EAWAG FORUM CHRIESBACH - A STEP TOWARDS THE 2000-WATT SOCIETY

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Summary

Eawag, the Swiss Federal Institute of Aquatic Science and Technology in Dübendorf is the internationally active aquatic research institute of the ETH domain. It is committed to the ecological, economical, and socially responsible management of water. In the spirit of scientific advancement, the competition brief for Eawag's new head office, Forum Chriesbach, called for the exemplary and progressive management of all resources and a visionary concept regarding ecological sustainability. The building was constructed in the years 2004 to 2006 and has been in use since June 2006. It meets the requirements of the 2000-watt society, a vision put forward by scientists of the ETH domain, which calls for freezing the worldwide energy consumption at the present level of about 2000 Watts/capita. With its approximately 340 MJ/m^{2}a or 600 Watts/capita, Forum Chriesbach proves not only that the vision is practicable for office buildings but also that this can be achieved by using conventional materials and existing technologies. The building meets high standards of functionality, aesthetics and comfort. Creating such a building, however, is possible only with a team of highly qualified architects, planners, specialists and, of course, dedicated clients. In order to achieve sustainability before fossil energy resources are depleted entirely and climate change effects become too disastrous, more such teams must become active: immediately and forcefully.

1. The Idea of a 2000-Watt Society

World primary energy consumption in the year 2005 amounted to about 123,557,142 GWh, supplied namely by coal (27.8%), oil (36.3%), gas (23.6%), nuclear energy (5.9%) and hydropower (6.3%) (BP 2007). With a world population of 6,514,751,000 people (UN 2006), this annual energy consumption is equivalent to a continuous power per capita of 2,165 Watts. The worldwide consumption of energy is still increasing by about 2-3% annually (Fig. 1). Given the fact that fossil energy resources are limited and their usage environmentally disastrous, scientists from the ETH domain have formulated the vision to stabilize energy consumption at the average level of 2,000 Watts per capita (= 17,520 kWh per year). While the USA uses more than 10,000 Watts per capita, developing and emerging market countries like Pakistan or China still consume less than 2,000 Watts per capita with, however, the trend tending upwards. Switzerland crossed the 2,000 Watt line in the 50s and at present every Swiss consumes more than 5,000 Watts (Fig. 2). The vision stipulates that the transformation should be possible without a loss in the standard of living.

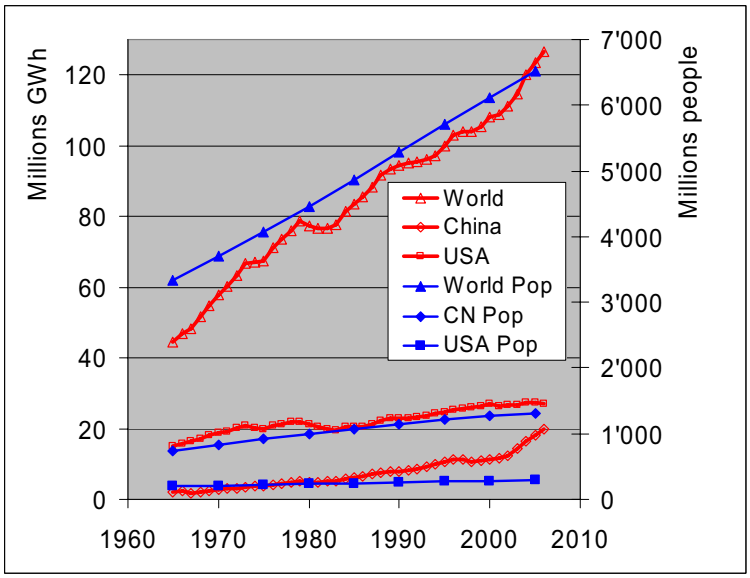

Figure 1 *Development of primary energy production (BP 2006) and of population (United Nations 2006) within the past 40 years. The USA and China, with a population of about 25% of the world, consume 37% of the energy.*

