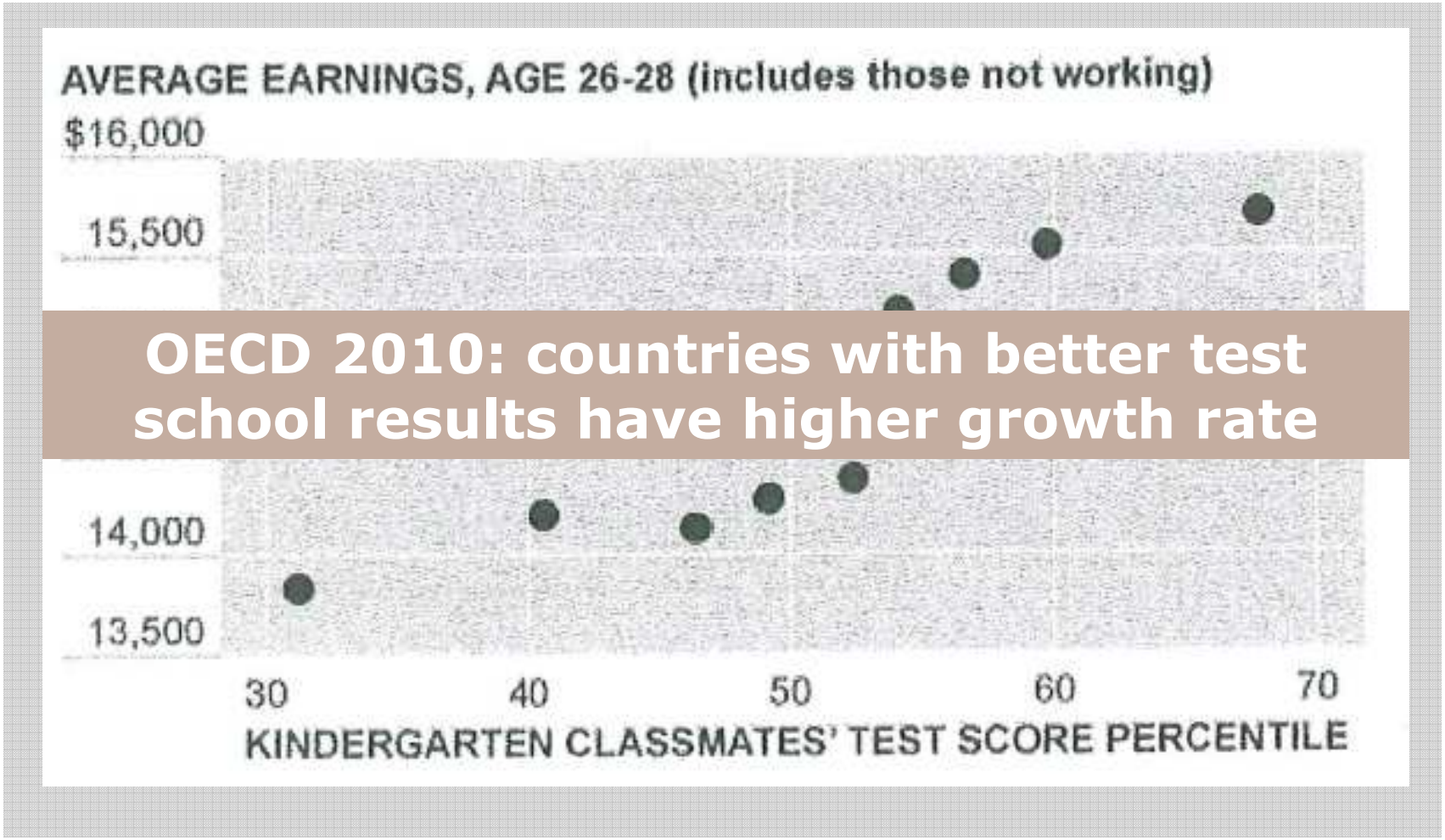
New Hampshire School District Ventilation Code, 1893

WHAT IS THE COST?

CONSEQUENCES

- 15% reduced performance (1/8) => 1 school year
- More time for teaching to reach the same educational targets, teacher cost => compare with the renovation costs
- Absence rates of pupils (& care takers) and teachers => cost of absenteeism
- Loss of opportunity (salary) as regards future work => socio-economic impact
- Consequences for national economy => GDP and public expenses/incomes

