The regenerative building: A concept of total sustainability

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Abstract. The concept of building’s sustainability is progressively evolving, from the mere issues of limiting the energy needs of the building, extends to include new areas. The long-term sustainability visions (in Switzerland the “2000 W Society” by year 2100) imply not only technological changes but above all radical changes in the human behaviour. A multidisciplinary study, carried out by SUPSI and specialists, proposes a method for determining the parameters for the design of a building by year 2100. It also shows that in order to achieve long-term sustainability goals (primary energy reduction and CO₂ emissions per capita, 2000 W and max 1 ton CO₂), alimentation can be considered as a building need. The high potential in reducing primary energy needs in this area makes possible to compensate other energy consumptions and CO₂ emissions of the building inhabitants and of the building itself. The sustainable building of the future shall therefore: - present a zero or compensated operating energy need; - present minimal energy need for construction; - allow food production (Urban Farming, Building Integrated Agriculture) through natural and regenerative agriculture (self-production); - promote and act as a shelter for local flora and fauna (regenerative); - respect the soil stratigraphy (reversible).

1. Introduction
The concept of building’s sustainability is progressively evolving, from the mere issues of limiting the energy needs of the building, it extends to include new areas. The long-term sustainability visions (in Switzerland the “2000 W Society” by year 2100 [1]) imply not only technological changes but above all radical changes in human behaviour. This vision is in line with the objectives of the Swiss Federal Council's Energy Strategy 2050 [2] and is a recognized instrument of the Swiss energy policy. In addition, land consumption and biodiversity loss are increasingly becoming important issues in Switzerland.

The present study proposes measurable values and target design parameters concerning energy and CO₂ emissions for the construction, operating energy and mobility of buildings by the year 2100. Moreover, it integrates themes such as biodiversity, reversibility and the innovative concept to consider alimentation as a building need in order to achieve long-term sustainability goals (primary energy reduction and CO₂ emissions per capita, 2000 W and max 1 ton CO₂). A concept of total sustainability is proposed.
2. Methodology

2.1. Society 2000W (Swiss long-term sustainability vision)

The 2000 W Society vision refers to a maximum per capita energy need equivalent to the consumption of 2000 W for 8,760 hours/year. Per capita consumption includes the areas of living, mobility, food, general consumption and infrastructure.

In the field of buildings’ construction, the 2000 W Society vision is translated in the technical norm SIA 2040 [3], which imposes limits on energy and CO₂ emissions for construction (grey energy), operating energy and mobility related to buildings. These limits have to be respected and operated by the end of the year 2050 (intermediate target of 3500 W per capita). Buildings, sustainable neighbourhoods and the 2000 W Areas built in Switzerland today are in line with the SIA 2040, i.e. the vision of the Society at 2000 W at 2050. The objective of the study is to provide measurable values and design parameters that are concretely applicable in the daily practice but extending the limits (kWh / m²) and (kgCO₂ / m²) from 2050 to 2100.

![Figure 1: Per capita energy power (total and not renewable) today (2005), targets for 2050 and 2100](image1)

![Figure 2: Sectors considered in the 2000 W Society concept. The objective for the year 2100 is to reduce by two thirds the maximum per capita total energy need to the consumption of 2000 W for 8,760 hours per year, which is currently around 6000 W.](image2)

The technical norm SIA 2040 imposes limits on energy and CO₂ emissions for construction (grey energy), operating energy and mobility related to buildings so that the energy performance of the
construction sector can achieve the objectives by the year 2050 (3500W per capita). The study extends the design limits at year 2100, using the same methodology as the actual norm and the 2000W Society (for housing). The value of non-renewable primary energy extended at 2100 for buildings results actually too low to be achieved in relation to what is feasible today (refer to Figure 3) [4].

An innovative approach is proposed to solve this problem. Is introduced the concept that another need is to be considered related to the building and its occupants: food. This topic is important in the way to get the goals of the achievement of the Society 2000 W. The total energy primary power today in the field of food is deduced from the global average per capita Switzerland balance according to the 2005 statistics and amounts to 1’300 W and 2.08 tons of greenhouse gases [5]. Relating these quantities to buildings and applying the reduction factors on total primary energy at 2100, the target design values were obtained at the year 2050 and 2100 (refer to columns “2100 Theoretical target” and “2100 Reachable” of Figure 3).

![Table](https://example.com/table.png)

**Figure 3:** Targeted values at 2100 in the different areas and reachable values (housing).

As can be deduced from Figure 3, the theoretical limit value of non-renewable primary energy calculated at 2100 (110 MJ / m²), is difficult to reach (evaluation according to the the SIA D0236 norm[4]) despite by providing efficient, well-insulated, low grey energy constructions, which exploit renewable energy sources (e.g. wood) in areas well served by public transport in the peri-urban area.

However, considering a personal completely vegetable diet, it is possible to obtain a value of non-renewable primary energy that is half of the limit value (98 MJ/m² vs 217 MJ/m²). Therefore, this energy and emissions savings can compensate the other needs for construction, operating energy and mobility. With this innovative approach it is possible to reach the total target value at 2100 of 327 MJ / m² (limit 327 MJ / m², obtainable 325 MJ / m²) (Figure 3 and Figure 4).

