Concepts for sustainable building technology

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4 authors, including:

Jörn Von Grabe
University of Liechtenstein

Stefan Winter
Technische Universität München

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J. von Grabe
Technische Universität München, Chair for Timber Structures and Building Construction, Munich, Germany

S. Gampfer
Technische Universität München, Department of Timber Construction, Munich, Germany

S. Winter
Technische Universität München, Chair for Timber Structures and Building Construction, Munich, Germany

H. Kaufmann
Technische Universität München, Department of Timber Construction, Munich, Germany

ABSTRACT: Two design-build-projects with similar prerequisites as far as size, functional requirements and means of realisation are concerned, have become exemplary structures for different climatic regions in South Africa. Both had to be realised with a minimum of technological equipment, but two different strategies were followed in order to generate a reasonably comfortable indoor climate throughout the year. While one of the buildings is laid out to generate comfortable indoor temperatures using solar gains without the need of additional energy, in the other project a solar heating system supplies energy for under floor room heating. The paper gives a detailed description of the different building techniques and technical measures used for the realisation of the structures, provide an analysis of these measures as well as a critical evaluation of the results achieved.

1 INTRODUCTION

Nowadays, sustainability is a societal dictum. However, while dealing with energy consumption, embodied and grey energy and similar ideas and expressions related to this field, one must not forget that the focus of any sustainable planning has to be the future occupant of the building. Only if the building and its components reflect and satisfy the special needs of its occupant, the basic requirements of a sustainable building can be met: firstly, having a long life span without the necessity of major changes of the building and secondly, being accepted as a good practice example and guide for future buildings of its type. The total energy consumption necessary to meet these basic requirements, i.e. the energy input into the construction and the energy needed for maintaining suitable indoor conditions, has to be minimized.

However, the meaning of sustainability can also be extended to more global and abstract views. During most of the university education, future professionals are expected to internalise an abundance of information without being offered the opportunity to link theoretical knowledge to personal experience. Giving students the chance to work theoretically first and then to evaluate the practical results of their planning helps them to find and to develop their personal skills. Doing this in a group of architecture and civil engineering students teaches these students communication and collaboration skills in an interdisciplinary team.

All these important aspects of sustainability have been covered by two exemplary student design-build-projects that have been carried out at the Technische Universität in Munich. Both buildings are kindergarten-buildings and were designed by students in the course of a semester-long design project and then finally built by the student group. One of these buildings is located on the Highveld near Johannesburg and the other one in the subtropical region of the Western Cape near Stellenbosch.

In both cases the planning was carried out by the students during one semester in the course of their studio work at the university. During the semester, the students were intensively supervised by the lecturers of the participating chairs and had to present their results to an audience regularly. Meetings with the students were held on a weekly basis.

A short period between the end of the design phase and the beginning of the building process was used to refine the design and to develop the details for the construction further. Then, a mixed group of students and lecturers travelled to South Africa and erected the buildings with their own hands.

The first project near Johannesburg was planned in 2006/2007 by architecture-students with some support from civil-engineering students, especially concerning climate and comfort questions. The building was realised in the summer of 2007 in a construction time of only six weeks by 30 participating students, two tutors and up to 20 workers from the local neighbourhood.

The second building near Stellenbosch is the result of an interdisciplinary student team co-operating from the beginning until the end. It was designed during the winter of 2008/2009 and then built in spring 2009. In this case the construction took nine weeks. Students arrived and stayed in two groups of approximately 15 to 20 students. At peak times, about 35 students took part in the building process simultaneously. During this time the team was supported by a number of local workers.

The following chapters will explain why both, the processes that lead to the existence of the buildings and the buildings themselves, are sustainable in terms of the above explained principles.

2 REQUIREMENTS

Naturally, the occupants of these buildings are infants and pre-school children. These children need spaces for playing as well as for resting and sleeping. Due to the different age groups, different activities can take place in rooms adjacent to each other. Thus, there is a great necessity for a well-designed sound protection between rooms and between rooms and outside. Thermally, children are susceptible. In order to provide them with an environment supportive of learning and development, they need to be protected against winter cold and summer heat more than adults. The risk of overheating must be reduced while at the same time providing the rooms with enough daylight through a sufficient amount of window area. Thermal mass that helps to reduce summer heat peaks, must not lead to extensive cold surfaces in winter. This is especially true if – as in the cases shown here– the floor is used directly as a playing and resting area.