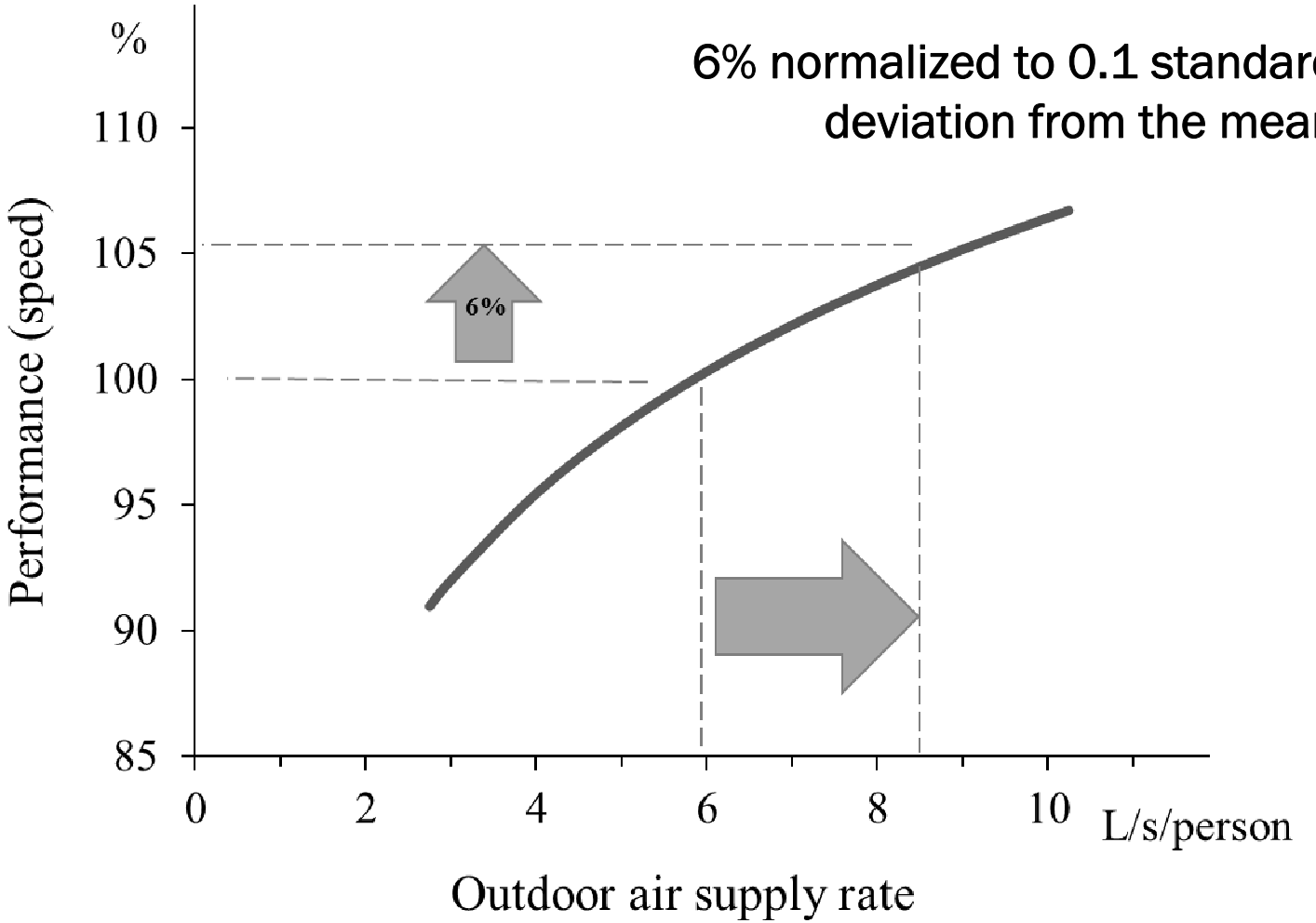
SOCIO-ECONOMIC CONSEQUENCES



OECD 2010: countries with better test school results have higher growth rate

Chetty et al., 2010

THE EFFECT ON PERFORMANCE OF SCHOOLWORK



6% normalized to 0.1 standard deviation from the mean

ESTIMATION OF EFFECTS OF IMPROVING CLASSROOM VENTILATION IN DENMARK FOR PUBLIC BUDGET AND GDP

	Average annual effect	Trend of effect
Public budget: TOTAL	**€37 million**	**Rising**
• increased productivity	€16 million	Rising
• fewer pupils in Tenth Class	€15 million	Rising
• lower teacher sick leave	€6 million	Constant
GDP total	**€170 million**	**Rising**
• increased productivity	€104million.	Rising
• fewer pupils in Tenth Class	€67 million	Rising
• lower teacher sick leave	N/A	N/A

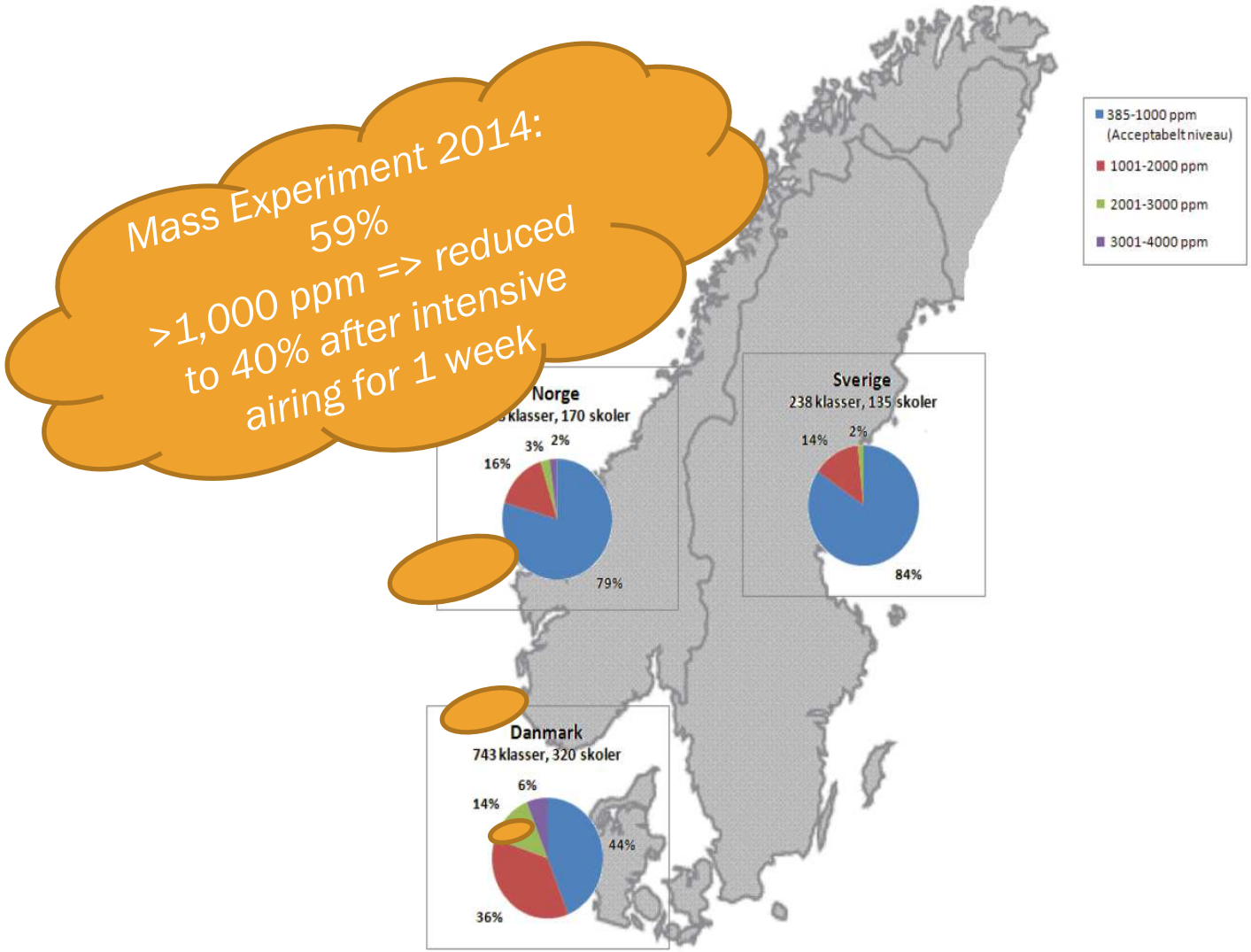
DANISH GDP (2011): €240,000 million (effects=0.07% GDP)

SLOTSHOLM A/S, Wargocki et al., 2013

POSSIBLE SOLUTIONS AND CONCLUSIONS

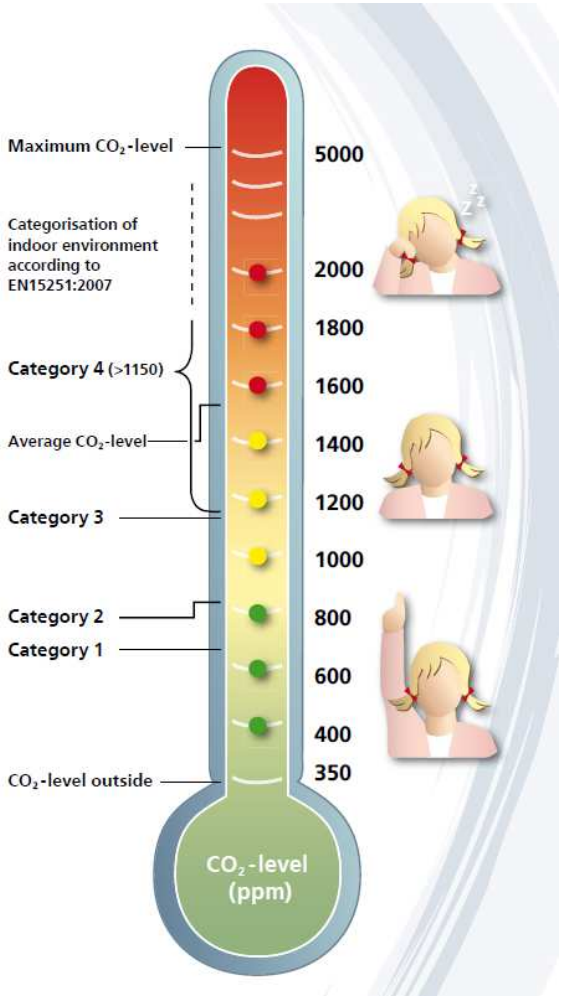
POSSIBLE SOLUTIONS (EXAMPLES) (MODERATE CLIMATE)