The theory introduces the innovative concept that it is possible to establish and respect the values targeted at 2100 in the areas of construction, operating energy and mobility, acting also in the context of the alimentation related to the building. Food can be considered as an energy need (with consequent emissions of greenhouse gases) related to living and the building itself similarly to the sector of mobility. In this way, considering the sector of food, it is possible to raise the target value on the building in a feasibility field but respecting the global limits at 2100. The target values for non-renewable primary energy for the Society 2000 W at 2100 are shown in the column “reachable” in Figure 3 and Table 1.

It should be noted that the values established at 2100 regarding operating energy, construction and mobility, although they are possible to be achieved, remain very low. The design of the building must therefore use materials and systems characterized by very low grey energy content (e.g. low or no tech solutions), characterized by a complete use of renewable energy sources. The respect for these target values remains a design challenge today that needs to be investigated.
Figure 4: Achievement of the new values targeted at 2100 (2100 feasible column) considering the compensation of the energy needs of the building thanks to the energy saving due to diet. Without compensation, the objectives on the building are not reachable (2100 theoretical column).

Table 1: Proposal of project target values in terms of not renewable primary energy for the building by the year 2100 within the framework of the Swiss Sustainability Vision (2000W Society).

| Areas of analysis      | 2100 Design values |
|------------------------|--------------------|
|                        | Primary energy\(\text{a}\) (\text{MJ/m}^2) | CO2 emissions (\text{kg/m}^2) |
| Construction (gray energy) | 110               | 8.5                      |
| Energy needs           | 13                | 0.7                      |
| Mobility\(\text{b}\)   | 104               | 4.9                      |
| Nutrition              | 98                | 5.67                     |
| Total energy           | 325               | 19.77                    |

\(Total\text{ power } [W] = 618^{\text{c,a}}\)

\(\text{a}\): Not renewable primary energy  
\(\text{b}\): Daily mobility  
\(\text{c}\): Considering a swiss average of 60 m\(^2\) / inhabitant (Society 2000W)
2.2. Alimentation

The alimentary theme can be no longer ignored and is to be tackled on a global [6][7][8][9], territorial [10][11][12], and local level, also by constructions [13], and by living [14] more generally. In 2011, study “Environmental Impacts of Swiss Consumption and Production” [11] edited by the Federal Office for the Environment showed that among the consumption categories, nutrition is the most important and causes 30-40% of the total environmental impacts. Moreover was confirmed in 2018 by the “Swiss Environment Report” [15] that the sector of consumption and production with the greatest environmental impact is food (28%), followed by housing (24%) and mobility (12%). Furthermore, a study [12] regarding the Society 2000 W, identified 107 people who would already respect today the concept of a 2000 W Society in terms of energy but do not respect the vision in terms of greenhouse gases because their meat consumption is responsible of approx. 0.9 ton / year alone, thus making impossible to respect the total limit for all areas (1 ton). Finally, it has already been determined in studies carried out analysing the energy impacts of in-place 2000 W Society buildings in Zurich (technical requirements for the year 2050), that the food sector (meat consumption) is very critical for the achievement of the per capita energy balance and emissions target [14].

From the point of view of buildings’ construction and architecture, this topic is translated through the integration of food productions in the cities or directly in buildings (Urban Farming and BIA - Building integrated agriculture [13]). The winning pavilion designed by the Swiss Solar Decathlon team could represent a valuable example [16]. The diet is strongly characterized by the behavioural aspect. In the present study, in order to allow energy or CO₂ compensation through food, a regime without animal derivatives is considered as it is characterized by the lower impact in terms of energy and CO₂ [5].

2.3. Biodiversity

Considering that in Switzerland about half of the natural habitats is threatened [17], nearly half of the native species are threatened [17], that 60% of urbanized areas are watertight [17] and urbanized areas may be richer in species than agricultural areas [17], the urban space can be considered a refuge for species that have lost their natural habitat.

In a view of total sustainability, biodiversity must be integrated into all aspects related to the building and the external area. It is possible to design the building in order to act as a refuge for flora and fauna (on facades, roofs and nearby area), so that the building can help regenerate an impoverished soil with its presence.

2.4. Reversibility

The expansion of urbanized areas and infrastructure causes fragmentation of habitats for animals and plants [17]. In Switzerland between 1985 and 2009, the urbanized area increased by 23% [17]. The soil is therefore to be considered as a non-renewable resource.

The sustainable building should avoid soil sealing and compaction. Typically, the building is suspended, i.e. with punctual pile structures. By the end of the computed building life-time the soil should be returned to the environment without damage and enriched in biodiversity (regeneration). Loss of soil and fertility must be avoided.

3. Case Study

After the execution of the study, the intention is to build an experimental building in Ticino in collaboration with a private partner. The experimental pilot building will have to enable the inhabitants to respect the per capita parameters of the Society 2000 W at year 2100 as well as to be regenerative and reversible (construction technology should increase local biodiversity). In this phase, preliminary evaluations were carried out on the construction characteristics that a single-family building (2 people) should have in order to respect the construction limits described in Table 1.

