Teaching Building Simulation to HVAC Engineering Bachelor Students

Gerhard Zweifel
Lucerne University of Applied Sciences and Arts
Engineering and Architecture Department
Horw, Switzerland

Abstract

Teaching building simulation in a bachelor program at a university of applied sciences to students with a strong professional rather than a deep scientific background is a challenge.

Over the time of 20 years, a method has been developed, with the aim of leading the students to a general understanding of the capabilities and the value of building simulation as a means of integrated design, rather than trying to make them expert users in the short time available.

From experience it can be stated that, for this type of students, extensive and deep scientific introductions do not lead to much success. However, to overcome the lack of scientific background, an introductory exercise in deriving a dynamic mathematical model for a limited physical phenomenon has proved to be a good step to get a sufficient understanding of dynamic effects.

Where earlier tools needed more introduction in the handling of the software, contemporary tools - especially the tool used in this case, one of the world's leading equation based simulation tools - support this with a built in tutorial and process guide, which the students then use to get familiar with the software.

A two step approach for the optimisation of a given 4-5 zone commercial building is chosen to provoke the students putting in their professional know-how and their curiosity. The model, with purposeful non-optimalities, is handed out to the students and analysed. The task is to optimise the building in respect of its overall primary energy consumption. The contribution shows the procedure in detail. Also the challenge of having mechanical and electrical engineers together is discussed.

In follow-up modules some of the students use the same software to make their first BIM experience and especially, the more interested students can chose a second course going more in depth of advanced mode simulation, modelling, controls, optimisation etc.

At the final stage, a specialisation is offered in the frame of the MSc program.

Introduction

Educational Background

To fully understand the background of the method presented in this contribution, the educational system of the country (Switzerland) needs to be taken into consideration. The system is described in detail in Wolter (2014). A simplified chart of the system is given in Figure 1.

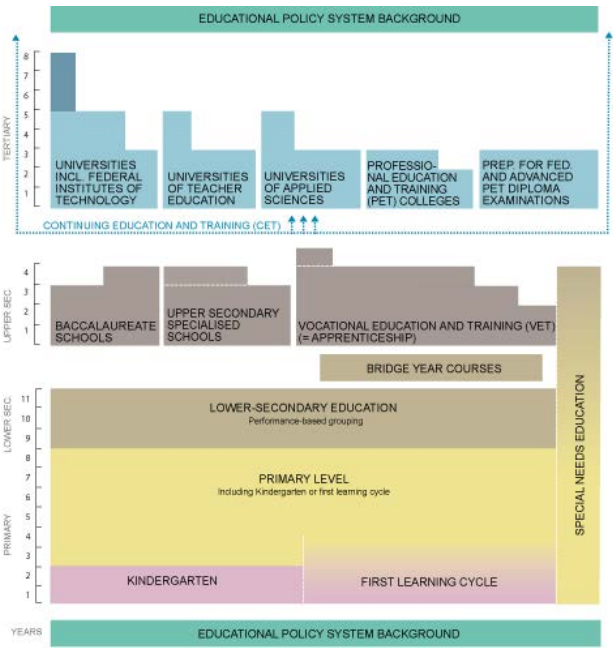

Figure 1: Simplified chart of the Swiss educational system.

The speciality of the system is the track "vocational education and training (VET)" in Figure 1 and the large proportion of young people (40 to >80%, depending on the Canton) according to Wolter (2014) following this track. This track is the backbone of the education of young people to prepare for entering the economy as employees. By many economists and politicians it is one of the main reasons for the prosperity of the Swiss economy, showing one of the lowest unemployed rates worldwide. It has found a considerable international interest and been subject to export activities it the recent years. Selected examples are shown in Bürgi (2015) and Zaugg (2015).

On this track, the people usually enter a company as an apprentice at the age of 16 years. After an introduction they work increasingly on the job under the supervision of a responsible professional and get a reduced salary. Thus, the economy bears a part of the educational costs. In parallel, the people visit an "upper secondary specialised school" for one day a week and, in addition for

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those who envisage the following track, in parallel or in sequence the "Specialised Baccalaureate" program.

The latter is the condition for the main consecutive education track for a fraction of these professionally educated people: the "Universities of Applied Sciences" (UAS, Figure 1, upper middle). There are 7 in total countrywide, offering a large variety of specialised degrees in arts, social, health and technical sciences. In technical areas, these people usually graduate after 3 years (or 4 years extra-occupational) with a degree acknowledged as a Bachelor of Science, a consecutive MSc program being offered, visited by a small proportion. The main reasons for this are the really large and attractive opportunities of these BSc graduates in the market. Often they are preferred to the MSc graduates from the technical universities (the two Federal Institutes of Technology), and are sometimes offered higher starting salaries. However, the two tracks are complementary, and there are branches who need and prefer the latter. There are also cross-pass possibilities.

