Design of a small scale “green” house to study electronic and thermal aspects of energy management

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Abstract: This paper presents an innovative multi thematic sustainable development project started at the electronic engineering school of Bordeaux. While a small scale realistic real materials “green” house was realised by the secondary school’s pupils, electronic equipment and energy management system were designed at ENSEIRB-MATMECA and Craiova University. The “green” house model (1/20 scale) required more than 1500 cumulated hours were necessary to be carried out. 8 young pupils and their secondary school professors, 4 students and researchers from ENSEIRB-MATMECA engineering school, members of University of Craiova participated to the project. Non academic partners such as the national French agency ADEME (Agence de l’Environnement et de la Maitrise de l’Energie), and MNE of Bordeaux (Maison de la Nature et de l’environnement) were also involved. The first paragraphs give the general context of study and specifications. Design and building are then detailed. Lastly, assessments and feedback are discussed. This model kit is now ready to use for practical lessons and for supporting 2nd year electronic projects at ENSEIRB-MATMECA.

Key words: Sustainable Development, Pedagogical experience, Multi thematic project, Low power electronic.

1. Introduction
This sustainable project was initialized at ENSEIRB-MATMECA electronic engineering school. It was carried out thanks to national collaboration with “the House of the Nature and the Environment” (MNE) of Bordeaux, national French organism ADEME (Agency of the Environment and the Control of Energy) France, the ENSEIRB-MATMECA, the colleges Chambéry and Henri Brisson (professors and pupils) for the realization of the small scale house. Thanks to a bilateral European collaboration with Faculty of electrical and environment engineering (Craiova university-Romania), it was possible to establish academic connexion on sustainable development, to refine the project definition and to find common scientific and pedagogical goals.

2. Sustainable Development context
After Rio de Janeiro conference (1992), Kyoto protocol, agenda 21 definitions [1], and IPCC expert reports (Intergovernmental Panel on Climate Change) the necessity of a harmonious development has been highlighted by a majority of scientific and political personalities. Sustainable development is obviously a complex concept, which concerns a wide range of social, scientific, economical and environmental issues. However, each of us is able to do something for humanity evolution [2].

The question is not “necessity or not necessity of sustainable development”. In fact, we do not have anymore choice. The future of our planet is concerned. A deep cultural change is needed in engineering education to embrace broad skills, environmentally aware attitudes, knowledge and fundamental values, human behaviour, as well as a sense of ethical responsibility [3], rather than the narrowly focussed “technical excellence” which is traditionally accepted as good engineering education definition.

Such is the formidable stake for which the present and future generations should devote all their energies and knowledge [4], [5], [6]. Thus, Education to Sustainable development is starting to be introduced, even if it is not still widespread [7] in sciences universities of European south countries.
3. Aim of the small scale house project
The project started through an individual conviction of a few teachers: What could we include in our research field and/or pedagogical thematic to have a citizen action in sustainable development, while respecting the main scientific fields of our engineering school? After a long maturation process, the « small scale green house » project was born. Thus, the aim of the work is to build a modular model of house with genuine construction materials and its “clean energy” generation system. Once finished, the model will be used as:
- demonstrator (exhibition in local sustainable development events, primary schools etc.)
- pedagogical support for practical lessons and electronic projects, for sensitizing ENSEIRB-MATMECA engineering students in first and 2nd year study. In particular, it will open to a wide field of students’ works such as the design of electronic devices, electric heating, temperature control, management of multi source energy (solar, wind, hydraulic, hydrogen), low consumption lighting system. The use of infra-red camera with emissivity correction for thermal measurements will be taught during practical lessons a well as insulator material thermal characterization, etc.

The chosen scale (1/20) makes the model big enough for ergonomic uses and small enough to be carried or moved easily. Moreover, standard and cheap electronic parts and COTS (components out of the shelf) components can be used for the future electronic equipment design student’s project.

4. Interest of the work.
Private architect offices have already designed small scale model cartoon houses. The national French agency ADEME [13] has also some models to exhibit insulation materials and assembly techniques. They explain new available green technologies to lower the consumption in individual and/or collective buildings. A “green” house full scale (1:1) 30m$^2$ demonstrator was created by the French ENSAM engineering school and Nobatek company for solar decathlon challenge 2010 [14] (which is obviously not easily transportable). And theoretical works have still been done on this subject [15]. However, a genuine building materials and fully functional (thermal and electronic aspects) small scale modular house did not exist till now, neither in France nor in Romania.
Thus, the presented design is an original work which will give opportunity to many multi thematic projects fully merged with the ENSEIRB-MATMECA and Craiova University main fields of study.

5. Technical specifications
The main specifications for the house model are:

1° Simple square house, one floor 100m$^2$, (i.e. 50 cm x 50 cm at 1/20 scale), south west France architectural style.

2° Total surface wood board on ground: 80cm x 100cm, 18mm thick (sized to be transported through doors and corridors).