SCANDINAVIAN SCHOOLS – WINDOWS OPENING



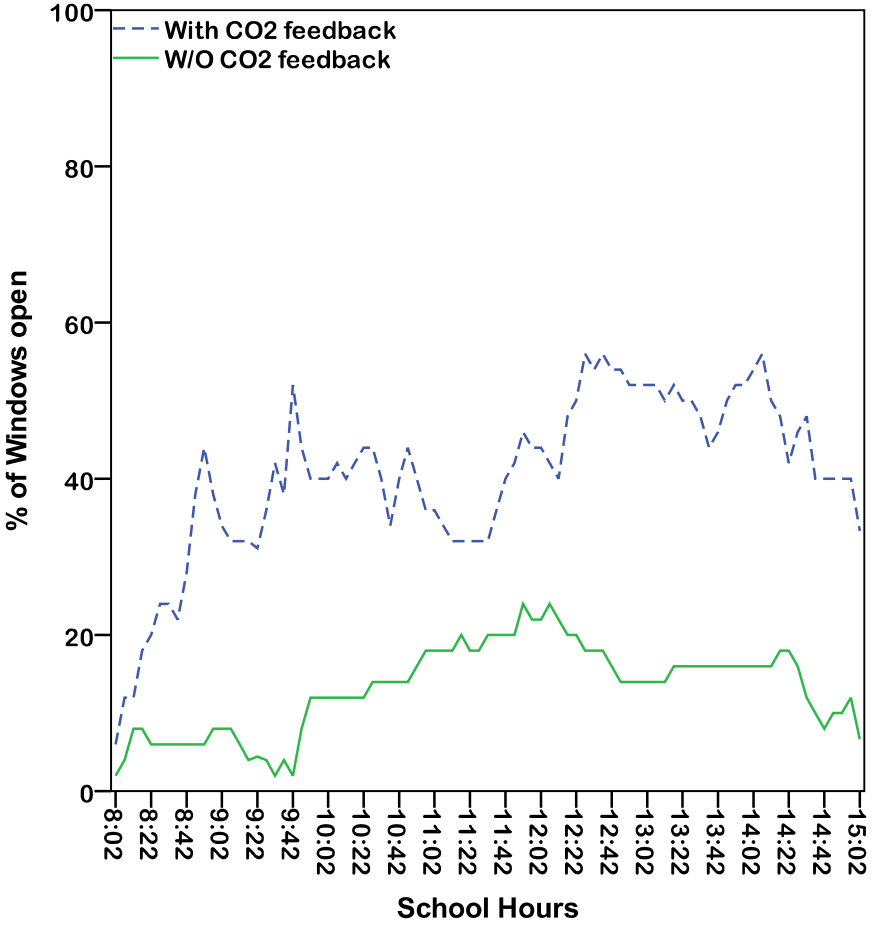
Report on Mass Experiment (2009)