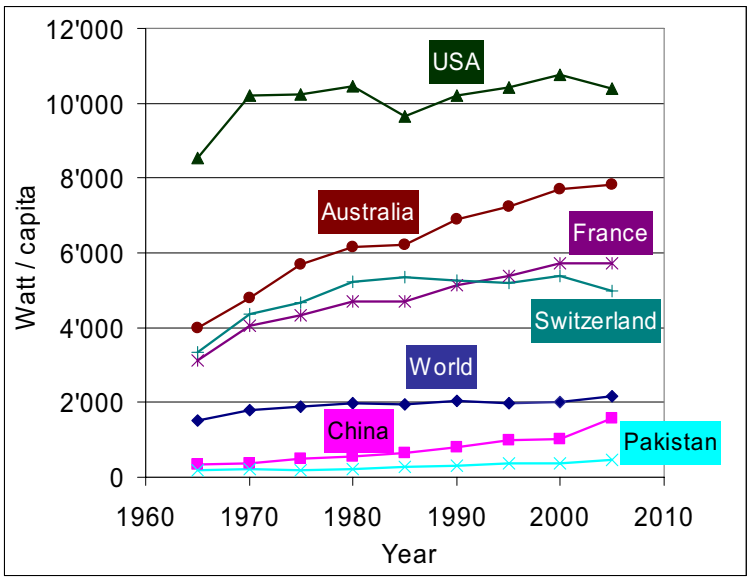

Figure 2 *Development of primary energy consumption per capita. From 1980 until 2000 the world average power demand remained relatively constant at a level of about 2000 Watts/capita, but has started rising again since then. While China has developed towards the 2000 Watt line, the USA and other industrialized countries have managed to slightly decrease their consumption. Data sources: BP 2006 and United Nations 2006.*

One fourth of the 323,897 GWh of primary energy used in Switzerland in the year 2006 is 'lost' during conversion to final energy (mainly nuclear energy to electricity) and the rest is used as shown in Table 1. We assume that about $^1/_3$ of primary energy, i.e. 600-700 Watts/capita can be used for work space. Koschenz and Pfeiffer (2005) estimate that in Switzerland about half of the total primary energy goes into construction and building operations and thereof 780 Watts/capita is used in office work space and 320 Watts/capita in industry. The grey energy imported with products is not taken into account in this data. Thus, if an office or industry building consumes less than about 700 Watts/capita, it can be considered as compatible with the 2000 Watt-society.

Table 1 Final energy usage in Switzerland 2006 (Population 7,557,000)

	GWh/a	%
Households	72,186	29.3
Industry	49,264	20.0
Services	40,217	16.3
Traffic	81,119	32.9
Agriculture	3,972	1.6
Total	246,758	100.0

2. The Forum Chriesbach Building

2.1 Eawag's Competition Brief for the Building

Eawag, the Swiss Federal Institute of Aquatic Science and Technology, is committed to the sustainable use of water. With its more than 400 employees it does research, teaching and consulting to further this aim both in Switzerland and globally, thereby bridging the gap between basic science and practice. It is located on a campus in Dübendorf together with its sister institute, Empa[1], which is concerned with materials and construction research. The new building is Eawag's head quarters, comprising office space for 150 employees, a lecture hall for 140 people as well as seminar and conference rooms for about 160 people. The room program also includes the new joint library of Eawag and Empa, a staff canteen, and a foyer for exhibitions and conferences.

Eawag and Empa, together with BaFA - their construction agent, insisted that their commitment to sustainability had to be realized in an exemplary and progressive form. The structural and technical measures had to be innovative and, indeed, exceed current technological standards. All resources had to be handled frugally - energy, materials, land and funds. At least $^1/_3$ of the electricity requirements must be covered by the building's own photovoltaic system. Room temperatures must not drop below 19°C and not exceed 26°C. Rainwater had to be used for toilet flushing and urine had to be collected separately for research purposes.

