SOLAR-CAMPUS JUELICH - ENERGY PERFORMANCE AND INDOOR CLIMATE

J. Göttsche, K. Gabrysch, A. Delahaye, K. Schwarzer

Solar-Institut Jülich, Fachhochschule Aachen
Heinrich-Mußmann-Str. 5, 52428 Jülich
Tel: 02461/99-3525
Fax: 02461/99-3570
Email: goettsche@sij.fh-aachen.de
Web: http://www.sij.fh-aachen.de

ABSTRACT

The Solar-Campus Juelich consists of two buildings, as part of the University of Applied Sciences, Aachen, and student dormitories for 136 students (5 row houses), see Figure 1. In a general agreement, the overall energy demand for space heating of all buildings was limited to 40 kWh/m^{2}a, which is less than 50% of the existing German national regulation (Wärmeschutzverordnung 1995). Extra costs were provided through the AG Solar of the German state North-Rhine-Westfalia.

Figure 1: Buildings of the Solar-Campus Juelich

The student dormitory consists of 23 houses with different heating and ventilation systems, the concepts ranging from passivehouse up to the actual low-energy standard. One aspect of scientific research is the comparison between different central and distributed ventilation systems with and without heat recovery. Some of the ventilation systems use ground-to-air heat exchangers.

Detailed measurements of energy input, air quality and comfort parameters were carried out in 11 student houses and one university building. The students' response to and acceptance of the different building and ventilation concepts has been evaluated.

Ventilation systems result in improved air quality compared to a reference building with only windows as ventilation elements. Relatively large variations are observed with respect to the energy consumption for space heating due to varying user acceptance and user behaviour.

KEYWORDS

Low-energy Architecture, Ventilation, Heat Recovery, Air Quality, Energy Consumption

ENERGY AND VENTILATION CONCEPTS OF THE STUDENT DORMITORIES

A comparison of five low-energy building concepts was made possible due to the installation of varying combinations of construction, heating and ventilation concepts in otherwise identical environments. The concepts are characterized by their planned heating energy demand ranging from 10 kWh/m^2a to 90 kWh/m^2a (see figure 2).

