A Retrofit for Sustainability:
Meeting Occupants' Needs within Environmental Limits

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ABSTRACT

The terms "Sustainable Development" and "Sustainable Building" are often overused and ill-defined. A refocus on the core meaning basically results in two requirements with regard to buildings: 1) stay within nature's limits, and 2) design according to human needs. In this context, the socio-technical system "dwellers and building" not only has to be "green" but "green *enough*". There is strong evidence about what green enough means: altogether 80 kWh/m^{2}a *primary* energy for heat (space heat, DHW) and embodied energy. Yet even in new buildings, almost nobody meets his dwelling needs with this small amount of energy. But the most prodigal energy needs prevail in existing buildings.

SOLANOVA applies the know-how from new "green enough" buildings to a real retrofit of a typical building with 42 flats in Hungary. Similar developments contain about 34 million flats in Eastern Europe alone. SOLANOVA is meant to serve as a best practice example for all of Europe, and therefore, gets support from the European Commission. The project demonstrates how to stay within environmental limits while meeting the dwellers' needs even in a retrofit situation. Initial interviews with all the dwellers in SOLANOVA revealed the topics that really matter to inhabitants as well as crucial behavioural patterns. These insights were fed into the design in order to exploit the full potential for increased well-being and energy savings of more than 80%. The retrofit was finished in October 2005.

Introduction

The terms "sustainable development" and "sustainable building" are often overused and ill-defined. Accordingly, this paper starts with refocusing on the core meaning of sustainable development and what it means to buildings. Initially, environmental limits have to be defined, which leads to extremely low allowable energy *consumptions*. To be successful, a "systems view" is helpful, where the building and the dwellers are regarded as a "socio-technical" system. Existing buildings have to be the largest field of activity for sustainable building. SOLANOVA started in January 2003. It is the first European project where the philosophy and know-how from new ultra-low-energy buildings are adapted and transferred to a real retrofit situation. The project is meant to serve as a European best practice example and therefore gets support from the European Commission. The demonstration building has a shop floor and seven-stories above with 42 flats. It was made with industrial pre-fab concrete panels – a typical 1970s construction with prodigal energy needs. In Eastern Europe alone, there are more than 10 million similar buildings, containing about 34 million flats and 100 million residents. SOLANOVA consequently follows a "socio-technical" systems approach. This paper gives a short overview about the project's technical issues, and then turns to a "social" focus. Based on interviews with all residents, the involvement of the dwellers into the design is discussed.

Sustainable Building with Respect to Sustainable Development

Nowadays, the terms "sustainable," "sustainable development," and "sustainability" belong to the basic vocabulary in academic circles while "common" people have hardly heard about it: in 2004, only 22% of Germans reportedly had heard about sustainable development (Kuckartz & Rheingans-Heintze 2004). In academic circles, there is significant interest in this field around the world. The U.S. Green Building Council's last international conference in 2005 had almost 9,000 participants. Also, in 2005, Tokyo hosted the "World Sustainable Building Conference" with 1,700 participants from more than 80 countries. A closer look at this conference hints to a less clear notion of "sustainable building" than might be expected. The conference ended with the SB05 declaration "Action for Sustainability". Among others, the declaration recognizes:

- The significant impacts current building practices and human settlement patterns have on resource use, global environmental degradation, and climate change, and,
- The urgent need to take immediate and permanent actions toward sustainability.

From this insight follows, among others, the commitment to

- Promote the spirit of the Kyoto Protocol and
- Implement sustainable building principles (SB05 2005).

First of all, this is a very honorable result, which reflects the positive nature of this conference. However, it also reveals and highlights a very surprising weak spot that prevailed throughout the conference. Although the main keywords are "sustainability" and "sustainable building principles," there was no systematic discussion, no paper or poster directly focusing on the questions: *what* is "sustainability," *what* are "sustainable building principles," and *what* could be a systematic approach to answer these fundamental questions. Having almost reached the 20th anniversary of the discourse about "sustainability," it seems to be necessary to refocus on these basic questions to encourage more reflective statements about "sustainability" (SRU 2002).