2.2 The Project Winner

In January 2003 the project 'Vision' of Bob Gysin + Partner BGP had been selected by the jury out of 6 projects, and in December 2003 the Swiss Parliament granted 32.72 million Swiss Francs to construct the building. In July 2004 construction started and in June 2006 the keys were handed over to Eawag.

Table 2 Technical data of Forum Chriesbach.

Building volume	38,615	m^3
Floor area	8,533	m^2
Energy reference area (weighted)	11,170	m^2
Roof area (building footprint)	1,886	m^2
Photovoltaic panel area (77 kWp)	459	m^2
Evacuated heat pipe solar collectors	50	m^2
Construction costs	30	Mio CHF

[1] The domain of the Swiss Federal institutes of Technology (ETH domain) consists of the two national technical Universities, ETH Zürich and EPF Lausanne, and the four research institutes Eawag, Empa, PSI, and WSL.

Figure 3 *Eawag Forum Chriesbach: Characteristic facade with blue louvers, solar energy equipment on roof and air inlet of thermal register (behind tree on the NE - side of the building. Photo, A. Bryner Eawag 2. March 2007).*

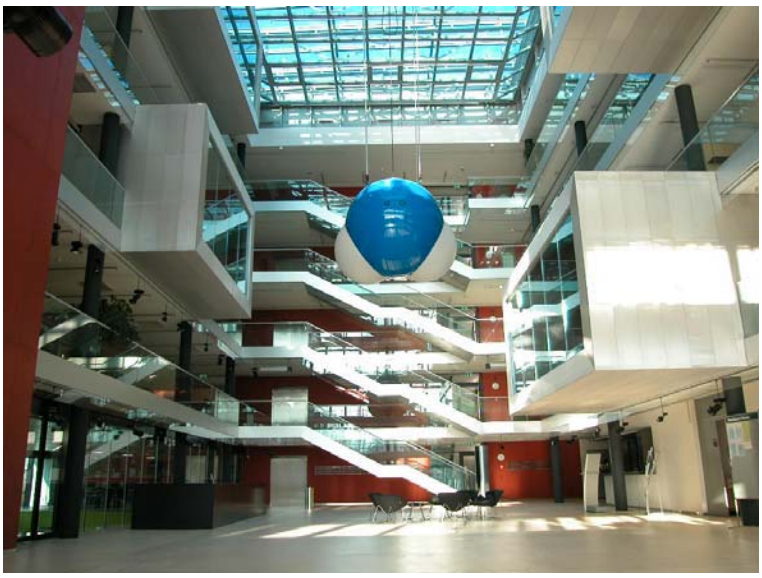

Figure 4 *Eawag Forum Chriesbach: The impressive atrium with conference rooms jutting out into the void and the model of a water molecule for projections with two beamers inside it (Photo H. Güttinger, 30. January 2007).*

The building has no active heating or cooling system except for a few radiators in the ground floor and cooling ceilings in the conference and seminar rooms. The energy concept relies on conserving the heat generated inside in winter and on preventing solar radiation energy from penetrating in summer. The minimized surface area of the compact building and its extremely tight insulation keep the heat 'losses' of people (~70 Watts), personal computers (~100 Watts) and light (~100 Watts) inside. These internal energy sources together with heat recovery from used air, waste heat from kitchen appliances and computer servers provide enough heat to keep the building at comfortable temperatures most of the time. The import of energy from the district network is therefore minimal and amounts to only some 31 MWh/a primary energy (~3,000 liters of oil), a quantity that is normally used for a conventional one-family house. Fig. 5 illustrates the

potential of heat and cooling energy reductions in Forum Chriesbach as compared to conventional buildings and the 'Minergie' standards. There are clear limits to the reduction of electricity and grey energy demands; these must be produced with renewable energies to attain sustainability. However, grey energy can be at least partly controlled by clever materials choices and by maximizing the lifespan of constructions.