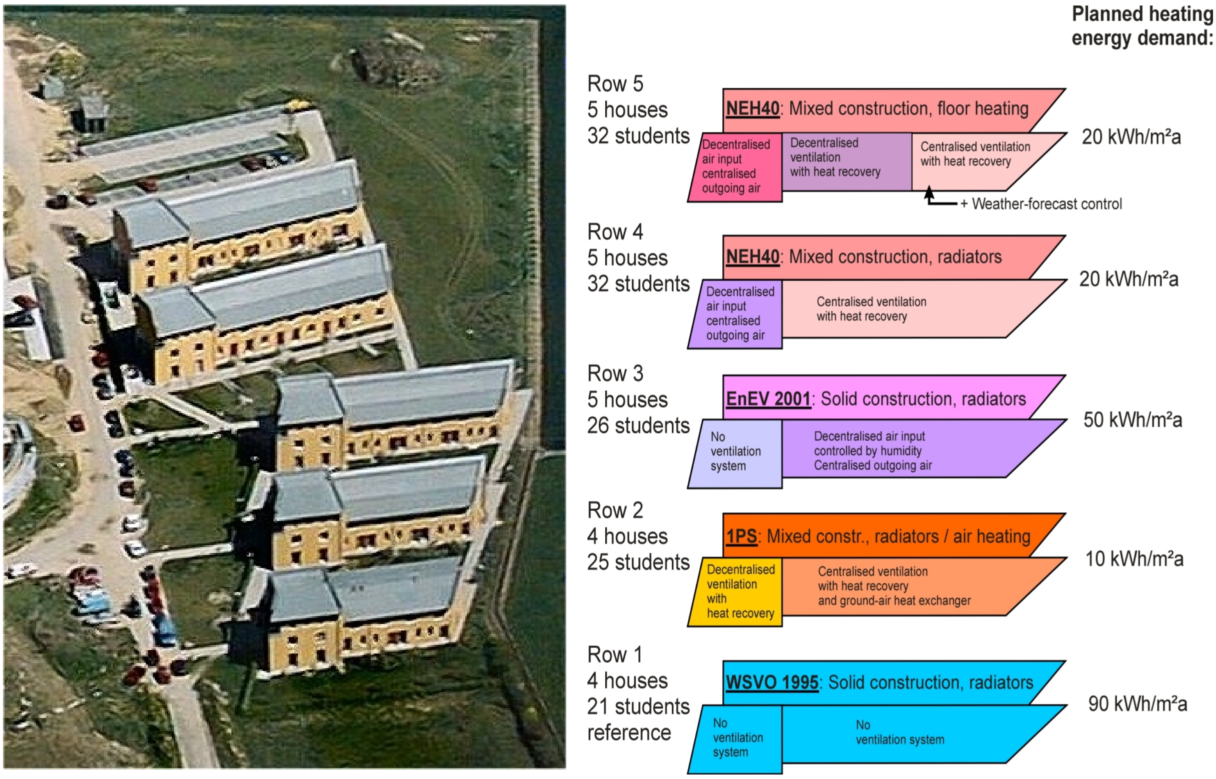

Figure 2: Construction, heating and ventilation concepts of the student dormitory

In order to build residential houses with an energy demand for space heating below 50 kWh/m^2a under German climate conditions, it is inevitable to install ventilation units with heat recovery. In this study, the performance and user acceptance of various systems is examined.

AIR QUALITY ANALYSIS

As indicators for indoor air quality we used the parameters relative humidity and CO_2 concentration, as most indoor emissions are coupled to these quantities and standard sensors are available. The corresponding acceptance levels are “30 % to 70 %” (rel. humidity, according to DIN 1946 T2) and “below 1000 ppm” (CO_2 conc., according to /Pettenkofer 1858/).

The following ventilation concepts are investigated and compared here:

A: Windows only
B: Centralized ventilation with heat recovery
C: Decentralized humidity-controlled air input, centralized outgoing air, no heat recovery
D: Decentralized manually controlled air input, centralized outgoing air, no heat recovery
E: Decentralized wall units with heat recovery (data only from Nov 2001 to April 2002)

The performance with respect to air quality is characterised by the fraction of time during which above parameters exceed the given acceptance levels (see tables 1 and 2). In case of systems B to E, data are only considered in periods during which the windows are kept closed.

TABLE 1

Time fractions during which allowed levels of CO_2 concentration and humidity are exceeded
(average of three rooms of each concept from September 1999 to February 2000)

Ventilation system	**% of time with CO_2 > 1000 ppm**	**% of time with humidity < 30%**
A: No ventilation system (reference)	19 %	3 %
B: Centralized ventilation with heat recovery	4 %	27 %
C: Decentralized humidity-controlled air input, centralized outgoing air	22 %	12 %
D: Decentralized manually controlled air input, centralized outgoing air	13 %	8 %

TABLE 2

Time fractions during which allowed levels of CO_2 concentration and humidity are exceeded
(average of three rooms of each concept from September 2000 to February 2001)

Ventilation system	**% of time with CO_2 > 1000 ppm**	**% of time with rel. humidity < 30%**
A: No ventilation system (reference)	15 %	4 %
B: Centralized ventilation with heat recovery	6 %	19 %
C: Decentralized humidity-controlled air input, centralized outgoing air	16 %	14 %
D: Decentralized manually controlled air input, centralized outgoing air	13 %	17 %

In all situations with ventilation units the air is more frequently too dry than in the reference situation. Concerning the CO_2 concentration, there is no significant difference between concepts A, C and D. The good performance of concept B is clearly correlated to continuous and relatively high air change rates, which has the disadvantage of resulting most frequently in too dry air. Although concept C is designed to control humidity (i.e. the openings are supposed to close when rel. humidity falls below 35 %), the lower limit of 30 % is below target during 14% of the time.