3° The house is located on one side of the wood board and on 20cm high piles for an easy access under the house where some electronic devices are installed and wired. A place is reserved for an inclined “garden” (cf. figure 1).

4° According to a concept of “turned over shoes box”, he house consists of 3 independent parts numbered from 1 to 3, on figure 2:
   Part one: walls in Autoclaved Aerated concrete (AAC) (scaled thickness: 2.5 cm), also known as Autoclave Cellular Concrete (ACC) [16] (which was invented in the mid-1920s by Max Ginsberg). (Small brick sawn and cut in a big AAC block). This local manufactured material is well known for its excellent insulation properties thanks to the internal micro air bubbles with represents 80% of material volume. Surface aspect: rough coat or smoothed.
   Part two: removable interior insulation double wall and ceiling, encasable by the top (cf. figure 2). Three types of insulators are used to make the users able to perform practical thermal measurement comparison:
   - Polyurethane (1cm thickness+aluminium coated). Polyurethane is a polymer -i.e. a chain of organic units joined by urethane (carbamate) links-. The thermal conductivity is between 0,023 and 0,028 W/m.K [13]
   - Polystyrene insulator, (thermal conductivity # 0,039 W/m.K).
   - Thin cork panels (thermal conductivity # 0,04 W/m.K).
Part three: two slopes roof, removable and encasable. The frame is machined in local pine tree wood; polyane thin film insulator or equivalent, and terra cotta tiles.

5° Esthetical elements and windows: the openings are carried out on the external wall part 1 and in opposite on part 2.
- 1 main door (wood)
- 1 glazed normal size windows by main frontages.
- Window frame in white extruded PVC, wood shutters, brass shutter fastening.

One of the windows is equipped with removable double glazing [17] screwed on part “1”. (width: #7 cm, height #7 cm, lintel # 2 cm). This window might be open, closed, single or double glazed, for energy losses comparative studies.

6° House bottom surface:
- Three opening (3 cm diameter) in the floor for underground electrical wiring, and a fourth one for fresh air flow circulation and control (cf. figure 3).
- Four stoppers to close theses opening when not used.
- Esthetical aspect ceramic tiling or equivalent.
- Optional floorboard for a floor heating system.

7° Interior design
- It must be as simply as possible to have an easy access to electronic circuits -i.e. no partition inside-.
- One chimney, with circular vertical conduit 20 mm diameter (type PVC), till the top of roof (to simulate an air extractor).

8° Roof
- Removable pitched roof (slope 33%, like in true roof in southwest of France) with pine tree wood parallel roof truss, industrial like. It is partially opened on one slope to encase a solar panel.
- Terra cotta tiles over the two slopes.
- Attic filled with 1 cm of mineral wool insulation.
- Two gutters.

9° House surroundings
- Soft slope garden till the border of the wood board, in recycled cardboard or equivalent, keeping free access under the piles.
- Surface decoration: green grass carpet, vegetable natural moss, footpath and flowering shrubs.

10° Compatibility for extension
Shape of surroundings must be compatible for joining a second and a third 80cmx100cm wood board (optional), which will be placed nearby.

11° Extension
A second board (cf. § 6.2.3), same size, receives different power energy generators: solar panels, hydrogen fuel stack, Stirling motor, wind generator, solar waterpump and pool etc.

For in-door demonstration uses, solar energy is replaced by Halogen lamp and the wind, by a compressed air gun.

6. Project progress
The project was managed and planed over a full academic year (2010-2011) as indicated below.

6.1 Project’s stages
The main stages of the project were:

- Project definition (July 2010),
- Specifications writing (August 2010),
- Architectural drawings and detailed quotation, weight estimation, thermal and mechanical differential constraints estimation (September 2010),
- Raw materials needs estimation and purchase (2 weeks),
- Student’s team constitution, tasks identification allocation, and scheduling (1 week),
- Test and training with the required mechanical tools (stone saw, drilling machines, sander),
- Manufacturing: (in mechanical workshop). Two weekly sessions of 4h over the academic year were dedicated to building with a 7 pupils group supervised by 2 secondary school teachers; Wall erection (1 month), windows milling and micro machining (1 month), insulator assembly construction and assembly (1 month), roof wood frame (1 month), roofing – #1000 scaled tiles and roof solar panel insertion- (1 month), rendering, finishing (1 month),
- Final control (one week),
- Inauguration: June 2011 with representatives of town hall, mayor of Talence city, local press and TV.