In some branches, there are no specialised tracks on university level, the UAS being the only possibility for a specialised degree. This is for example the case in HVAC technology, where the Lucerne University of Applied Sciences and Arts (the UAS of Central Switzerland, see HSLU, 2017*)* is the only one countrywide offering a degree. Since a couple of years, a second track has been activated in electrical engineering for buildings. The entering students usually have a background from an apprenticeship in installation like heating or ventilation or electrical installers and plumbers, or – more often – in design as heating, ventilation, sanitary and electrical designers, having absolved their apprenticeship in engineering offices.

This is where the method described here is situated.

Position in the curriculum

From the above description, it must have become clear that the students addressed by the method described here will have a scientific background in the basic technical sciences like fluid and thermodynamics, which, however, does not go as deep as in usual university education. In turn, they have a strong practical background. This has to be considered in the design of the method.

The method is, in its total, distributed on several of the modules of the normal curriculum. The core, however, forms a 3 ECTS module (one afternoon a week during the term of 14 weeks) "Modelling and Simulation 1" in itself and is positioned in the 5th semester as one of the modules to be chosen from a set of compulsory deepening modules. Thus it is in competition with other modules.

It can be continued on a completely voluntary basis in a module "Modelling and Simulation 2" in the 6th semester, which runs in parallel to the bachelor thesis module, where often topics are chosen by the interested students which involve simulations.

Finally, there are a few modules, where some aspects of simulation show up again. A special one (BIM) will be emphasised below.

Teaching methodology review

It is hard to find literature references which cover a comparable field of application both in terms of the educational prerequisites and the professional area. The majority refers to architectural students. However, there are always aspects which can be applied and/or adapted to the specific situation.

Augenbroe et. al. (2008) describe a course which claims to "trains a new guild of building simulation experts that acquire good knowledge of the underlying modeling assumptions, equations and solution methods". They argue that it is a necessary requirement to use commercial tools judiciously, recognize limitations and inspect the critical assumptions that ultimately determine the relevance of simulation results in real life decision making. The aim at the students to leave with a critical attitude towards the use of simulation, sincce one does not have full control over the underlying assumptions.

Schmid (2008) describes the introduction of building simulation in case studies treated in a "design studio" setup, using an own software. The design studio setting is a typical architecture related form of teaching, which, however, would have potential for other disciplines as well. There is a one week module at the author's home university, the "interdisciplinary workshop", which has this aspect even in a multi disciplinary way, involving architects, civil engineers and building services engineers. It is a free choice of the latter to use their knowledge from the course described in this paper in this setup. Since the author is not part of the coaching team, many of the students are rather reluctant to do so, but a few do.

Charles & Thomas (2009) present four methods of introducing building simulation in undergraduate architecture and engineering education: a) bringing in an outside expert, b) the instructor acting as a simulation provider, c) students volunteering before receiving any training and d) students volunteering after receiving basic training. Rather complex design tasks were treated involving different tpyes of simulation: theral, air flow network (coupled) and CFD. Even the combination with measurements in physical test cells was included. The aspect of the appropriate level of detail of simulation models is discussed. Some of the findings such as the lack of applicability of the tools may be outdated due to more recent developments.

Reinhart, et.al. (2012) describe a method to involve simulation for first year architectural students in a short competition exercise called a "game" by the authors. The students are, however, not doing the simulations themselves, but give the "experts" the order to perform the variant runs. The emphasis is on reading the results of a simulation and adapting a design accordingly to improve it. This is, indeed, a very important aspect. Both the way of result presentation and the game setup are common aspects with the method described here.

Bauer et.al. (2014) describe a workflow for a detailed introduction of thermal building simulation in the teaching of engineering students. They present a step by step introduction from the building element to the whole building, involving digital building modelling and IFC based data transfer. For the crosschecking of the results, comparison with standard based calculation methods are used. Recognizably the same software is used as in the method of this contribution, and some individual steps, such as the modelling of a one dimensional wall by itself at the stage of transferring from the modelling exercise (see below "entrance module", first bullet) are virtually done the same way.