A first step in this effort might be to re-read and analyse the *full version* of the most cited definition of "sustainable development" from the report "Our common future," which was written by The World Commission on Environment and Development in 1987 (WCED 1987):

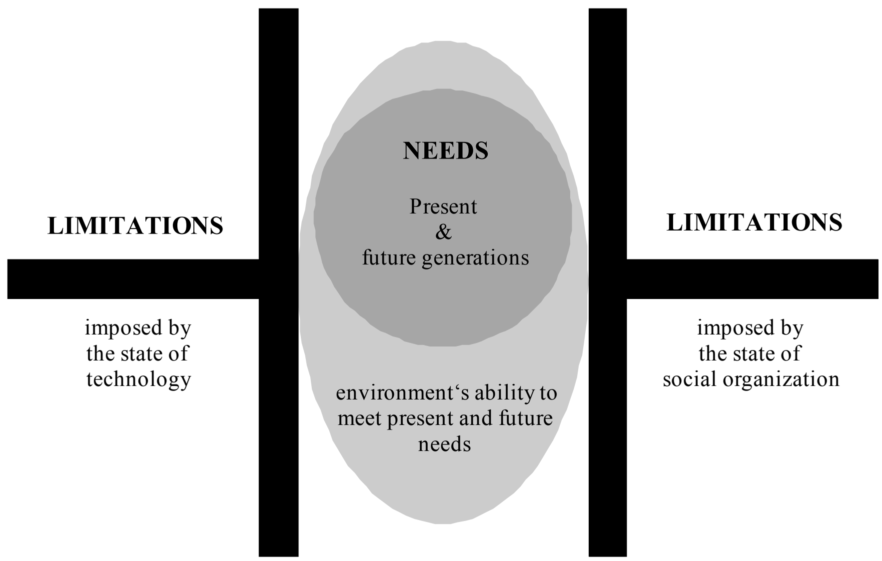
"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and
- the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs."

When comparing the "two key concepts" with the current discussion, it is amazing to see how little attention has been given to "needs" in the context of sustainable development. According to the definition, needs are not exclusively restricted to the world's poor. This means this part of the key concept is universally applicable. Another interesting result of the analysis is that "limitations" does not mean the same as "limits," e.g., like the term is used in the well known three editions of “Limits to growth” (Meadows, Meadows & Randers 1972, 1992, 2004). “Limitations” in the meaning of Figure 1 only indirectly refer to physical limits of the nature itself. The focus of the Brundtland definition is the environment’s ability to meet present and future needs. This ability is restricted by limitations imposed by technology and social organization *and* the environment’s limits itself. These limits are not mentioned in the Brundtland definition, but they belong to the prerequisites of the report. In a nutshell, “limitations” refer to human capabilities (technology, social organization) while “limits” refer to physical environmental limits. To meet the needs of present and future generations, this is what can be done by humans:

- not much about the limits but much about their determination and consideration,
- stay within the limits by enhancing the state of technology and the social organization.

Figure 1. Keywords of Brundtland-Definition for Sustainable Development



What are the consequences of this analysis of the basics of sustainable development for “sustainable building” as part of it? First of all, the main characteristics, and thus, demands are inherited from sustainable development:

- To know the limits
- To stay within the limits.
- To meet the needs.

Surprisingly, few scientists dare to quantify or not even qualify environmental limits. But how can we evaluate being within the limits without at least having a rough idea where they are? Recently, Swiss researchers attempted to determine the limits for buildings. The steps were defined as follows (Haas 2002, Zimmermann 2005, Koschenz & Pfeiffer 2005):

- determine the acceptable environmental load for sustainable development worldwide and for the nation or region (e.g., Europe, USA);

- determine the acceptable share of the activity field "building and habitation" as a whole for the nation (This share is derived from the total monetary household expenditures for this activity field, as this indirectly reflects the consumers' evaluation of their corresponding needs. For Switzerland, e.g., the share is approximately 23% (excluding the furniture etc.).)
- distribute the share to single dwelling units. Without going into the details of the interim steps, the final result (average of *all* residential buildings) is presented in Table 1:

Table 1. Key Figures on Sustainable Limits for Residential Energy Consumption

Energetic purpose	Final energy Switzerland 1990 [kWh/m2a]	Final energy Sustainable level [kWh/m2a]	Primary energy Sustainable level [kWh/m2a]
Heat (Space heat & DHW)	175	26	40
Household Electricity	38	15	56
Embodied energy	27	23	43
TOTAL	240	64	139