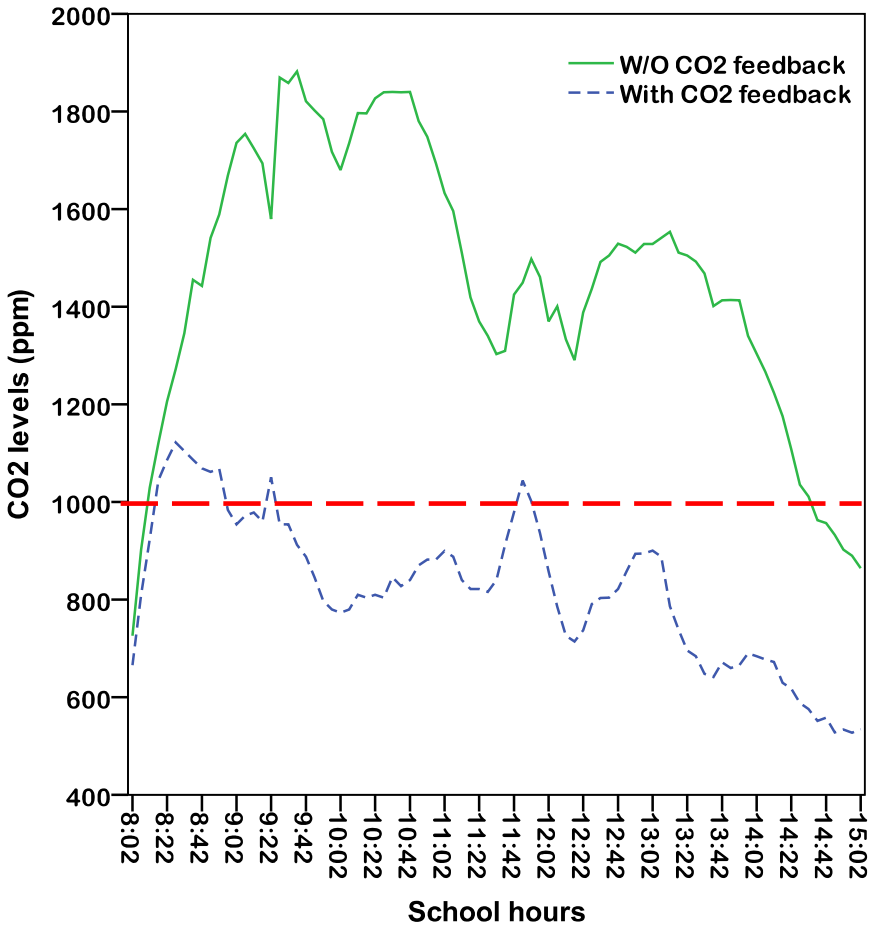
VISUAL CO_2 FEEDBACK AS A RETROFIT SOLUTION



Wargocki et al., in the Press

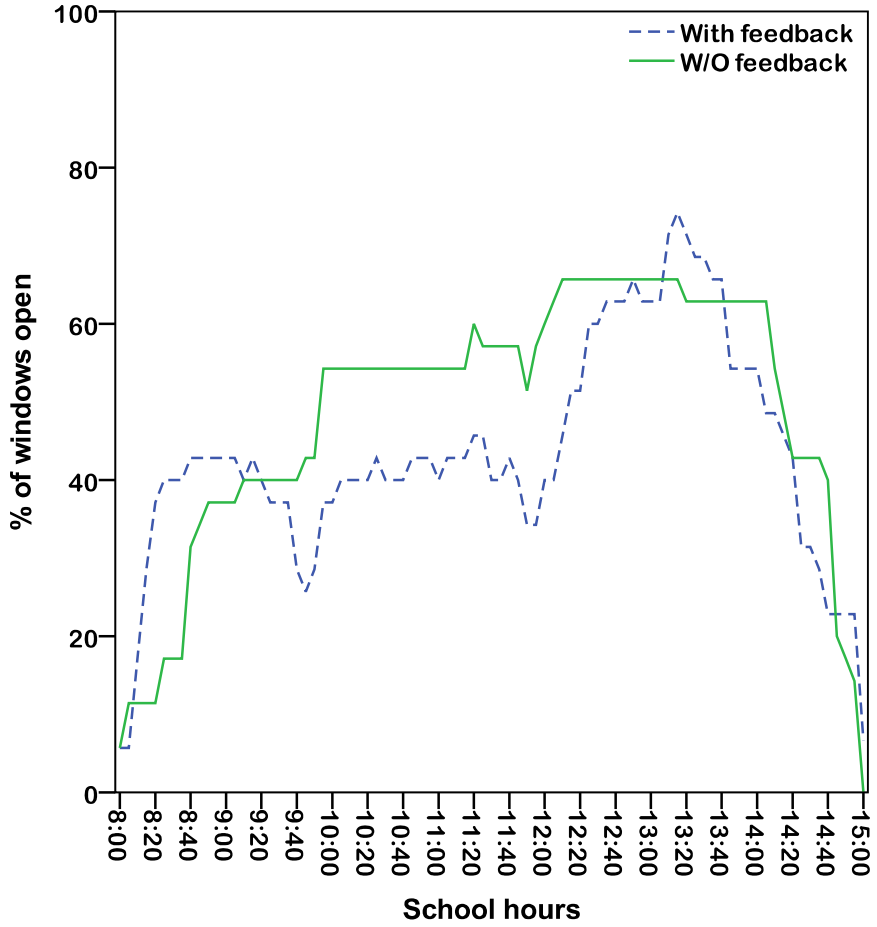
HEATING SEASON, WINDOWS OPENING AND CO_2

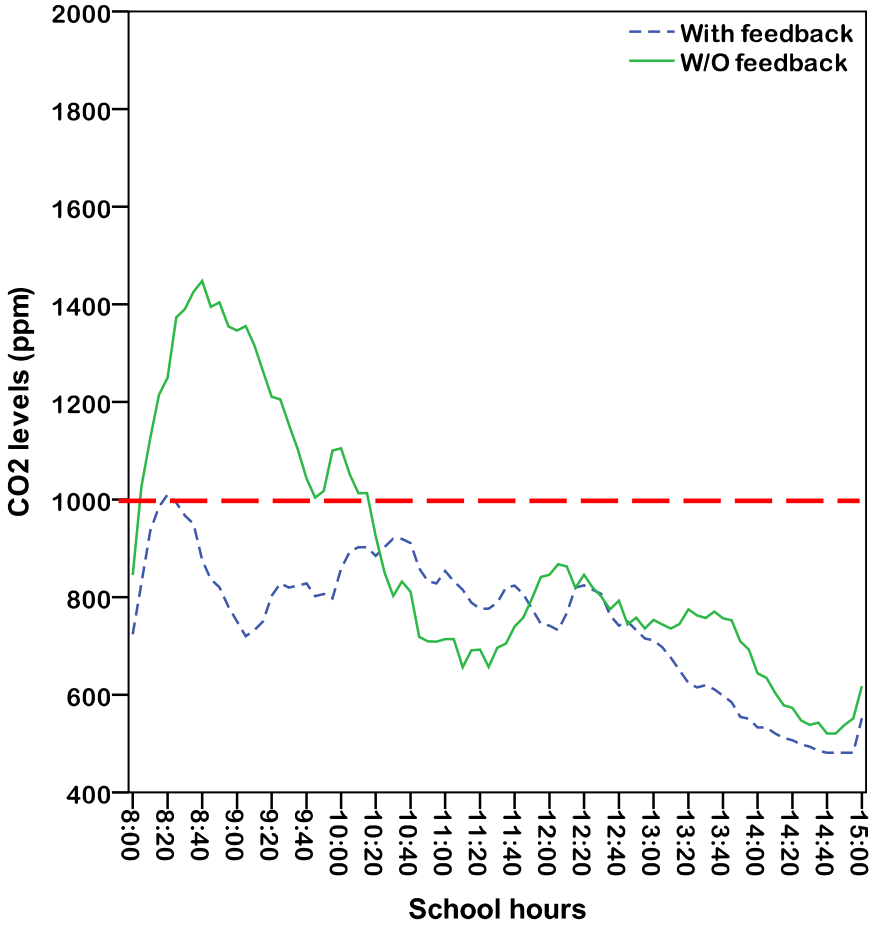




Wargocki et al., 2014

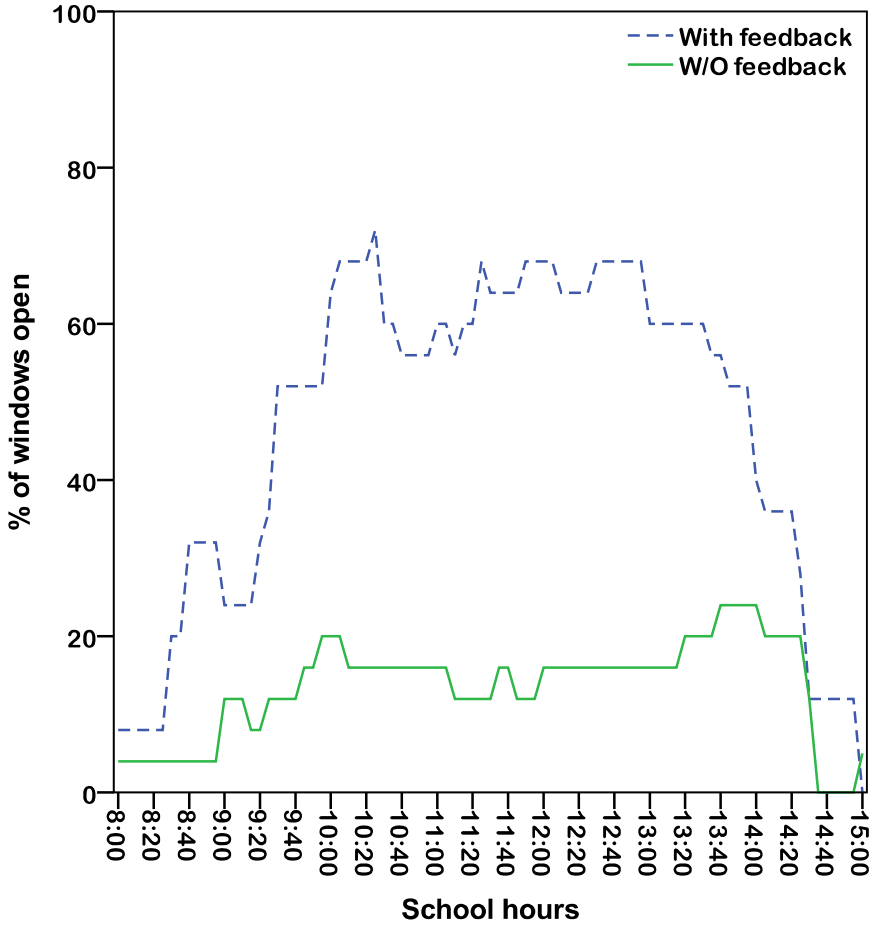
(W/O COOLING)
COOLING SEASON, WINDOWS OPENING AND CO_2