All these requirements that arise from the occupant’s needs had to be met without losing sight of the technical and mechanical skills of the team: basically, a large number of untrained students, the minority of them having a practical education. Therefore the structures had to be simple and easy to be built. It was also part of the strategy to incorporate local workers. On the one hand, to include local technologies and through this make the building easier to be accepted and copied. And on the other hand to employ people that are part of an incredibly large and underprivileged community in the area of the building site.

3 SOLUTIONS

Different locations and different climates need different strategies. For two kindergartens in South Africa realized by students of the Technische Universität München, the strategies will be explained in the following sub-chapters.

3.1 *Khanyisani Preschool, Orangefarm*

Figure 1. View of Khanyisani preschool in Orangefarm

The first design-build-project realised by students from Munich was a kindergarten with 3 playrooms, kitchen, storeroom, office and a sanitary unit for a neighbourhood in the large township Orangefarm near Johannesburg, South Africa (Fig. 1).

Situated in an area characterized by poverty and an extreme lack of resources, the project offered the opportunity to try out and evaluate the use of inexpensive, locally manufactured building materials and methods of construction. The use of bricks, signifying a permanent structure, marks a certain value in public perception. In a larger context, the relevance of the new building comes from the fact, that it uses standard building components to create a much higher level of architectural quality than that which exists in the surrounding area. It uses easily comprehensible images like the large sheltering roof, which illustrates the value of such transitional spaces in the South African climate, in an effort to contribute to a better understanding of functional and aesthetic qualities for future buildings in the township.

3.1.1 *Layout of the building*

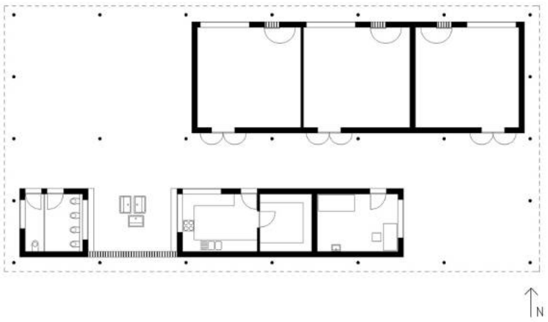

Figure 2. Floor plan of Khanyisani preschool

High solar radiation and heavy rainfall during the summer months led to the principal concept of the building. A freestanding roof construction spans the schoolrooms as well as the large open space in between and offers protection from sun and rain.

The rooms are arranged in two parallel rows with a central open passage. The secondary rooms are lined up along the South side of the building facing the village street. Their solid rear wall screens the children from direct outside views. The playrooms face North with large, single glazed windows towards the open play area (Fig. 2).

3.1.2 *Building materials*

The large roof is a timber construction on standard local gum-poles with corrugated fibre-cement covering. (Fig. 3)

Figure 3. View of covered play space form the Northwest

The large trusses of the roof construction form the only exception to the precondition of using only local materials: European plywood was used to permit the large span (Fig. 4).

The surrounding walls of the rooms were made from a locally manufactured air-dried scoria and cement brick. Their properties vary due to the low-tech manufacturing process. An analysis at the Centre for Construction Materials and Materials Testing (CBM) at the university in Munich showed that they have a density of about 1500 kg/m^3, comparable to a hollow clay brick. Presumably, the material has a heat conductivity of λ= 0,46 W/mK and a heat storage capacity of c=1000 J/kgK.

Figure 4. Roof construction with timber trusses and fibre cement covering

Figure 5. Production of local scoria and cement bricks

Only standard building components were used for the windows and doors of the rooms. In this context, this means single-glazed steel frame windows and chipboard door leaves.

3.1.3 *Energy concept*

The ecological objective of this building is to come up with indoor spaces that retain a comfortable temperature throughout the year without any need for heating or cooling energy. The context of University education allowed the question to be introduced to a group of students from the Faculty of Civil Engineering, who studied climatic conditions and simulated the physical behaviour of indoor spaces. Specifications were needed for the size and position of openings, both in terms of solar gains and ventilation, as well as for the materialisation of walls, floors and roofs of the buildings. Due to the difficult conditions of the project and the restricted technical possibilities, the acceptable comfort temperatures were extended to a range from 16°C to 30°C.