6.2 Concrete work

6.2.1 House erection
Figures 4 to 6 show the mains steps of the house’s building.

6.2.2 Surroundings realisation
Surroundings are made of reusable materials such as cardboard, paper, wood, dry plants, (cf. figure 7) using classical flocking techniques.
6.2.3 Power sources and accessories integration

According to specifications given in § 3, some “clean energy” kits are installed on extension board as shown on figures 8 to 11:

- Hydrogen fuel stack kit (from H-tec company) [18]
- Stirling motor [19], with mechanical transmission belts, dynamo and cement mixer assembled at ENSEIRB-MATMECA
- Wind generator (anemometer Vaisala company given by “Météo France” connected to a three phases brushless mini generator)
- Roof solar cells
- Autonomous solar panel hand made motorised [20]
- Solar water pump and pool (Opitec retailer)

Details on interest and uses of this power sources are given in § 8.1.

7. First assessments

7.1 Technical and financial assessments

More than 1500 cumulated hours of work were required for the whole realization (all included i.e.
150h were dedicated to the feasibility study and specifications writing. Around 1000h were devoted to the practical realization. The realization of the surroundings and establishment of the energy sources required 300h. According to a sustainable behaviour, the project was achieved with a minimum budget (labour costs excluded). Raw materials and various basic devices represented a few hundred Euros as indicated in table 1. Siporex (AAC), insulators and wood pieces were salvaged materials from local factories.

<table>
<thead>
<tr>
<th>Materials and devices</th>
<th>Price (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood board 80x100cm</td>
<td>80</td>
</tr>
<tr>
<td>Building material</td>
<td>50</td>
</tr>
<tr>
<td>Chemical resin and glue</td>
<td>50</td>
</tr>
<tr>
<td>Surroundings material</td>
<td>100</td>
</tr>
<tr>
<td>Hydrogen fuel electrolyser and stack</td>
<td>500</td>
</tr>
<tr>
<td>Solar cells</td>
<td>180</td>
</tr>
<tr>
<td>Solar泵 and pool</td>
<td>40</td>
</tr>
<tr>
<td>Stirling engine</td>
<td>450</td>
</tr>
<tr>
<td>Total</td>
<td>1450</td>
</tr>
</tbody>
</table>

Table 1: Project cost

7.2 Human experience assessment
This project was an interesting individual and collective human experience. Indeed, some of pupils were “out” of the school system, in “school failure” or had strong social or family difficulties. Working in collaboration with an electronic engineering school was a powerful source of motivation and valorisation. Over passing social and knowledge level differences, they worked all together with solidarity pride, joy and enthusiasm to complete this federating project. Four professors of College Chambery used this project as illustration for their courses and for supporting collective pupils work: Professor of mathematics (sizing, scaled drawings works, two Professors of building technology (walls, insulation and house manufacturing), Professor of art and technology (surroundings creation and design) and two students at ENSEIRB-MATMECA were involved in power sources integration.

Thus, despite the lack of financial support and heavy technical means, it was an opportunity for sharing human and scientific values, and mainly to show that it is possible to obtain “incredible” results with nothing, when working together with humility and strong motivation.

7.3 Promotion

The house model was awarded by town hall of Talence city: It received the special prize in education to sustainable development thematic during an opening ceremony with local politics representatives and press in June 2011. The house model will be exhibited for a sustainable development workshop in the “maison de l’éco-citoyenneté” in Bordeaux (eco citizen house) very soon.

8. Work ahead
Small scale house erection is now completed. Second phase of the project is starting with electrical wiring and electronic equipment definition. Power energy sources should be connected in a near future, to supply these equipments. Several future student’s projects will be dedicated to this work as detailed in the next paragraph. Design and results will be published later.

8.1 Futures designs
The following electronic equipments are going to be designed and included.
1° Multi “clean” energy production management to power the house:
- Roof solar panel, battery charger, with its charge and discharge low power management circuit,
- Hydrogen fuel stacks and hydrogen production management (H2 level control and over heating safety control),
- Mobile solar panel and its solar tracking system (it will consists of low voltage analogue feed back loop, servomotor and light sensors),
2° Garden “lighting”:
- Low consumption LED switching circuits powered from solar battery previously designed,
3° House electrical heating and temperature control:
- Power ceramic resistors (to match the real ceramic electrical heater) controlled by a PWM switching feed back loop and integrated temperature sensor circuits,
4° Artificial river circuit and water pump management circuit (Switching “on” and “off” criteria),
5° Canadian well and fresh air flow management. (Fan supplied by the hydrogen fuel stack),
6° Home automation (to be described in a future paper).

9. Conclusion
The building of the small scale “green” house was completed successfully. We checked the first functionalities. Electronic design and wiring for house energy management will be carried out next year.
during a second project’s stage. This model kit is now ready to use for practical lessons and for supporting 2nd year electronic projects at ENSEIRB-MATMECA.

Moreover, we showed that sciences, technology, creative arts, hand work, humanism and humanity [21], [22], [23] may be merged to stir the conscience to the sustainable development necessity while respecting the scientific goals of traditional education. Finally, we hope that this ethical project will sensitize general public to the necessity of energy consumption reduction and power saving for the respect of our planet.

References:
[19] Sven Gütte web site: http://www.guette-feinwerkechnik.de/