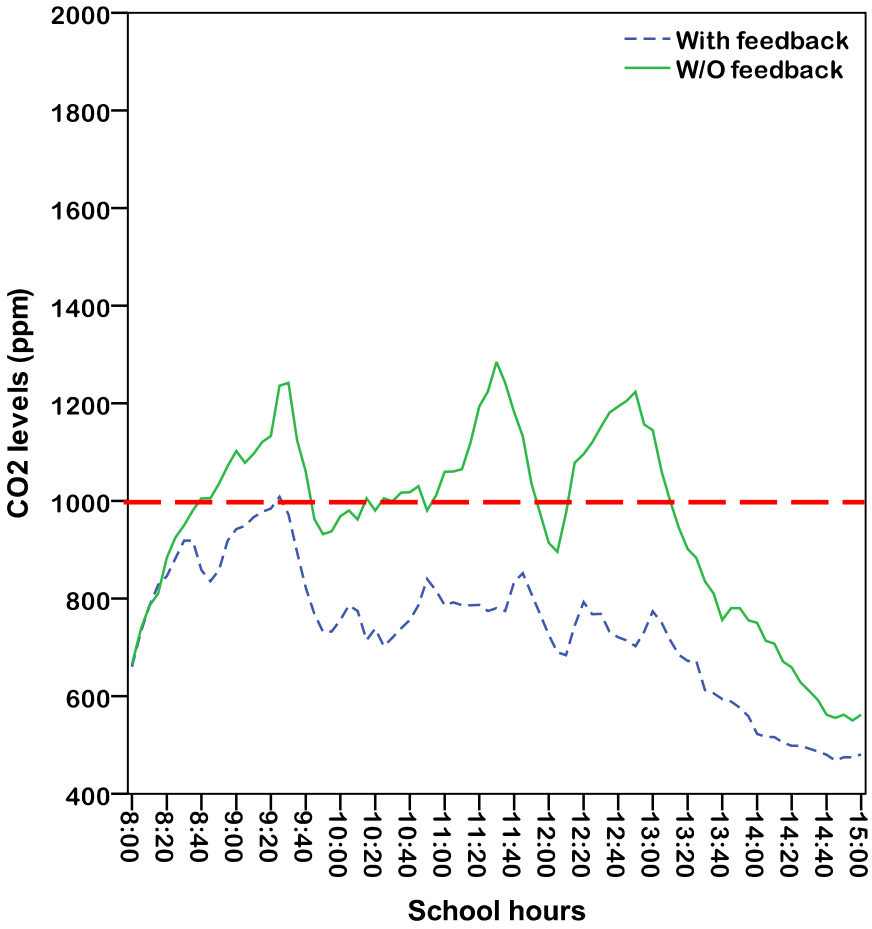




Wargocki et al., 2014

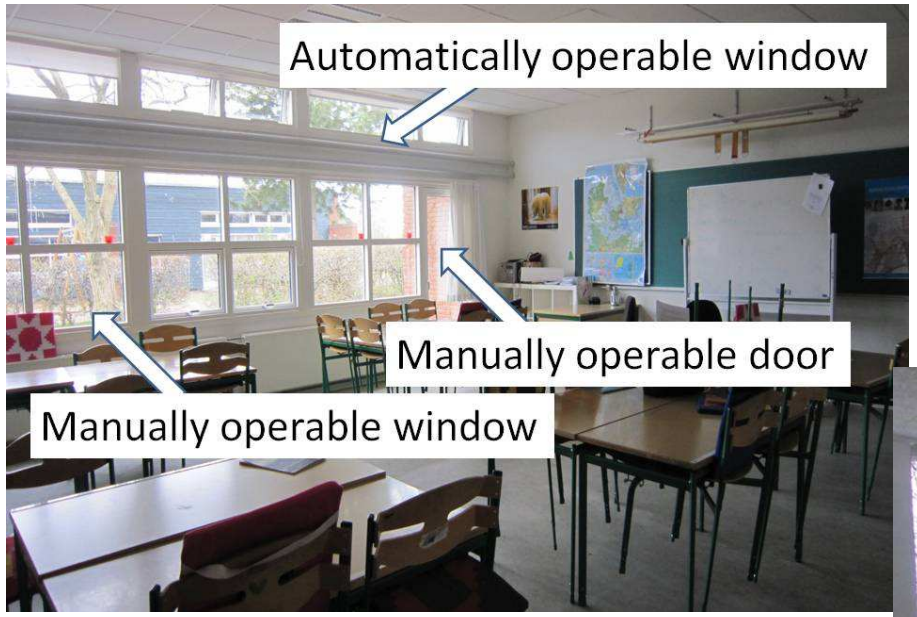
(WITH COOLING)
COOLING SEASON, WINDOWS OPENING AND CO_2

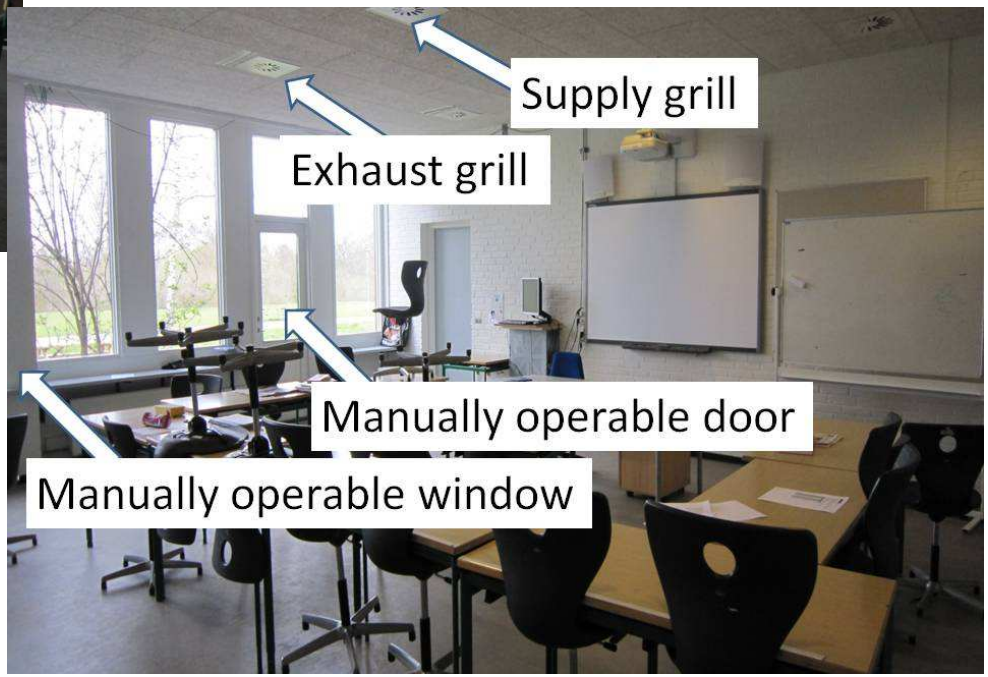




Wargocki et al., 2014

VENTILATION SYSTEM TYPE

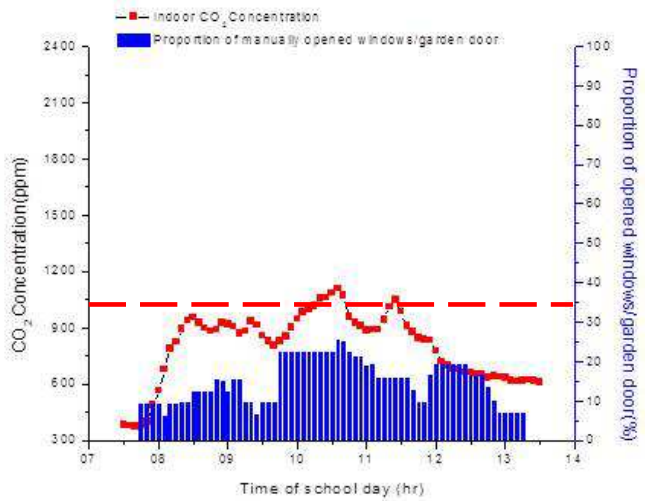


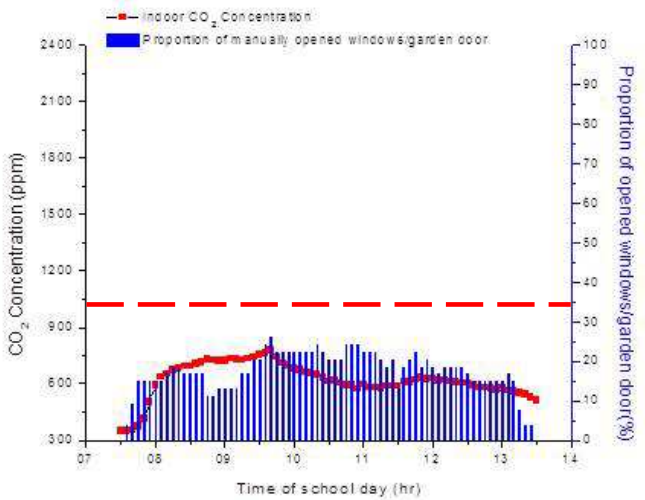