Beausoleil-Morrison and Hopfe (2015) introduce an "experimental learning cycle" for teaching building simulation, based on a set of observations found in the current simulation practise. The exemplary application of the proposed method makes use of the characteristics of the ASHRAE 140 (BESTEST) validation suite, which is designed to provide diagnostic power in order to find the problems when validating software tools. Naturally, this attribute has also educational value, in addition to the fact, that the building model contained in this suite is rather simple and therefore understanable and manageable. An approach, which is partly taken up by the lighting container exercise shown below.

Kumaraswamy and de Wilde (2015) and Göçer & Dervishi (2015) show methods using recent simulation technology and making use of the 3D graphic visualisation of the results in the context of architectural education.

Method

Goal

The goal of the method, primarily of the entrance module, is not to enable all students to be simulation experts. The time is too short for this, and their professional goal for the majority will be more in the HVAC design and/or installation industry. But for this, they shall have a basic understanding and be a competent discussion partner for specialists. The special focus is on the strength of building simulation as a means of integrated design.

For a few however, who chose the follow-up modules and stay with the topic also for their bachelor thesis, it can go quite a bit farther than this, as can be seen from below examples.

Entrance module

The entrance module "Modelling and Simulation 1" consists of the following parts:

- A 3 weeks "warm-up" exercise on modelling, where the students are lead to create a mathematical-physical model on a problem known to them from a more practical point of view. The goal is to sensibilise the students for the process and restrictions of building up such models, emphasising the need for clear boundaries and simplifications, and the technique of balancing.
- A sequence on thermal building simulation, consisting of two phases:
    - A partly self-study based introduction to the handling of the used software. Due to the contemporary make of the software used (see below), including a built-in tutorial and process guide, this can be minimised. This phase, however, includes also the creation "from scratch" of a simple two-zone model and a first sensitivity study on this model. In the recent years, the container for lighting and daylighting measurements on the campus (Figure 2, see also Licht@hslu (2016)) was used for this. This is backed up with master students as tutors.
    - A following "optimisation" exercise based on an existing simulation model. This part is explained in detail below.
- For the last 5 weeks part, the students are separated in the two disciplines:
    - the HVAC students get an introduction in computational fluid dynamics (CFD);
    - the building electrical engineering students get a similar introduction in the lighting and daylighting simulation.

In the following, the emphasis is put on the "optimisation" exercise in thermal simulation mentioned above, which is the core of the module.

Figure 2: External view of the lighting/daylighting measurement container on the campus

Choice of the software

The software chosen for the thermal building simulation part – and in the meantime, due to the transportation of the knowledge by graduated students – the leading thermal simulation software in the country, at least in the HVAC branch, is IDA Indoor Climate and Energy, one of the world's leading equation based thermal building simulation tools (Equa (2016)). This choice was made many years ago, even when a much less advanced version of the program was available. The following reasons lead to this choice:

- Very simple and low level starting possibilities in form of "wizards";
- At the same time very far going possibilities in terms of flexibility to implement and simulate tailor made building and HVAC component models;
- Full transparency of the models used;
- A useful and far developed graphical user interface;
- Local language versions available

In the course of the development, even more reasons added recently to this list:

- Localisation add-ons considering local climate and standards;
- BIM capabilities (IFC import interface);
- Specific aspects, more recently implemented, support the enhancing participation of electrical engineering students, e.g. daylighting or the simple possibility of introducing PV production.

The thermal building simulation "optimisation" exercise

For this optimisation, typically a 5 zone commercial building is chosen. The model contains a two storey building (example see figure 3) which consists typically of 2 offices, 2 meeting rooms and an entrance hall which is 2 storeys high.

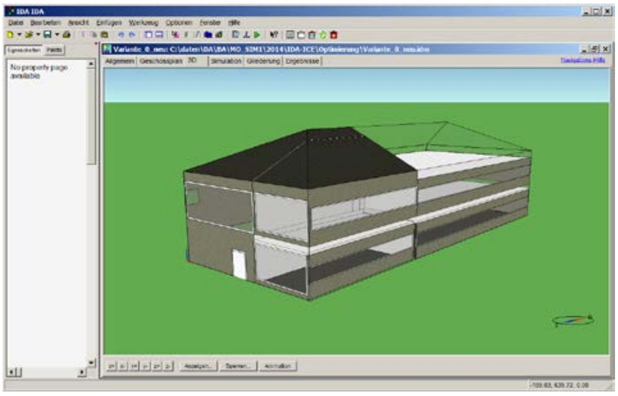

Figure 3: Example model of the commercial building to be optimised

A commercial use is chosen because this is typically a use, which in practise under Swiss climate conditions will involve comprehensive HVAC equipment. The model covers also an air conditioning system and a simple heating and cooling generation plant. This choice also provokes the students to put in their professional know-how and their curiosity, since it is close to their basic professional know-how and future task.