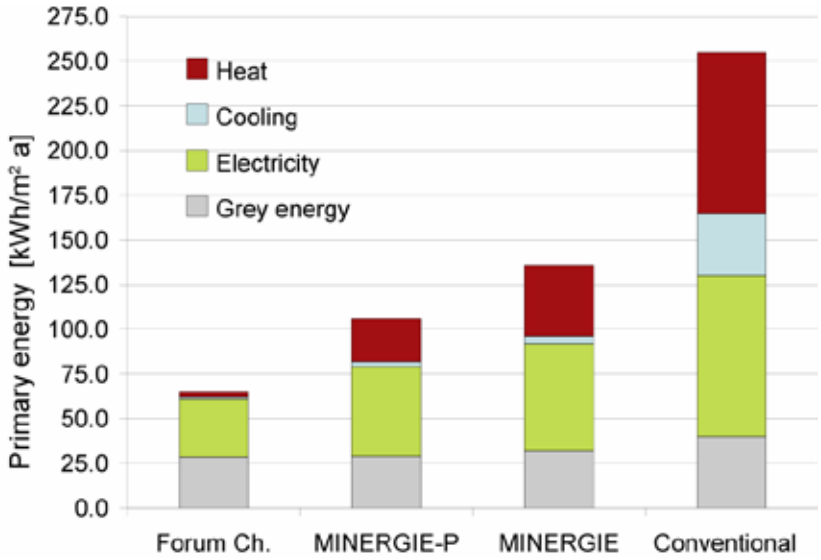

Figure 5 Energy demand in Forum Chriesbach as compared to a similar building designed and constructed without concern for sustainability (conventional) or according to the Swiss standards Minergie or Minergie-P. Heat and cooling demands can be reduced relatively easily to almost null while electricity and grey energy for construction and materials remain significant.

Another special feature of Forum Chriesbach is its thermal register, a collection of 78 pipes 20 m long and buried in the soil in the northeast of the building (see Fig. 3). Fresh air enters the building through this register and is thus cooled in summer and warmed up in winter by advective heat exchange with the soil, which has temperatures fluctuating at around 10°C. All the computer servers for the whole of Eawag are installed in the Forum Chriesbach and are cooled mainly by air. During winter this warmed up air is also used to heat the fresh incoming air, which is then distributed into the comfort zone, i.e. into the office, conference and seminar rooms, the library and the restaurant.

The most striking feature of the building is its 1,232 blue glass louvers. They are fixed on the fire egress scaffolding around the building. Their main function is shadowing and to that aim they rotate in 5° movements about their axis, following the daily track of the sun, all panes of each facade in synchrony. However, when outside temperatures rise above 30°C, shadowing by the louvers and cooling in the thermal register are not sufficient to keep room temperature below 26°C as required. Compounding this problem, internal heat sources from men and computers also emit their extra heat in summer. To overcome these difficulties a night cooling system has been installed: when outside temperatures drop below inside temperatures during the night, the hopper windows in each room and in the atrium roof automatically open, allowing convection driven air circulation. The intruding fresh air then cools the concrete mass of the building and thus the inside temperatures can be kept at comfortable levels of 24-26°C the whole day long, even when it is very hot outside.

2.3 Two Years' Experience in Forum Chriesbach

In June 2006 Eawag employees began to occupy their new space in Forum Chriesbach and the theoretical concepts had to prove their everyday fitness. A two-year optimization phase was started to fix everything that has not been properly designed, constructed or installed, and to adjust the control system in accordance with the real behavior of the building and its inhabitants.