Gao et al., 2014

CO_2, WINDOW OPENING, SUMMER

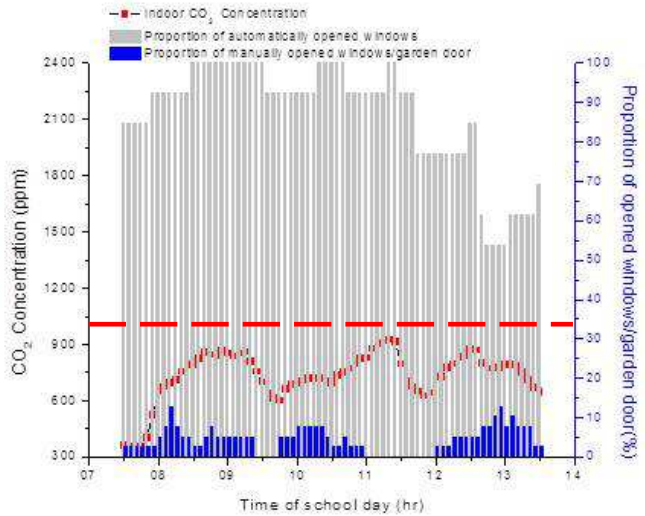
Manually operable windows

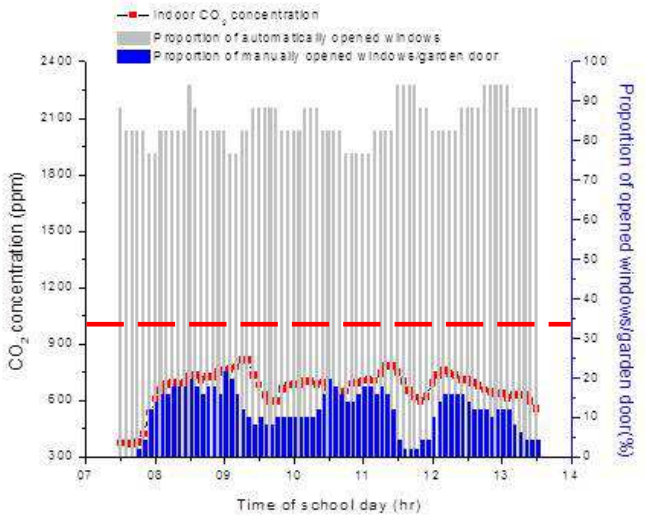




Mechanical ventilation

Automatically operable windows



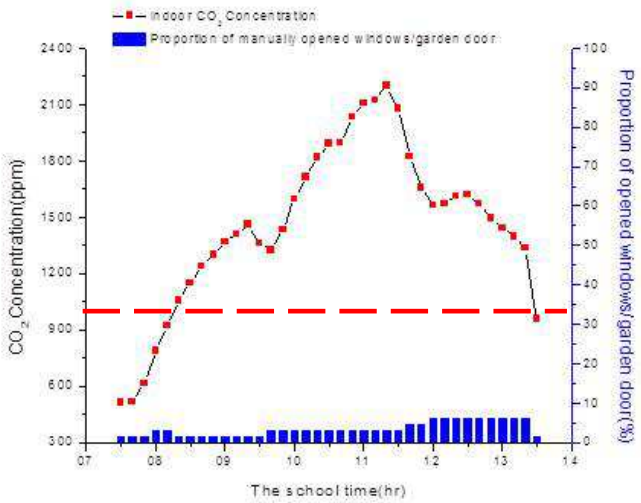


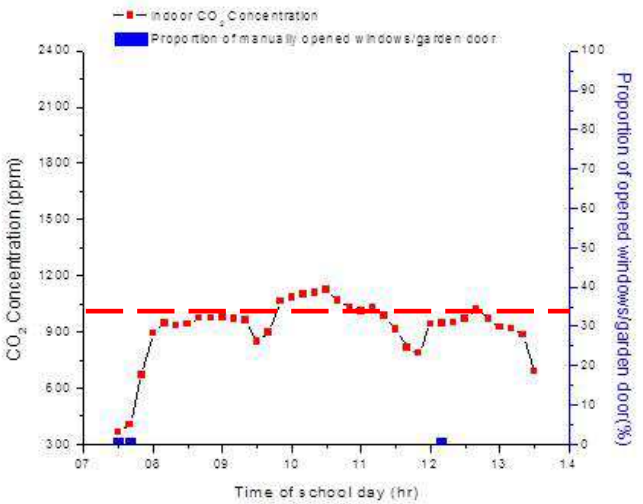
Automatically operable windows w/exhaust fan