Three different housing plans (Figure 5) and 3 different system configurations have been evaluated (heat pump and photovoltaic, wood heating, wood heating with certified electricity purchase) for each scenario (total of 9 scenarios). The limits concerning non-renewable primary energy have been verified. With regard to mobility, the average standard conditions in Ticino were considered, while for food it
was considered a completely plant-based regime without animal derivatives [5]. The preliminary characteristics of the building (construction / plant) were determined in order to respect the limits, in terms of W per capita.

Figure 5: 3 different housing plan were evaluated. (1) Single floor suspended with concrete blade (94 m²). (2) Two suspended floors with pillars (94 m²). (3) Two floors compact (125 m²).

Table 2: Case Study - Target values and project values

| Areas of analysis          | Case Study | 2100 Target values | Project |
|----------------------------|------------|--------------------|---------|
| Primary energy a (MJ/m²)   |            | 110                | 111.78  |
| Construction (gray energy) |            | 160                | 157     |
| Energy needs               |            | 13                 | 13      |
| Mobility b                 |            | 104                | 167     |
| Nutrition                  |            | 98                 | 98      |
| Total energy               |            | 325                | 389     |

*Total power [W] 618 c 580 d

\[ a \] Not renewable primary energy
\[ b \] Daily mobility
\[ c \] Considering a swiss average of 60 m² / inhabitant
\[ d \] Considering the project value of 47 m² / inhabitant
\[ e \] Considering 2 parkings and the average public transport service in Ticino Canton
\[ f \] Standard Swiss complete vegetarian nutrition

The study variant that presents the energy characteristics shown in table 2 (respecting the 2100 Targets values in term of Total power per capita and nearly reaching the energy requirements in terms of MJ/m²) is the housing plan number 2 with the following general characteristics:
• The building structure must be compact, the internal surfaces limited
• Building envelope and structure should be prefabricated in wood
• Transmittance of the construction elements according to the Swiss state of the art (0.15 - 0.20 W / m²K)
• Wood heating in central position of the house without heat distribution
• Domestic hot water heating by a heat pump
• Without photovoltaic or thermal solar panels
• Purchase of certified electricity from renewable sources (hydroelectric)

Notes:
- Photovoltaics: the annual amount of grey energy of a photovoltaic system (in the considered cases) is broadly equivalent to the annual compensation in terms of operating energy computed according to the technical norm [18]. Basically, the presence of a photovoltaic system involves roughly ca. +120 MJ / m² in terms of grey energy and subtracts approx. 120 MJ / m² in terms of operating energy (systems from 10 to 14 kWp);
- Due to the fact that in the vision Society 2000W there is the possibility of considering the certified energy purchased as full renewable, the presence of a photovoltaic system is always unfavourable (buying certified energy compensates the operating energy without having the grey energy load of the PV system).
- At this stage, for the agricultural self-production of food a surface of at least 2'000 m² was estimated. The area has to be cultivated through natural and regenerative agriculture which should provide self-sufficiency after 7 years with a commitment of 1 person for 4.8 hours per day.
- The targets established have not been reached in terms of energy MJ / m² but in terms of power per capita (W). Mobility has a certain weight in respect of the limits, however, it is a sector hardly influenced by designers because it depends on where the building is build.

4. Conclusion
Swiss energy policy has ambitious long-term goals. The way to reach them is not yet determined. This study provides a multidisciplinary approach to determine the characteristics of buildings and living-style in order to achieve sustainability goals both from an energy and a long-term environmental point of view. An innovative holistic approach, which partly concerns technical and design aspects, partly regarding behavioural aspects such as nutrition is proposed. The innovative concept of alimentation considered as building need in the energy balance, has been introduced.

The energy values (present and achievable target) for the alimentation related to the building were quantified (today 683 MJ/m², target 98 MJ/m²). A proposal for a practical design limit value for the Society 2000W at 2100 is quantified (considering operating energy, grey energy, mobility, nutrition) at 325 MJ/m² (618 W per capita) primary non-renewable energy. A preliminary case study has shown that the values are achievable today by focusing on a low-tech approach, with low grey and operating energy, and with a fully plant based diet.

A vision of total sustainability of the buildings that will be the home of a mankind of the near future for which integration in the ecosystem with positive impacts is a moral imperative is proposed. The shift of the paradigm of the role or non-role of mankind in the ecosystem allow to reinterpret inhabitation and construction technology.

4.1. Next Steps
The next steps are:
- Calculation of the energy and emission target by year 2100 considering the global energy need (renewable and non-renewable)
- Verification of the feasibility of the target for a CO₂ neutral construction (0 kg / m²)
- Determination of technical solutions, materials and approaches to achieve the objectives concerning the target of grey energy needs of the construction through pilot projects (construction of an experimental single-family house)
- Development of systems for integrating the production of eatable plants onto the building envelope through models in full scale
- Quantification of the objectives in the sector of biodiversity regeneration
- Development of building foundation systems and site management in order to preserve the stratigraphy of the soils.

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