Similar to Zimmermann 2005

It is evident that residential buildings in industrialized countries exceed the sustainable limit by far. In Germany, the energy standards for new and retrofitted residential buildings are laid down in the "energy saving ordinance". Worldwide, this is one of the most demanding standards: for *new* buildings, between about 70 kWh/m^{2}a and 150 kWh/m^{2}a primary energy consumption for heating (space heat and DHW) are required as upper limits; for *existing* buildings having undergone a *major* retrofit, a supplement of 40% is granted, which results in 100 kWh/m^{2}a to 210 kWh/m^{2}a. The lower end of this range is connected with huge multifamily buildings, while the upper end is connected with single-family buildings with electric DHW heating. This means that even current *new* German buildings (in cases where they just meet the standard), exceed the sustainable limits of Table 1 (last column) by 75% to 275%. For refurbished buildings, this range is 150% to more than 400%! This result is a most important fact, which usually is overlooked when discussing "green" buildings. Almost none of them are "*green enough*". The highest priority for action clearly is energy consumption for heat: a drastic rise in energy efficiency—on average more than 80%—is needed. According to Table 1, using green materials alone (embodied energy) is definitely not what makes a building compatible with sustainability.

But which building standard matches these requirements? In Europe, the best practice for new buildings is the so called "Passive House Standard". Some key figures are as follows (all values calculated for treated floor area): 10 W/m^2 maximum power for space heat, 15 kWh/m^{2}a of space heat demand (useful energy), 120 kWh/m^{2}a of primary energy demand (as the sum of space heat, DHW *and* electricity) (Schnieders & Hermelink, 2006). Table 1 suggests 96 kWh/m^{2}a (40 kWh/m^{2}a + 56 kWh/m^{2}a) of primary energy for heat and electricity, which means, even the best practice, supplied by an average Western European energy mix, does not completely meet the requirements for sustainability! But it is very close. Minimal changes in the supply structure like supply of solar thermal heat for DHW or more efficient electricity generation would lead to staying below the limit. Conclusion: in order to be considered a building compatible with sustainability, a *new* building has to match the Passive House Standard.

From this result, we can derive what we should do with *existing* buildings to enable them to reach a sustainable level. Table 1 shows the proposed primary energy distribution to space heat/DHW, electricity, and embodied energy in a *new* building, compatible with sustainability. It is not an easy task to reach a similar total in a retrofit situation. In any case, the distribution will differ from a new building: because of indelible heat bridges, generally the space heat consumption will be higher whereas the primary energy, embodied in the materials necessary for retrofit, will be less than for new buildings. From a strictly environmental point of view, the resulting optimisation can be summarized by the following deprecated question:

"Which is the better option?

- *RETROFIT*: To do a retrofit, matching the total sustainable limit of Table 1 (final column) or
- *REBUILD*: To tear down the old building and build a new one (Passive House Standard)?"

Another Swiss study (Ott et al. 2002) hints to "*REBUILD*" as the preferred option!

Case Study SOLANOVA: Retrofit as Preferred Option

Determining Target Values for Energy Consumption in Retrofit

From Table 1, we know the total limit and its distribution for a *new* building. As already mentioned, from an environmental point of view, in a retrofit situation we also have to stay below this total limit, to make *RETROFIT* a viable option. Compared to *REBUILD* the distribution will differ: Embodied energy will be saved and may be compensated by higher space heat consumption. In SOLANOVA, in-depth life-cycle assessment (LCA) has been done for the demo building to learn about this compensation and to derive the target space heat consumption.

Table 2. Calculation of Target Space Heat Consumption for SOLANOVA

	[1] Embodied primary energy *RETROFIT* [MWh]	[2] Embodied primary energy *REBUILD* [MWh]	[3] Period of examination [a]	[4] Max. *additional* annual primary energy [kWh/m^{2}a]	[5] Max. *additional* annual useful energy for space heat [kWh/m^{2}a]	[6] Target value: annual useful energy for space heat [kWh/m2a]
Alternative 1	300	2400	20	40	32	47
Alternative 2	600	2400	20	34	27	42
Alternative 3	600	1800	20	23	18	33
Alternative 4	300	2400	40	20	16	31
Alternative 5	600	2400	40	17	14	29
Alternative 6	600	1800	40	11	9	24

Table 2 shows a sensitivity analysis that results in a range for the target space heat consumption. For the calculation of the embodied energy, that would be saved by realizing *RETROFIT* instead of *REBUILD*,

- First, we have to calculate the embodied primary energy that would be added to the existing building in the *RETROFIT* case. [1] The calculation yielded 600 MWh. A variation is 300 MWh, to see the effect of "greener" materials on the allowable space heat demand.