Gao et al., 2014

CO_2, WINDOW OPENING, WINTER

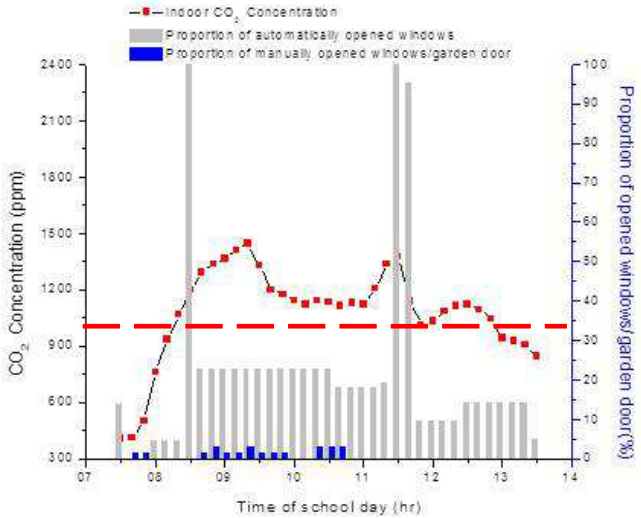
Manually operable windows

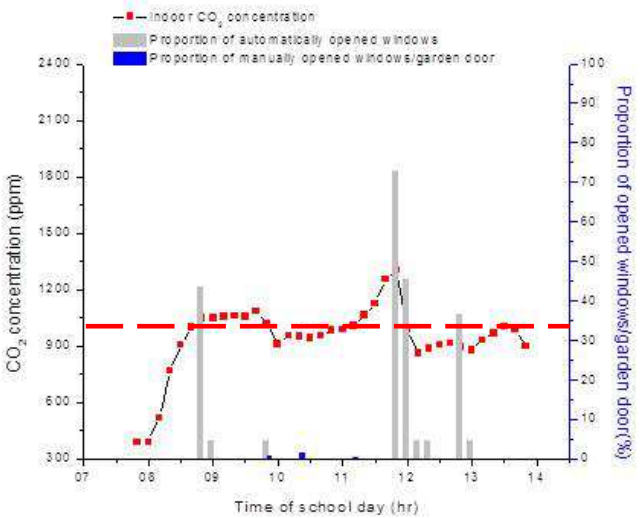




Mechanical ventilation

Automatically operable windows

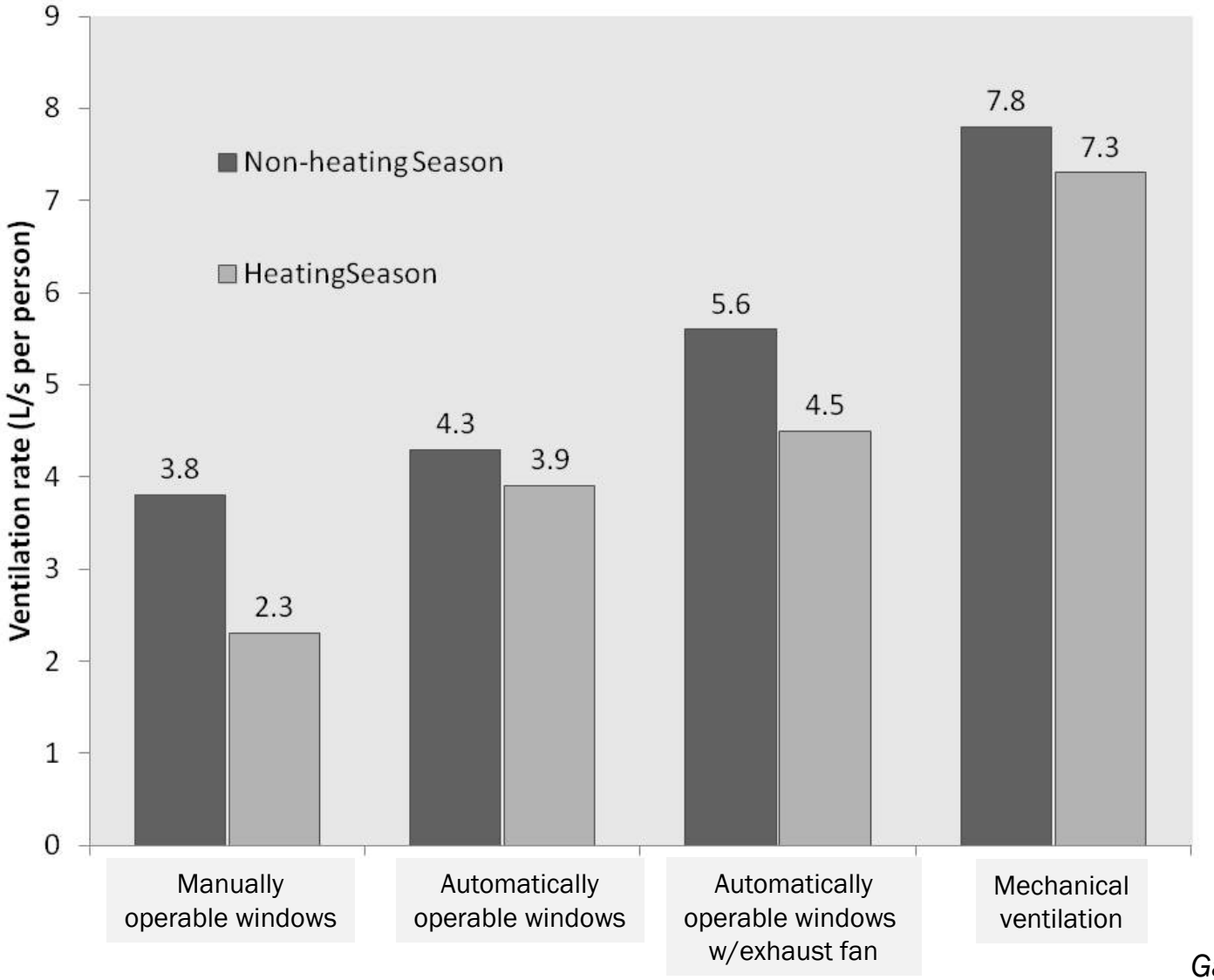




Automatically operable windows w/exhaust fan

Gao et al., 2014

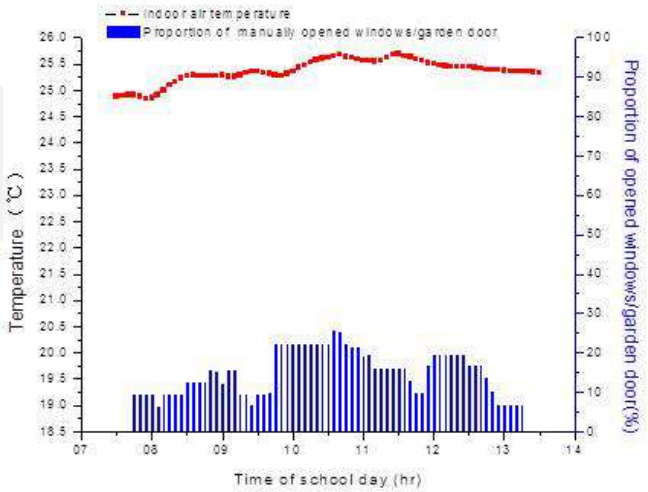
VENTILATION RATES

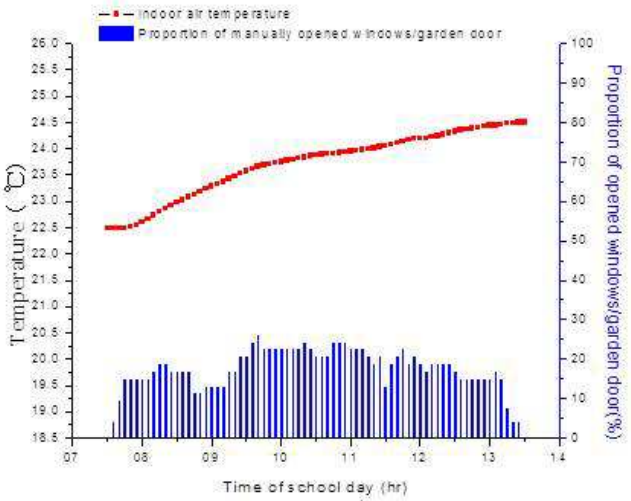


Gao et al., 2014

TEMPERATURE, WINDOW OPENING, SUMMER

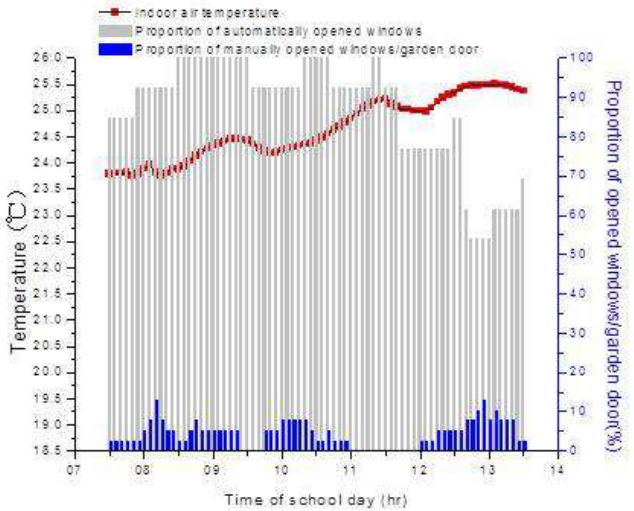
Manually operable windows

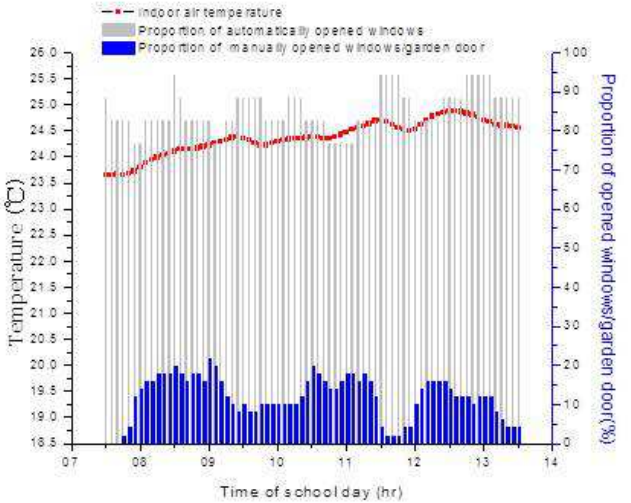




Mechanical ventilation

Automatically operable windows



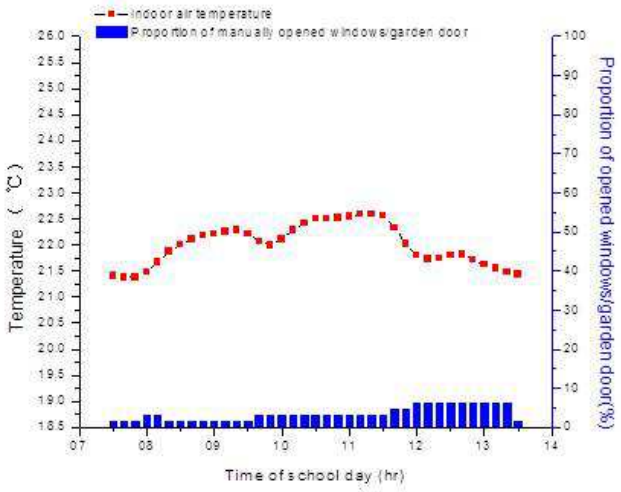


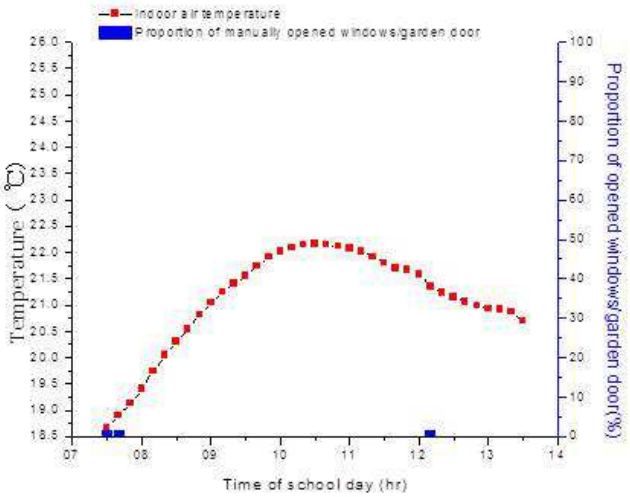
Automatically operable windows w/exhaust fan