The air quality situation is characterized more completely by a correlation plot of CO_2 concentration vs. rel. air humidity as given in figures 3 to 7. In order to characterize the performance of the ventilation unit without the interference with open windows, data are only displayed for time periods during which the windows were kept closed. Data are displayed as hourly mean values of the heating period 2000/2001 (1 October 2000 to 30 April 2001). The green frame indicates the acceptance ranges of humidity and CO_2 concentration. Due to limitations of the CO_2 sensors, all concentrations above 2700 ppm are recorded as 2700 ppm.

Typical data for standard houses with only windows as ventilation systems are displayed in figure 3. Even two years after completion, CO_2 is absorbed by the wall materials leading to concentrations below ambient in case nobody is present and windows are kept closed.

Figure 4 shows typical data from a well working centralized unit. Under normal operating conditions the air change rate guarantees an equilibrium CO_2 concentration of below 1500 ppm. This figure is exceeded only if the system is switched off or during the presence of many persons.

The correlation plots in figures 5 and 6 demonstrate the sensitivity of concepts C and D: The air change rate is generally very low, due to open windows and doors in other rooms forming a short-cut. Only a well-disciplined behaviour of all occupants results in reasonable system performance as displayed in figure 6.

Decentralized wall units with heat recovery require extremely silent ventilators. The operation at a minimum noise level (and a corresponding low volume flow) during the night results in increased CO_2 concentration up to 2000 ppm (see figure 7).

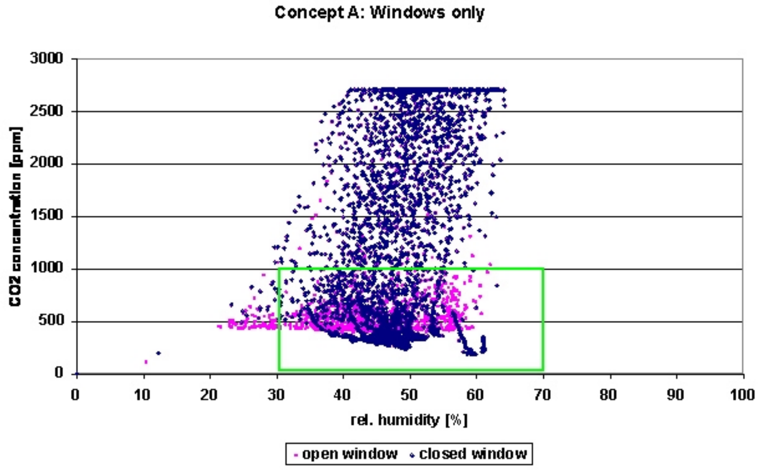

Figure 3: Typical CO_2 - humidity correlation in concept A: windows only

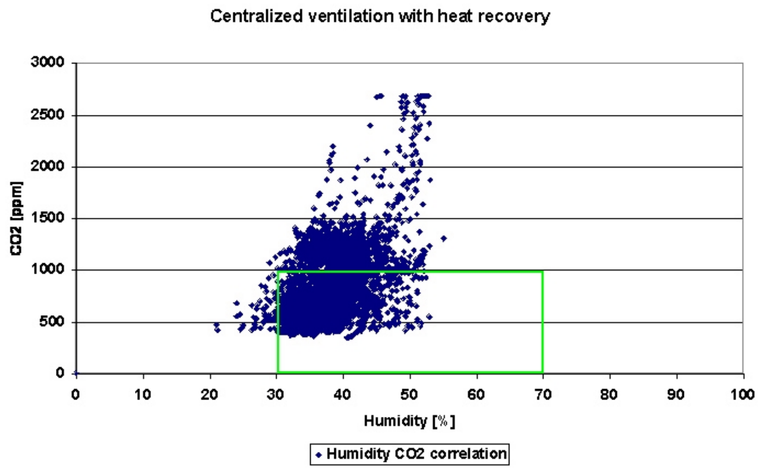

Figure 4: CO_2 - humidity correlation in concept B: centralized ventilation system with heat recovery