To the great relief of the architects and planners, of the directorate of Eawag, and of those working in the building, things have gone well: summer temperatures have remained at perfect levels between 24°C and 26°C in hot July and August. Spring and autumn temperatures were too low but could be adjusted, and winter temperatures did not drop below 19°C - normally. It has turned out that not all of the office spaces are occupied full time and by as many people as planned. Scientists spend part of their time in the laboratory, doing field work, attending conferences, or are lecturing at other institutes, and many of the administrative employees work part time. Additionally, some exposed rooms in the corners of the building have greater losses through the walls and less passive solar gains than projected. Also, many Eawag workers use laptops

and flat screens instead of less energy-efficient desk top models. Therefore, more heat energy had to be drawn from the district area network than planned. But, even if this extra heat remained about twice as much as projected, in absolute terms it still is very little energy. And, most importantly, there is optimization potential left because some systems still do not perform properly. One of these is the shading system in the glass roof of the atrium, whose blinds too often shut in winter, not allowing passive solar gains. Another is the heat storage tank, which does not get all the available solar energy but too quickly recharges from the district network; its control system has yet to be adjusted. We are confident, however, that once the remaining problems have been ironed out the building will perform better and the number of Eawag people working in it who are content ,even in cold winters, will increase. In summer everyone is happy with the building's performance.

Table 3 Energy consumption details in Forum Chriesbach. The relative values have been calculated using the height weighted energy reference area of 11,170 m^2 and the average number of people working in the Forum Chriesbach, some 200 people in total. (150 office workplaces and 50 people using library, restaurant and seminar rooms). The estimations of elevated energy usage (last column) are based on extrapolations from measurements in the months July to December 2007.

	Final energy (plan)		**Primary energy (plan)**		**final energy (real)**
	MWh/a	kWh/m2 a	MWh/a	W/cap	MWh/a (Estimations)
Electricity without servers	181	16.2	543	309.9	190 - 210
Electricity servers (15.5 kW)	136	12.2	408	232.5	130 - 140
Heat from network	24	2.1	31	17.7	30 - 50
Heat export to network	-6	-0.5	-8	-4.3	-10 - 0
Cooling from network	22	1.9	24	13.5	20 - 45
PV-system (77 kWp)	60	5.4	180	102.7	60 - 65
Solar collectors	24	2.2	31	17.9	15 - 30
Grey energy			319	182.2	(37.6 years life span)

Electricity demand has been above projections as well. Luckily enough, the performance of the solar panels has also been above expectations. Several causes have been identified for the elevated electricity consumption: about twice as many people as projected take their meals in the staff canteen and office lights have to be turned on longer because of the shading by the louvers, which have not yet been optimally adjusted. The most extraordinary revelation was that the hopper windows' motors were turned on permanently and consumed an extra 20 MWh/a - about $^1/_3$ of solar production! These have been fixed meanwhile.

In Eawag Forum Chriesbach an extensive monitoring system with several thousand data points has been installed, but not every sensor and energy meter has worked well from the beginning. We still do not have reliable energy usage data for a whole year but we believe that most of the problems observed can be solved and that the real energy consumption will be at levels very close to those projected.

3. Conclusions

The two years of working in Forum Chriesbach illustrate that the main promises concerning its sustainability have been fulfilled. The buildings performance meets the requirements of a 2000-watt society, namely the 600-700 Watts/capita energy demand. With a demand of 340 MJ/m2a it also meets the 2000-watt society requirements for office buildings, which have been stipulated to be 480 MJ/m2a (including 140 MJ/m2a for mobility, SIA 2006). Fig. 6 shows how much energy per person is used in Forum Chriesbach for construction, cooling, heating, electricity and computer servers. With heating and cooling minimized, it is particularly electrical energy that remains to be produced sustainably and used efficiently. The optimization of usage and performance of computer servers is of particular importance and must be given high priority. Grey energy can be controlled, at least partially, by careful choices of materials and by taking into account the life spans of buildings. With 572 CHF/m3 the construction costs of Forum Chriesbach has not been significantly different to those of comparable buildings. Intelligently designed buildings are not only affordable and can be energy efficient, they can also provide more comfort than conventional buildings, as summer working conditions in Forum Chriesbach demonstrate.