- Second, we have to calculate the embodied primary energy for tearing down the old building and building a new one at the Passive House Standard, which would occur in the *REBUILD* case. [2] In fact, we calculated the erection of the existing building in the 1970s with 1,800 MWh. This number should also be a good value for *REBUILD*. In order to take into consideration uncertainties as to the primary energy input for tearing down the building, a variation is done with 2,400 MWh.
- Third, we have to determine the number of years of the examination period [3]. This is important, as in the calculations for columns [4], [5] and [6] the *difference* between the embodied energies of *RETROFIT* and *REBUILD* is evenly distributed to this number of years to make it comparable with the annual consumptions.
- If *RETROFIT* is to be the preferred option, its *additional* annual input for primary energy for space heat compared to *REBUILD* must be smaller than the *additional* annual input for embodied primary energy for *REBUILD* compared to *RETROFIT* [4]*:*
  [4] = ([2] – [1]) / ([3] * 2650 m^2 treated floor area)
- To proceed from maximum *additional* primary energy to the maximum *additional* useful energy, we need an efficiency for this conversion. In the example it is an optimistic 80%.
  [5] = 80% * [4]
- The final target is a value for the maximum allowed space heat consumption [useful heat] to make *RETROFIT* at least equal to *REBUILD*. In this case, *REBUILD* would meet the Passive House Standard.
  [6] = 15 kWh/m^2a + [5].

Conclusion from Table 2: taking sustainability seriously, a space heat consumption between 25 and 40 kWh/m^2a should be aimed at in retrofit. This is drastically lower than what is usually connected with green buildings of any shade, especially in retrofit. Only if this level is not feasible, *REBUILD* or an increasing share of renewable energy on the supply side should seriously be considered; in the end, the decisive number is the primary energy consumption.

These are the basics that led to the measures taken in the SOLANOVA project, in which we combine a retrofit with passive house philosophy and solar thermal support for DHW. The target value for space heat demand after retrofit is between 30 kWh/m^2a and 40 kWh/m^2a compared to 220 kWh/m^2a before retrofit. The solar share for DHW is to be approximately 50%.

Technical Parameters of SOLANOVA: Before and After

A detailed overview about the SOLANOVA project was given by the author who initiated and manages the project (Hermelink 2005). Therefore, only a rough overview is given here for the reader. On January 1, 2003, the combined research and demonstration project SOLANOVA (Solar-supported, integrated eco-efficient renovation of large residential buildings and heat-supply-systems) started. SOLANOVA is supported by the Fifth Framework Programme of the European Commission.

In the Hungarian town Dunaújváros, a building of the 1970s, made of industrially prefab concrete panels, with shops in the ground floor (300 m^2) and seven living floors including 42 flats (2350 m^2), was refurbished by applying a „Factor 10" approach: the space heat demand of the flats is reduced by more than 80%. Being the first EC project of this type in Eastern Europe, SOLANOVA serves as best practice example for the proper implementation of the European

Union's Energy Performance of Buildings Directive. All flats in the condominium are owner occupied and all retrofit measures had to be implemented in the occupied state.

The biggest challenge of the SOLANOVA project is to transfer the know-how from new passive houses to the case of obsolete panel buildings. Moreover, the demo building is situated in Hungary, where no such standards exist like in Germany, Austria or Switzerland. Thus, neither architects nor builders have practical experience with the Passive House Standard.