Detailed planning of the building and roof construction as well as the size and placement of openings in the exterior walls made it possible to achieve both maximum solar energy gains in winter and sufficient shading of indoor and outdoor spaces during the summer months, when the rooms can also be cooled through natural ventilation at night.

Overheating of the rooms in summer could be avoided with only a very small roof overhang, thermal mass of the walls and screed floors, and an effective system of night ventilation. The ventilated space beneath the large shading roof avoids overheating of the ceilings of the individual rooms. Shutters for burglar-proof night-ventilation were hidden behind screens made from cement wine-coolers in the North and South walls of the playrooms (Fig. 6).

Since no suitable material for outside insulation and an exterior cladding was available, the properties of the solid outside wall were a precondition for the energy concept – even though it does not have a U-value sufficient for the cold winter nights of the area, when temperatures frequently drop below 0°C. This proved to be one of the greatest challenges of the concept, because only a reasonable behaviour of the users could ensure even the fairly low accepted temperature of 16°C: it could be reached only through reducing the ventilation rate by keeping doors and windows shut from the early morning until the temperature had risen to a certain level. On extremely cold winter days, the morning temperature was still expected to fall to 14-13°C.

Figure 6. Playroom window in the North wall, screen made of wine-coolers on the right.

This situation would have meant a great improvement compared to the former situation of the old kindergarten, or even to the standard dwelling of the township, where indoor and outdoor temperatures are almost identical throughout the year. Nevertheless, reality of everyday use showed that low temperatures were no longer accepted by the users once they had been provided with electrical power and the means to install room heating.

This problem was tried to overcome by a different strategy in a subsequent project:

3.2 *Kindergarten Brak en Jan, Raithby*

3.2.1 *Plan*

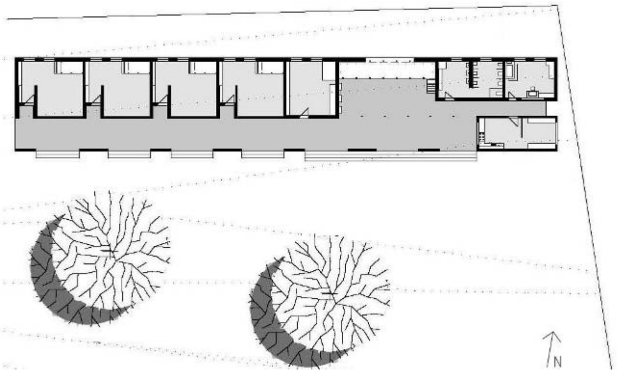

Figure 7. Floor plan of Brak-en-Jan kindergarten in Raithby near Stellenbosch.

Fig. 7 shows the floor plan of the Brak-en-Jan kindergarten in Raithby. The total area covered by the roof is about 500 m², half of which is taken up by the rooms. The rest is a shaded external play area. The complex is North-South oriented. The playrooms are in the Western half, along the North wall. Sanitary rooms, kitchen, storerooms and an office are located in the East near the entrance from the street. These functional areas are connected by a central, roofed space (Fig.7).

3.2.2 *Achieving suitable indoor conditions*

Heating loads in South Africa are frequently under-estimated. However, with usual winter temperatures of 5 to 10°C and minimum values around the freezing point, the southern part of South Africa has a notable necessity for heating throughout the winter season. However, the buildings' thermal quality is extremely poor compared to Northern-European standards. That relates to both, active and passive means. The lack of insulation of the opaque building envelope combined with common single-glazed windows, leads to an average U-Value that is about four times higher than that of new buildings in Germany. At the same time, central heating is virtually unknown in South Africa. Thus, buildings are heated with easy-to-use electrical heaters with hardly any investment expense. Electricity in South Africa comes from a mix of nuclear and coal fired power stations, both of which are not sustainable energy sources. Using this technology in combination with the poorly insulated building stock described above, the carbon dioxide expenditure for heating is – roughly estimated – in the same magnitude as in Germany.

The combination of a notable but moderate heating demand in winter and a rich offer of solar radiation in summer naturally leads to the idea of saving summer warmth until the winter to heat the space. This is the basic principle of the thermal solar heating system that was planned and built for the four playrooms of this kindergarten.

Figure 8. North facing wall with solar panels.