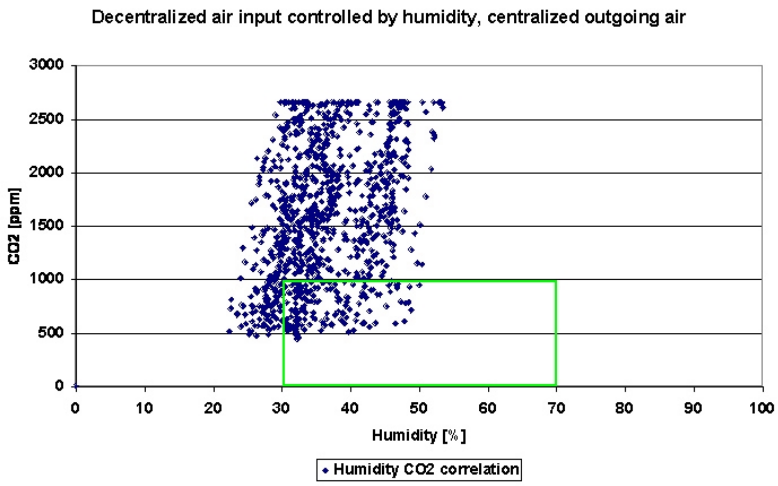

Figure 5: CO_2 - humidity correlation in concept C: Decentralized humidity-controlled air input

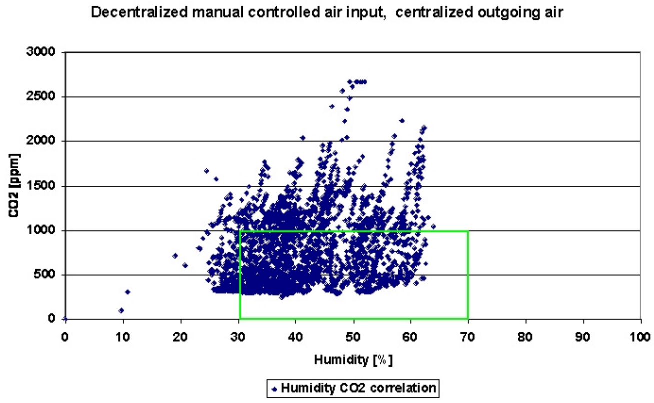

Figure 6: CO_2-humidity correlation in concept D: Decentralized manually controlled air input

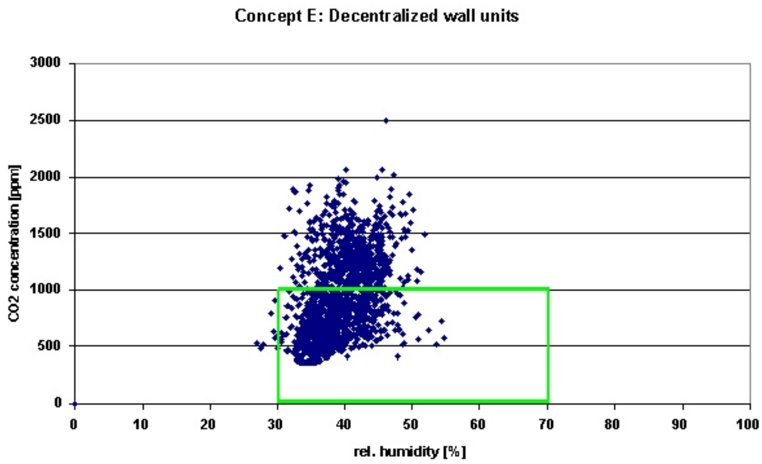

Figure 7: CO_2 - humidity correlation in concept E: Decentralized wall units with heat recovery

ENERGY PERFORMANCE

Performance data of the systems with heat recovery during the heating period 2001/2002 are summarized in table 3. In concepts B1 and B2, electricity consumption, volume flows and outgoing air temperatures were measured continuously. Data for concept E are based on continuous measurements of electricity consumption and short-term measurements of system performance under various conditions. The air change rate has been determined via tracer gas measurements. Derived quantities were calculated according to /Hausladen 1997/.