To achieve the target value, this is what finally has been implemented during retrofit:

- decentralized ventilation units with 82% real heat recovery, one ventilation unit per flat.
- 75 m^2 solar thermal area *as* canopy, providing not only heat but also shade for the shops in the ground floor.
- new heating system with radiators and thermostatic valves that is easy for the dwellers to use and understand.
- Insulation of the cellar ceiling: 10 cm polystyrene.
- Roof insulation: 30 cm with extensive green roof.
- Wall insulation: 16 cm polystyrene.
- Apartment space Windows:
  South and West: 2+1 glazing with integrated venetian blinds for shading,
  U_W = 1.1 W/m^2K, g-value = 0.55 or 0.10 with fully closed blinds respectively.
  North: double-glazing, U_W = 1.4 W/m^2K.
- Retail space windows: U_W = 1.4 W/m^2K.

Most of these measures had never been implemented in Hungary before, not even as singular measures. Table 3 gives an overview about the planned savings and their origin.

Table 3. Characteristic Values (Initial Measured Values Versus Planned Values):

	Before		After		Savings absolute		Savings %	
	Final Energy	**Primary Energy**	**Final Energy**	**Primary Energy**	**Final Energy**	**Primary Energy**	**Final Energy**	**Primary Energy**
Space heating [kWh/m2a]	220,0	310,1	29,4	41,4	190,6	268,7	87%	87%
DHW-total incl. solar and water saving equipment [kWh/m2a]	49,0	69,1	12,8	18,1	36,2	51,0	74%	74%
Total heat [kWh/m2a]	269,0	379,3	42,2	59,5	226,8	319,7	84%	84%

Meeting the Dwellers' Needs in SOLANOVA

Now that we have gained a better understanding of environmental limits and what is required to stay within these limits, it must be remembered that these are necessary but insufficient conditions for sustainable development and sustainable building. What is missing is meeting the needs. In our case the most important group, whose needs have to be satisfied, are the building occupants. There is some debate about precisely defining the difference between "need" and "want". Real needs are quite difficult to find out. Quite often, they are explicitly unknown to building occupants when asked about it. In practice, we have to take the expressed wants and the reported and observed behaviour as proxies for the needs.

Figure 2. SOLANOVA Demo Building Before and After Retrofit, Southern View

From an engineer's point of view, it may be great to have built an ultra-low-energy building, but what if it only turns into a zero-energy building after the last frustrated dweller has moved out?. To avoid such results, in SOLANOVA, we integrated several measures to learn about the needs, wants and habits of the dwellers from the beginning. This procedure was meant to result in a retrofit-design, largely matching the dwellers' expectations, wants and habits to reach the target energy consumption of less than 40 kWh/m^2a.

In summary, the focus on these human aspects has two sides:

- A project only can be considered successful when the participants, i.e., the occupants, consider the project to be successful. Low energy consumption alone is not sufficient. Thus, the occupants' wishes regarding their "technical environment" which will be manipulated by the retrofit must be known to avoid a mismatch after renovation.
- Without doubt, how occupants behave and use the system is the most decisive factor that explains the difference between measured consumption and calculated demand. By experience, highly ambitious projects far too often ended up with quite a big unfavorable difference. To develop strategies aimed at minimizing this difference by "optimizing" the behavior, the physical parameters having the highest correlation with the energy consumption must be known as well as the behaviors which influence these parameters. Quite often, current behaviors do not match the "optimal" behavior after retrofit, which makes behavioral changes an indispensable part of integrated approaches to exploit the available potential as far as possible.

Integration of Survey Results into Design

To avoid these traps in the design of the SOLANOVA project, the users' opinions are integrated in the development of the various concepts for renovation. Three waves of structured personal interviews are part of the project: one before retrofit and two more after retrofit (after the first heating period and after the first summer). Because the renovation was only completed in October 2005, results from the interviews are only available from the first wave in April 2003, which was only three months after the project's start. The second survey was conducted in March 2006; results are not yet available.

To get a sound baseline, not only the dwellers of the demo building were personally interviewed with the help of structured questionnaires, but the dwellers of an identical building nearby were interviewed. In the demo building, 41 out of a maximum of 41 interviews were made (one family is occupying two flats); in the reference building, 30 out of a maximum of 42 interviews were conducted. In the following text, numbers in brackets represent the value of the reference building. Only the results *which had an impact on the design* will be presented now.