The system consists of eight thermal flat plate collectors, which are mounted vertically and in pairs on the north-facing wall of the rooms (Fig.8). Every two of them are connected in row and the four pairs are consequently connected in parallel. They are feeding a 5000 litre plastic tank in a separate technical room (Fig.9). This tank is extremely well insulated with an average insulation layer thickness of about 30cm. A pump, which reacts to temperature differences between the collectors and the tank water temperature at the inlet position and to maximum tank temperatures, runs the solar circle. The system is not pressurised but open, therefore there is no need for a heat exchanger in the tank. This increases the robustness of the system and at the same time reduces the investment.


Figure 9a/9b. Hot water storage tank with insulation.

Moreover, it is a coherent solution as the tank is able to withstand maximum temperatures of about 60°C. As a consequence of this relatively low achievable temperature a system with the ability to make use of low temperatures had to be found. Consequently, we used a floor heating system, which combines a number of advantages. The large heated area leads to the fact, that the system is effective over a wide range of temperatures and that a very large portion of the stored energy can be utilized. Apart from that, a well-tempered floor is advantageous for the children that play and rest on the floor. As the tank temperatures are limited anyway, it was possible to use very simple plastic tubes, which are placed in a layer of floating screed (Fig.10).

Each room has its own heating circle, however, all circles are connected via valves to one single pump. Each valve is controlled by temperature sensors, which are located in the screed: The appropriate screed temperature can be set manually by thermostats.

The solar system is a powerful heat source; nevertheless, to make the system work reliably, it was necessary to have a building envelope with a thermal quality far better than the usual standard for South African buildings. This passive part of the strategy is essential; otherwise the heating demand exceeds the storable energy by far.


Figure 10. Plastic pipes for under floor heating.

Therefore, not only the tank was well insulated, but also the external walls, the roof and the floor. The heated floating screed sits on a layer of 5cm polystyrene insulation. The space between the posts of the south facing timber framed wall, as well as the space between the rafters of the roof is filled with 15cm insulation (Fig. 11).

The north-facing wall, which is fully exposed to the weather, is not made of timber but of sun-dried, plastered clay-bricks without additional insulation. The windows are also made of timber and – based on extensive calculations – we decided to use insulated low-E-glass instead of simple double or even single glazing. Only because of this consequent insulation of the space the use of a solar heating system is possible.


Figure 11. Insulation of the timber framed walls.

Proper insulation of the building helps to reduce heat transfer into the building and thus is also part of the strategy to prevent overheating in summer. Additionally, and most importantly, the rooms are well provided with thermal mass, not only by the external brick wall on the north side and the screed, but also by the partitions between the rooms. Instead of filling the gaps of the timber frame walls with insulation they were also filled with clay, thus generating more thermal mass while also maximizing the sound protection between rooms (Fig.12).

Thermal mass works by storing heat energy throughout the occupancy time and thus reduces peak loads. However, the precondition for this is a discharge of the mass during off-occupancy times. To allow for this, we have created windows on the north side as well as on the south side to facilitate cross ventilation at night. For night ventilation, there are casements on both sides, which are smaller than the casements for daytime ventilation in order to improve the security situation in terms of rain and theft.

Figure 12. Clay brick filling of the partitioning interior walls.

For situations during which there is no wind pressure, these two opposite vents were located on different heights to make use of the natural stack effect. The size of the northern windows, i.e. those which are exposed to beam radiation, has been carefully adjusted by thermal simulations to find the best compromise between solar gains during winter, cooling loads in summer and daylight provision. With an area of about 1.7m² each the two North windows are considerably smaller than those on the shaded south side. Thus, the rooms are continually lit by diffuse light but confronted only with the minimum necessary amount of direct light.

3.2.3 *Using appropriate materials*

We have laid emphasis on using materials with a low energy input. Therefore we abstained from using fired bricks. Instead we used unfired adobe bricks for all the walls that are exposed to the external climate (Fig. 13).

They are produced locally on a nearby wine farm so that even transport to the site was not an energy intensive issue. For all the external walls, which were covered by the roof and thus were not exposed to the rain we used timber, being a material with low energy content by nature. The window frames are made of recycled wood, taken from demolition sites and produced by a local carpenter according to our details. The only ecological compromise had to be made regarding the insulation material. Recycled insulation material that is available in South Africa does not comply with our understanding of fire protection. Therefore we used the standard mineral fibre for the insulation of the tank, the roof and also the timber-framed walls.