Gao et al., 2014

TEMPERATURE, WINDOW OPENING, WINTER

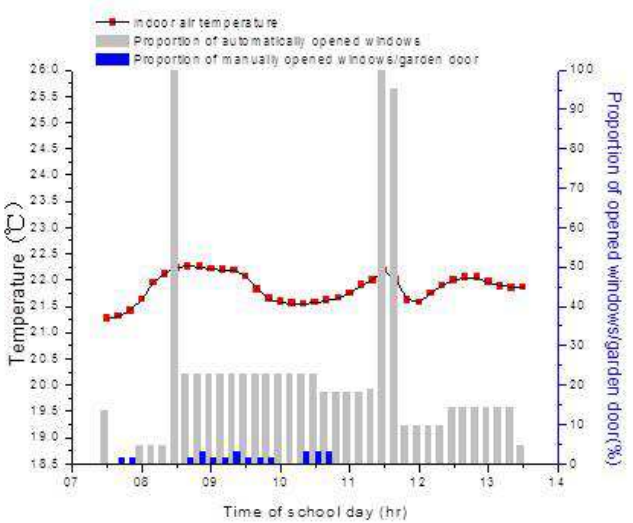
Manually operable windows

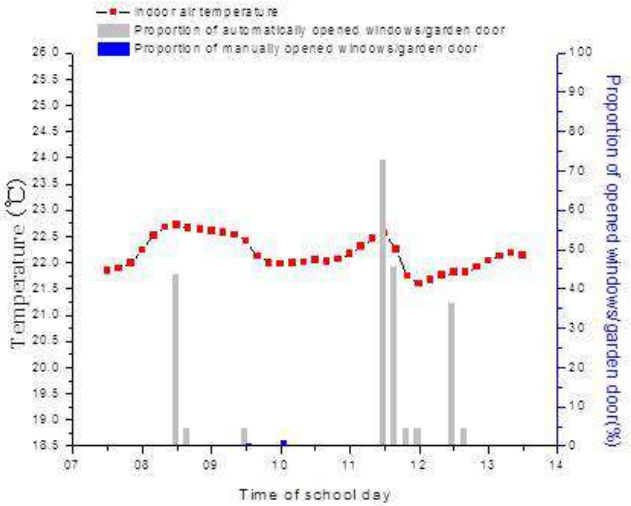




Mechanical ventilation

Automatically operable windows





Automatically operable windows w/exhaust fan

Gao et al., 2014

CATALOGUE OF WELL-PERFORMING VENTILATION SOLUTIONS FOR SCHOOLS

Hviid et al., 2014

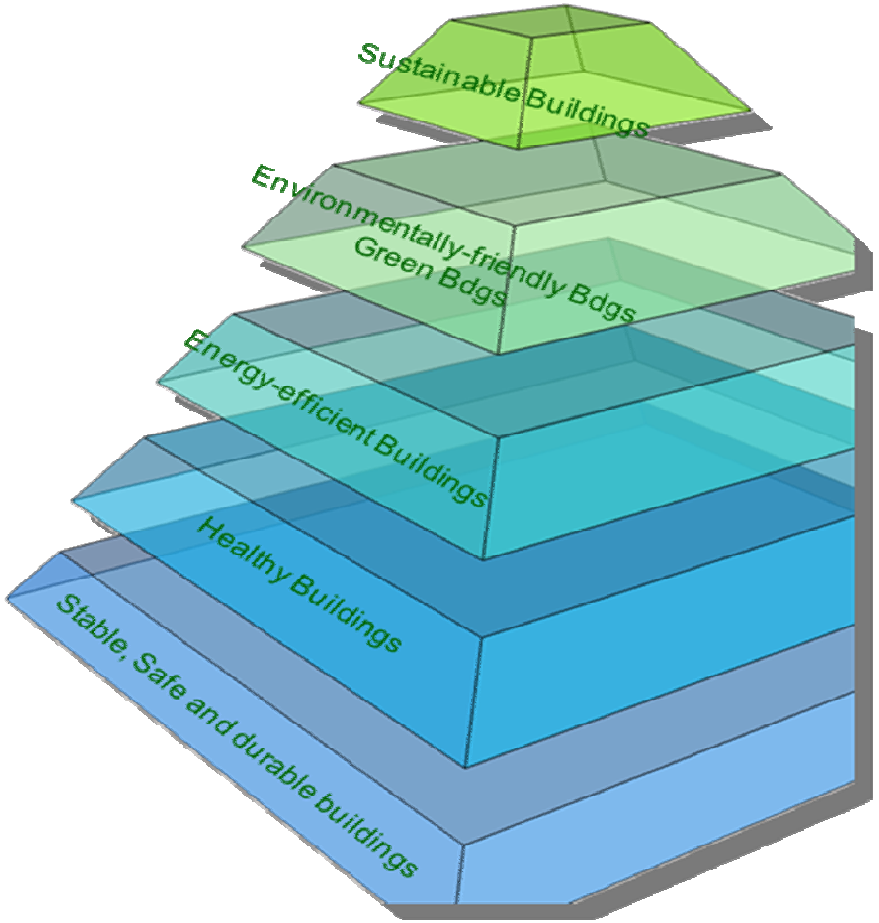
SUMMARY REMARKS

ENERGY IS A LOW HANGING FRUIT

Source: independentresidentialenergy.com

PURPOSE OF THE SCHOOL

- Buildings are not constructed to save energy
- They must first promote health together with energy and sustainability, health is included in the sustainability concept
- The primary purpose of school building is to provide an optimal conditions for learning and then to conserve energy
- IEQ in classrooms plays an important role in learning process, probably as important as teaching materials and methods
- High IEQ should become an urgent educational priority



HELSINKI 2007 DECLARATION

- **IEQ in many schools worldwide is inadequate.** This leads to unacceptable health effects, poor comfort and lower learning performance leads for both pupils and teachers.
- **All children & teachers, independent of socio-economic status, have the right to breathe healthy air at school**. The quality of the indoor environment should stimulate (the joy of) learning.
- It is our mission to ensure that IEQ in schools is improved to at least the minimum requirements prescribed by the current standards and codes.
- School building users have the right to information about the importance of healthy air at school and potentially harmful exposures. *Dissemination of knowledge on good IEQ should be disseminated broadly.*
- *HVAC systems for schools should be designed, installed, operated and maintained in such a way that unnecessary health risks from indoor air are minimized, whether harmful agents are of outdoor or indoor origin.*
- HVAC consultants, installers, HVAC equipment manufacturers and others involved in school buildings bear responsibility to achieve good IEQ.
- **Special needs for some groups should be taken into account, e.g. children with asthma.**
- Performance criteria for design and evaluation of IEQ in schools should be disseminated.
- **Decisions about school HVAC systems should be based on life cycle cost not on investment costs.**
- IEQ optimization in schools should be combined with improvement of energy performance.
- Adequate operation and thorough maintenance of HVAC systems are essential for creating a healthy learning environment. *So is a consequent monitoring of IEQ.*
- **An action to establish "Well-being indoors label" to be used together with the energy performance label should immediately take place.**