The average number of persons per flat is 2.8 (3.0). Compared to western European standards this is very high. In Germany, the corresponding value is only 2.2. In SOLANOVA, the average living area per person is only 19.2 m^2. This area is less than half of the German average, which recently exceeded 40 m^2 per person. A side effect of this occupancy density is unusual high specific internal heat gains. While an average of 2 W/m^2 can be put into heat demand calculations in Western Europe, an average of 4 W/m^2 had to be used in the SOLANOVA case. Related to the maximum heat load of about 10 W/m^2 in passive houses, this insight led to a major consequence:

- The internal gains belong to the category of so-called “unsupervised” heat sources. The higher the share of unsupervised heat, the less the ability to control the indoor temperature properly by means of thermostats. Moreover, the danger of overheating in summer increases dramatically. As a result, a very strong focus was put on the utmost reduction of sources of unsupervised heat: distribution pipes for domestic hot water and space heating. This was very hard to pass on to the local team, whose “intuition” had been trained by prodigal buildings where these effects are irrelevant.

To preserve the things that people like and to know the things that should be considered for improvement, four open questions were asked (implying a very high effort for data evaluation). Generally the results opened the eyes of several team-members, that nonenergy aspects generally enjoy the highest priority of the dwellers and have to be addressed at least with equivalent intensity:

- What do you like best about your flat?
- What would you like to have different in your flat?
- What do you like best about your building?
- What would you like to have different in your building?

The *favorite characteristics* of the flat and of the building. The mentioning of “lightness” and “quiet” for the flat as well as only seven floors and the bright stairwell for the building contradicted some of the designers' early ideas. Consequently, all these ideas were cancelled:

- *Reduction of window sizes* in the flats and in the stairwell, in order to reduce heat losses and cost and to gain some additional space for shelves and wardrobes. Without having asked the dwellers, this seemed reasonable, as all windows in the flats and in the stairwell exceed the size required by building regulations. In the case of a new building, these ideas certainly would have been implemented. In our case, the dwellers were accustomed to these sizes and to the resulting lightness. All dwellers would have had to agree – an impossible mission.
- *Addition of an 8th floor:* except for the absence of financing, this would have contradicted the satisfaction with seven floors and it certainly would have increased the noise.
- *Ventilation solutions that contributed to noise pollution*.

***Things that could be different* regarding flat and building.** A bigger bathroom, airtight windows and doors, better heating system, better noise protection, more color, a balcony, better windows, waterproof roof, better insulation and better or safer entrance doors were mentioned most often. Within the budget of SOLANOVA, it was not possible to change the segmentation of the flats or to build balconies. For the retrofit, the conclusion was drawn that even the slightest decrease of available space had to be avoided and a more colorful look and some recreation area should be generated. All other aspects would be solved "automatically" by the new components like windows, doors, and wall and roof insulation. A space-saving solution for the mechanical ventilation was found to be within a new, very shallow suspended ceiling, the unit having a height of only 20 cm. A balcony surrogate with recreational value could be established by building an extensive green roof. Before, the flat roof could not be used at all.

Another aspect which turned out to be a real problem for the dwellers was air quality. 92% (77%) shared the opinion that something is wrong with the air quality. Above all "dust," "Malodorousness," and "Dry air" were the reasons for this unexpected result. The main sources are various factories in the neighborhood. This result was a strong argument for ventilation systems enabling filtration of the incoming air. After installing mechanical ventilation, the rationale for opening the windows decreases. Above it is advisable to keep the windows shut for highest possible summer and winter comfort and maximum energy efficiency performance. The "keep out dust" argument might be very valuable in achieving this inevitable change of habits.

Probably the most valuable results was satisfaction with indoor temperatures, cf. Table 4.

Table 4. Satisfaction with Indoor Air Temperature in the Demo Building [%]

	1 Very Dissatisfied	2	3	4	5 Very satisfied
Demo building winter	8,1	16,2	32,4	29,7	13,5
Demo building summer	35,1	27,0	27,0	8,1	2,7

In winter, there are more "satisfied" than "dissatisfied" people, whereas in summer, much more people are on the "dissatisfied" than on the "satisfied" side: 62.1% versus 10.8%.

For the concept phase of the retrofit, this was completely new information. Usually, the focus is on winter because of the energy used in winter. In this case, it became obvious that planning for comfortable conditions in summer needed even more weight than providing for ultra-low-energy demand in winter. In spite of a higher cost, therefore, the design team insisted on very efficient Venetian blinds within the windows. A special device for keeping the windows securely open for sufficient natural ventilation during summer nights was developed.