An essential prerequisite for having the potential to build a “best practice” building that becomes an accepted prototype in its area is the use of available and affordable materials. In our case, all materials were purchased in the close vicinity of the site, i.e. Cape Town, Stellenbosch or Somerset West. All materials, apart from the collectors and the control unit of the solar system, are South African products. Also the low-E coated glazing, even though not usual in South Africa, is locally produced.

3.2.4 *Social aspects*

Most of the physical work was done by the students. However, the teams of both kindergarten-buildings were supported by a number of local workers. They were employed for specialists work, like plumbing and electricity. But as mentioned above, it was a part of the strategy, to incorporate locals to improve the local work-situation on the one hand and to increase the acceptance of the building on the other hand. Therefore, for the Stellenbosch kindergarten we worked with a large group of craftsmen who are specialized on working with unfired bricks and who are from Kayelitsha, the large township that is part of Cape Town.

From this group, students and tutors learned about the complete building process related to this material. Therefore, knowledge transfer took place bi-directional and there is no doubt that everyone who took part in this project, be it the students, the university employees or the workers, benefited from the project.

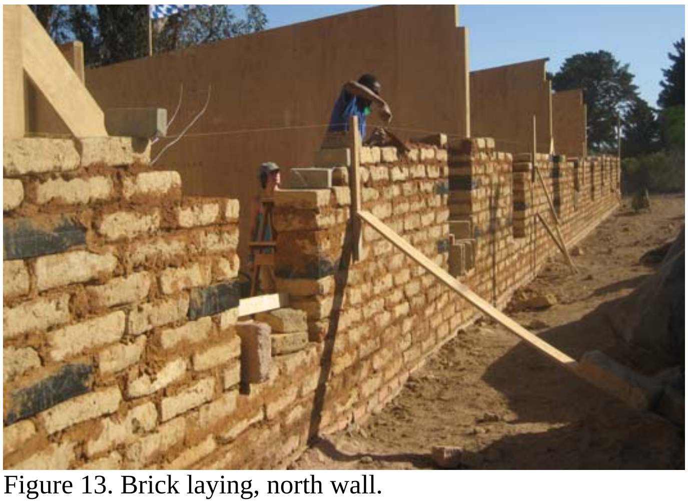

Figure 13. Brick laying, north wall.

4 COMPARISON AND EVALUATION

4.1 *Climate*

Although most places in South Africa have a fairly similar climate, there are some decisive regional differences, which had to be taken into consideration for the projects described above.

The site near Johannesburg is about 1800 m above sea level. The Highveld is characterized by summer rainfalls and extremely dry, sunny winters. Nevertheless, temperatures can drop well below zero during the winter months June, July and August. Summer days can be very hot.

The site in Raithby is only a few metres above sea level, the Atlantic Ocean is only a few kilometres away. Near Cape Town, rainfall is typical for the winter months. It does not become quite as cold in winter and there is rarely any frost. Winter days are often overcast, restricting solar gains during the cold season. On the other hand, there can be extremely hot and sunny summer days.

In both regions, there are extremely hard rainstorms possible. Solar radiation is very high on sunny days throughout the year.

4.2 *Different strategies for different situations*

4.2.1 *Reasons for passive and active room heating*

Considering these prerequisites - especially the frequent occurrence of clear skies and sunny days – it seemed reasonable to try to achieve heating of rooms by solar gains, without using extra heating energy, for the building in Orangefarm.

This kindergarten is situated in an area of informal housing, where a lack of infrastructure, unclear ownership of the plots and poverty prevail. Any sort of valuable appliance on houses, even electrical wires or building parts made of metal, are in danger of being dismounted and stolen. It was therefore impossible to provide the building with solar panels at the time of construction. Also, the use of conventional electrical heating was not only considered to be ecologically objectionable, but also beyond the financial means of the users. Consequently, a completely passive energy concept was the only practicable solution for this situation.

In Raithby, the situation was quite different. Even though the children at the kindergarten come from a social background very similar to that in Orangefarm, the building itself is situated in a village with a standard of security unusual for South Africa. The installation of expensive technical equipment on the outside of a building was therefore an option. The climatic conditions in the Western Cape region do not allow solar gains that are constant and reliable enough to provide passive heating during the winter months. It was therefore mandatory to find means of additional heating for the rooms. The use of conventional electrical power was out of the question, as this approach is partially responsible for the energy problems of the country, as has been explained earlier.