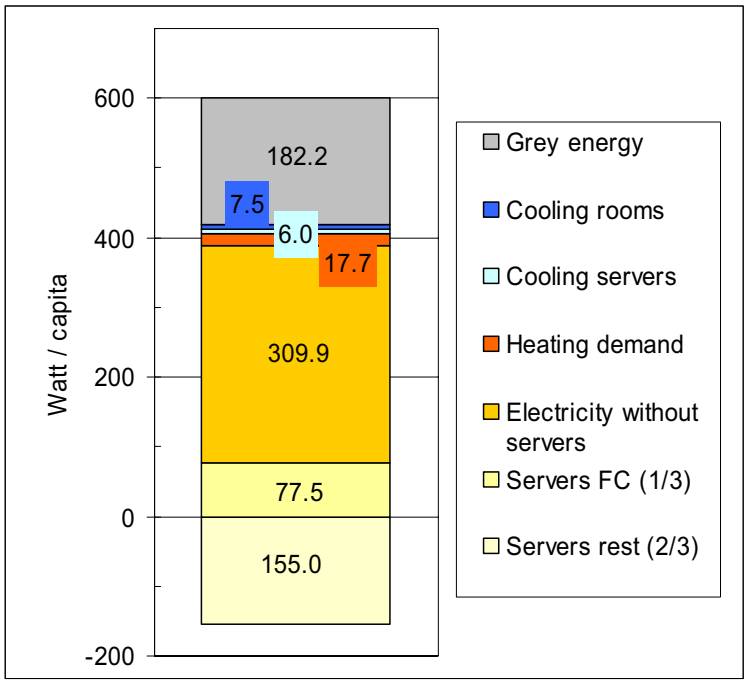

Figure 6 *Per capita primary energy consumption of Forum Chriesbach for the different usages (see Table 3 for absolute values).The calculations have been performed assuming that 200 people work in the building. Because the computer servers installed are for the whole of Eawag, only $^1/_3$ of their total electricity demand has been allocated to those employees in Forum Chriesbach. Thus the energy demand per capita amounts to about 600 Watts.*

There are some prerequisites to the realization of such a building. Daniel Wentz (2007) has put these down in his beautifully written book about Forum Chriesbach:

It is not the central architectural concept that is new (super-insulated passive solar buildings have existed for decades). The significant distinction here is how the people behind the project worked together with a shared sense of responsibility, commitment, and purpose. Showing social, environmental, and scientific engagement, the client prescribed standards for the design that go far beyond the norm, beyond any building code, and expressly sought to test the limits of what is possible. The design team shares the client's philosophy, and delivered the necessary background and know-how, working together with the client, users, and contractors throughout the five-year duration of the project. ... The lessons of Forum Chriesbach have global ramifications. The building proves that by using conventional materials and known transferable technologies, a high level of performance is not only possible, but affordable and practicable. This level is vital to a sustainable future. This building makes sense in every respect - economically, socially, ecologically, functionally, and aesthetically. In a world in which sustainability is in question, in which better ways of shaping and managing our environment must urgently be adopted, Forum Chriesbach stands as a model of how to build for the future.

The goal to stabilize energy consumption at a level of 2000 Watt/capita means that industrialized countries have to reduce their energy demand drastically while developing countries might still increase theirs. It also means that fossil fuels have to be substituted for within the next 80 years2 at the latest because they will then be exhausted. Therefore, 1.25 % of fossil fuels have to be compensated for annually and an additional 2-3% for the growth in demand. These challenges require all our creativity and effort and must be tackled as soon and as quickly as possible. Avoiding the additional negative effects of climate change, of course, would demand an even faster substitution of fossil fuel energy.

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[2] Reserves/production for oil is 40 years, for gas 63 years, and for coal 147 years, but production is still increasing by more than 2% annually (BP 2007).

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