Integration of Survey Results into Teaching Strategies

Passive technical devices alone won't help to achieve a comfortable indoor climate in summer, unless the dwellers use them actively. The most effective behavior would be to use the Venetian blinds resolutely, to open the windows at night and to close them in the morning. To develop suitable strategies to foster such behavior, it is indispensable to know the current behavior, which had to be restricted to window opening due to absence of Venetian blinds. As to the window opening a new instrument, defined here as "window opening maps" have been applied to visualize the results of a ten-day observation where photos had been taken in the *early* morning, at noon, and in the evening each day. To get an immediate impression, the well known traffic-light colors have been used (Figure 3). Green: permanently closed; yellow: sometimes opened; orange: often opened; red: permanently opened.

Figure 3. Observed Window Opening in Summer, Western Facade, in the Morning, at Noon and in the Evening (from Left to Right)

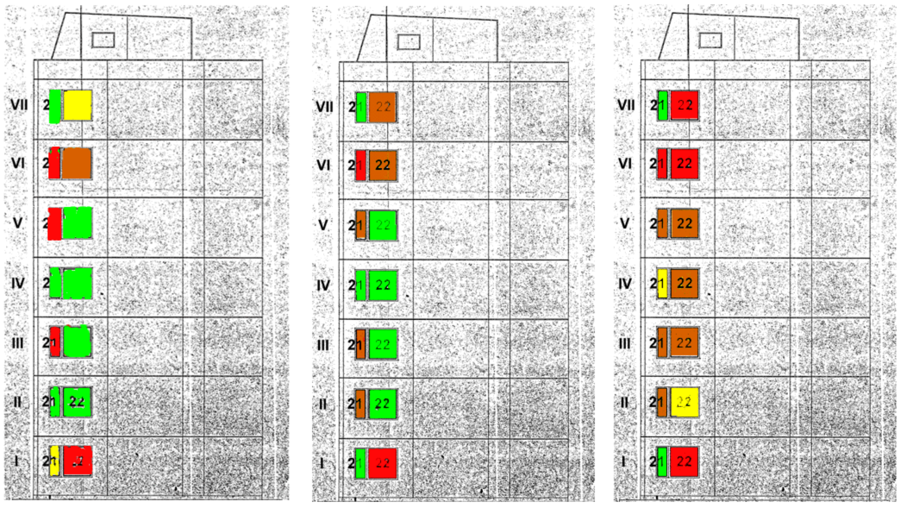


Figure 3 shows the result of the western façade of the summer survey: from the left to the right the day passes from early morning, via noon till evening. The best behavior would have been to open the windows during night till early morning (where outdoor temperature reaches its minimum) and to shut them before noon. The opposite can be seen at once: the ventilation intensity *grows* during day and reaches its climax in the evening, when the sun is shining directly on the western façade. Thus, the evaluation of these data gave a clear hint that a teaching focus has to be on effective summer ventilation in order to exploit the full comfort potential.

First Results and Conclusion

The first winter after retrofit is over. The measured space heat consumption was reduced by more than 80%; it remained below 40 kWh/m^{2}a. For this type of building this is probably a new world record. Considering the following points this is remarkable:

- The *average* indoor air temperature was between 24°C and 25°C! This is approximately 3-4 Kelvin more than in comparable new ultra-low-energy buildings—but quite the same as before retrofit. After retrofit the space heat demand increases by 12-15% per Kelvin! By this example, we see the dwellers impede comfort theory, which forecasts a temperature drop resulting from higher surface temperatures (walls, windows) and elimination of any draught. Next winter will provide evidence if the dwellers change their habits or not.
- The ventilation system was adjusted badly, which was changed only by the end of the winter.

It is urgently recommended to refocus on the core meaning of sustainable development. Translated to buildings this implies a double challenge: satisfy occupants within environmental limits! These limits are drastically lower than current standards. An efficiency revolution is badly needed to turn us on a path toward truly sustainable buildings. As occupant satisfaction after the first winter is very high, SOLANOVA demonstrates that it is feasible to master this double challenge. Last but not least SOLANOVA gives the lie to all prejudices regarding "cost-efficiency" of such efforts: a total investment of only net 250 EUR per m^2 treated floor area was sufficient to get us on the right track.

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