4.2.2 *The influence of user habituation*

After a few years of operation, the Orangefarm project showed, however, that the consideration of user behaviour and user habits has to be an integral part of all conceptualisations: Firstly, the use of the rooms according to plan requires an understanding of the need to operate doors and windows in order to control the room temperatures. While this works well in winter, opening of the inside shutters for night ventilation in summer is prevented by a much more dominant habit of keeping houses completely shut an secured during the night.

Figure 14. Inside view of window and shutter with screen at Khanyisani preschool

The shutters are closed for the night even though they are behind impenetrable concrete screens (Fig. 14). Measurements have shown, however, that for the indoor temperatures this is negligible: Summer temperatures are never outside the comfortable range. What proved to be much more influential was a change of user behaviour that was only indirectly influenced by the new building: the existence of a new, high-quality structure led to a considerable increase of the desired standard of use. Installation of electrical heaters became not so much a necessity, as a means of raising the standard of the service offered by the kindergarten – as well as a means to justify higher fees paid by the parents. This result of the project can be seen as one of the most important issues to be considered in future projects of similar background.

To obtain descent information on the thermal performance of the Kindergarten in Raithby, the temperatures in the playrooms, the temperatures of the tank and the temperatures of the solar circle are monitored permanently. Comprehensive results of the monitoring will be published in the future. However, so far, the kindergarten has not been operated for a full year, so its performance during the different seasons can not be assessed yet. Nevertheless, preliminary data show at least and amongst others two things: Firstly, the summer temperatures in the playrooms are lower, i.e. more comfortable, than predicted by the thermal simulation. For the thermal simulation it was assumed, that the occupants of the building open the windows if the air quality is below a certain standard, no matter how warm it is outside. In fact, our measurements show that windows are kept close during most of the time of the day. This results in less cooling load on the rooms and consequently lower temperatures. Thus, internal temperatures can turn out to be 5 degrees less than external temperatures during summer days. Secondly, the windows that were planned to be used for night ventilation have obviously not been used so far. The reasons are not clear at the moment, but it can be assumed, that there is more reluctance due to security reasons to leave windows open overnight, than expected before. Obviously, this is thermally counteracted by the fact that the users are also keeping the windows closed during daytime. So the real performance is not worse than the predicted one. Nevertheless, regarding its importance, this result is comparable to the previous result of the Orangefarm building: In both cases, non-environmental aspects influence the environmental performance of the building and it is essential to carefully take this aspect into account.

Figure 15. Inside view of playroom in Raithby.

5 CONCLUSION

In this paper, we have tried to explain our view on the concept of sustainability and have illustrated this by the description of two exemplary projects. Both projects are kindergarten buildings that are located in South Africa, one near Johannesburg and the other one near Stellenbosch.

Our idea of sustainability is not only related to the building, its energy content and consumption but also to the acceptance of the building and its characteristics by the occupant. The latter is the prerequisite for the longevity of the building and its potential to be accepted as a best practice example. In our view, this understanding of sustainability is extended further by including the educational process of the students: they not only have the chance to link theoretical work and practice, but get the opportunity to experience a different culture and to get in contact with people with a very different background. Finally, improving the local work situation by employing local workers, even though only for the time of erection, is also part of a broader view on sustainability.

Both buildings and the related processes meet these requirements: the living conditions for the children have been greatly improved by the new buildings and therefore the buildings are well accepted by the children as well as by the teachers. All materials that were used are optimised with regard to local availability, energy content and thermal performance. Local workers were integrated into the process of construction and we managed to literally interweave student theoretical and practical work with local techniques and practice. Nevertheless, a lesson we have learned from these projects is the fact that habituation and cultural imprint have an influence that must not be ignored.

REFERENCES

‘Learning to Build in 40 Days‘
S.Gampfer, M.Dobmeier, M.Hoppe, W.Haupt
Oxford Conference 2008 (S.Roaf, A.Bairstow editors., WIT Press, 2008)

‘Teaching Sustainability - An Interdisciplinary Approach‘
M.Hoppe, W.Haupt, S.Gampfer, M.Dobmeier
4. International Building Physics Conference,
(Bayazit N.T., Manioglu G., Oral G.K., Yilmaz Z. (editors)
Istanbul 2009)