By intention, the modelled building has non-optimalities such as

- a building envelope quality representative for the existing building stock;
- off-standard set points for temperatures and humidity;
- too long operation hours;
- a poor heat recovery efficiency;
- no daylight control of the lighting
- etc.

So it offers a big variety of measures to find, to improve its energy performance. Also, with the building layout, e.g. with the two-storey entrance hall, potential for passive measures like natural ventilation or additional roof

This model is handed out to the students and first analysed. The task is then to optimise (not a software-based optimisation is meant here, but a "handish" step-by-step optimisation) the building including the HVAC system in terms of its overall operation primary energy use, while still keep the comfort conditions in an acceptable range.

Groups of 2 to 3 students are formed, who are asked to first discuss the measures to be applied and make an estimation of the impact. Then apply the measure one by one and report the results. A pre-defined EXCEL sheet is provided for this.

However, this optimisation is made in two rounds. In the first round, the groups are restricted to apply measures only in an area of technique assigned to them. These areas are defined in a brain storming session before, based on the knowledge of the possibilities of the software gained in the preceding steps. The result of the brain storming session is usually an unstructured list of about 20 to 30 topics, sometimes unclearly formulated and needing interpretation, e.g. the following list (an example from one year):

- Building shell (Insulation / U-values, tightness), opaque
- Building orientation
- heating system (floor panel heating / radiators, basic load by air, heat generation)
- Ventilation system (control, heat recovery, settings…)
- Windows (U-value, g-value, areas….)
- Solar protection (inside/outside)
- External shading
- Room temperatures
- Cooling system (waste heat recovery, generation, heat rejection...)
- Free cooling
- Media temperatures
- Lighting
- Location / exposition
- Surroundings (trees, neighboring buildings…)
- Internal heat sources
- Building inertia
- Thermal bridges

- Architectural shaping
- Zoning considerations
- User behaviour
- Solar radiation
- Daylighting, Lighting control
- PV
- Humidification

This list is then structured and grouped (to the number of student groups available) by the coach and presented to the students for the choice of one topic. The structured list can look like in table 1.

Table 1: Example of a grouped topic list

Number	Topic	Group
1	Orientation, location, climate, exposition	H
2	Shell/construction (insulation, inertia, tightness)	E
3	Windows (quality, size)	I
4	Lighting (quality, control)	D
5	Set points (temperatures, humidity)	A
6	Ventilation system (heat recovers, operation time, CO_2 control, fans, pressure drop)	F
7	Office equipment (efficiency), PV production	G
8	Heat and cold generation	B
9	Heat and cold emissions systems	J
10	Solar protection (properties, control)	C
11	Natural ventilation, free cooling	K

One of the challenges in this exercise is to encourage and fascinate the electrical engineering students, because they see a focus in thermal aspects and do not feel competent in this. Some of the topics in table 1 can be recognised as tailored for the electrical engineering students.

In this topical "corset", the first round of "optimisation" is performed. This can sometimes lead to frustrating results, because measures in some areas will not lead to the desired result due to influence of other, more predominant areas. But it is very useful to recognise that everything is interconnected and this is really representted in the simulation model.

After the presentation of the group results, the second round is performed, where the groups are free to choose any combination of measures. By having seen the results of the other groups, they have the tracks of the tracks with more impact. An important issue, regularly causing interventions, is that they tend to combine measures at one time rather than sequencing them one by one.

This round is then performed as a competition, with the best group (leading to the lowest total primary energy consumption) winning a price (a bottle of wine sponsored by the coach). This usually enhances curiosity, fantasy and eagerness to win. It also enhances the tendency to cheat (e.g. by using unrealistically low internal gains or high efficiencies etc.). This is considered in the ranking for price allocation, although with a twinkling eye: if the students figure out how to cheat, the learning effect is also reached.