All air change rates are calculated as house averages, based on the total measured volume flow and the ventilated internal volume V_{house} of 351 m^3. System B2 may achieve higher mean air change rates because of its undisturbed operation potential even during frost periods.

From measured exhaust air temperature and volume flow data, the energy content of the exhaust air is calculated as “heat loss without heat recovery”. The fraction of energy that is recovered from the exhaust air is determined by measuring outgoing air temperatures before and after the heat exchanger. The ratio of the two is referred to as “mean rate of heat recovery”. It is interesting to note that the temperature gain due to the ground-air heat exchanger results in decreased heat recovery in the air-to-air heat exchanger unit.

The hydraulic system performance varies between 1895 m^3/kWh in concept B2 due to the pressure drop in the ground pipe and air filters and 3920 m^3/kWh in concept E, where the short air path leads to very efficient ventilator operation.

The total heat gain is the total amount of energy transferred to the ingoing air via heat recovery, waste heat from ventilators and (in concept B2) the ground-air heat exchanger. This energy gain is a multiple of the electricity input as described by the mean performance factor: Again, concept E is most efficient, where 16.6 times the electricity input is gained as contribution to space heating. In the last row of table 3, the amount of saved primary energy is specified for concepts B and E. Given the floor area of 149 m^2 of each house, the saved primary energy ranges from 15 (concept B2) to 28 kWh/m^2 (concept E).

TABLE 3

Energy performance data of heat recovering ventilation systems
averages / total values for heating period 2001/2002

	unit	**B1: Centralized ventilation with heat recovery**	**B2: Centralized ventilation with heat recovery and ground-air-heat exchanger**	**E: Decentralized wall units with heat recovery**
air change rate	**[h^{-1}]**	0.64	0.75	0.57 (a)
heat loss without heat recovery	**[kWh]**	5924	8840	5765 (a)
recovered heat	**[kWh]**	4294	1989	4843 (a)
mean rate of heat recovery	**[1]**	0.73	0.23	0.84
electrical energy	**[kWh]**	554.7	792.1	290
hydraulic system performance	**[m^3/kWh]**	2310	1895	3921
total heat gain	**[kWh]**	4618	4596	5013 (a)
mean performance factor (heat gain per electricity input)	**[1]**	8.5	5.8	16.6 (a)
saved primary energy	**[kWh]**	2955	2220	4143

(a) derived indirectly from measured data
- : does not apply to this concept

CONCLUSION

A comparison of a variety of ventilation units was carried out with respect to air quality and energy performance. In the context of the student dormitory of the Solar-Campus Juelich, it appears that concept E (decentralized wall units with heat recovery) is most suitable as it provides sufficient air quality with the highest energetic efficiency. The only disadvantage of this system is the noise produced by the ventilator unit, resulting in low air change rates at night. User acceptance for this system is highest because each individual controls her own unit, while all other systems are controlled centrally and may be too sensitive to user behaviour.

REFERENCES

Pettenkofer, M.v. (1858). *Über den Luftwechsel in Wohngebäuden*. Literarisch- Artistische Anstalt der J.G. Cotta'schen Buchhandlung, München

Hausladen, G., Meyer, C., Schramek, E.-R. and Banck, U. (1997). Beurteilungsgrundlagen für Lüftungsgeräte gemäß WSchV ´95. *Gesundheits-Ingenieur – Hautechnik – Bauphysik – Umwelttechnik* **118:1**, 28-31

ACKNOWLEDGEMENTS

This project was funded by the "Ministerium für Schule, Wissenschaft und Forschung Nord-Rhein-Westfalen" through the AG Solar NRW.