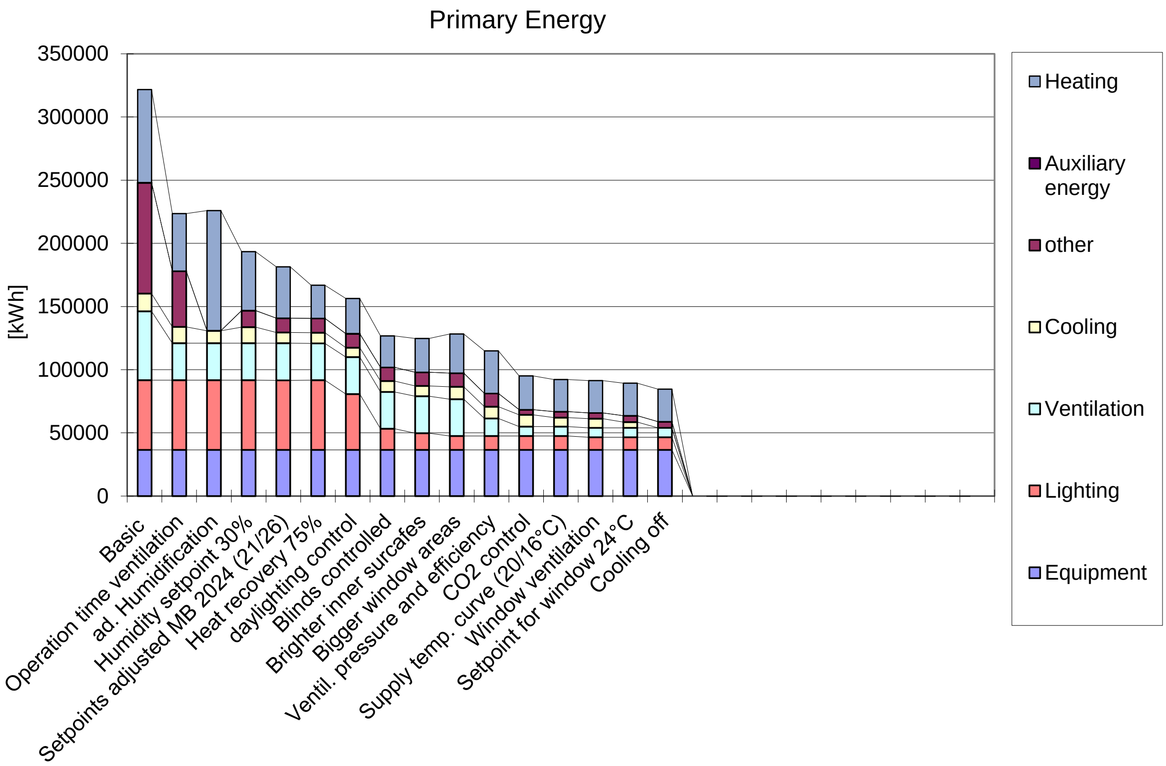

Figure 4 Example result of the building optimisation

The second round is finished with a discussion and feedback, where the coach usually presents an example solution. Such an example is shown in figure 4. One of the main messages transported by this example solution is the big potential of operational measures, such as adjustment of set points and reduction of operational times to the time where it is really needed. These are low cost potentials which can easily be applied and also show up in reality. Another issue is the interdependence of measures: e.g. the daylight dependent control does not deploy its full potential until the control of the solar protection is adjusted and more daylight can penetrate.

Some of the student's sequences come close to this example. They find the "low hanging fruits" and the potential – in the order of 75% in this case – is also reached.

Besides the special issues already mentioned above, it is one aspect where the electrical engineering students can find their competence represented and influencing the result in almost every area: building automatization and control. In the simulations of the HVAC systems, this is an omnipresent issue with big impact.

Evaluation by the students

Students' feedback is gained in two ways: a spontaneous oral feedback round at the end of the "optimisation" exercise, and through the School's usual online evaluation tool. The students usually appreciate the competition approach of the "optimisation" exercise and confirm this being both motivating and instructive. Not unexpectedly, the piece often less appreciated is the introductory "warm up" modelling exercise, the value of which is not fully recognised.

Follow-up modules

In the voluntary subsequent module "Modelling and Simulation 2", some advanced simulation topics are introduced:

- Advanced level modelling, for building up own HVAC system structures;
- Integration of control options in the models, picking up the knowledge from the respective modules;
- Writing and implementing own component models (using the program's inherent modelling language "Neutral Model Format, NMF"; in future this will be changed to MODELICA).
- Implementation and use of a plug-on optimization tool for automatic optimization;
- Continued CFD or daylighting simulations.

In parallel, a "simulation studio" is held, where the students can bring their own models – sometimes originating from their bachelor thesis work, and develop these under the coaching of the lecturing team.

Quite impressive complicated HVAC system models can show up in this phase, depending on the skills and motivation of the students. An example is shown in Figure 5. This originates from Elmiger and Sebastiano (2015) and represents one of many options of DHW generation and distribution systems for a multi-family house, for which the performance was compared.

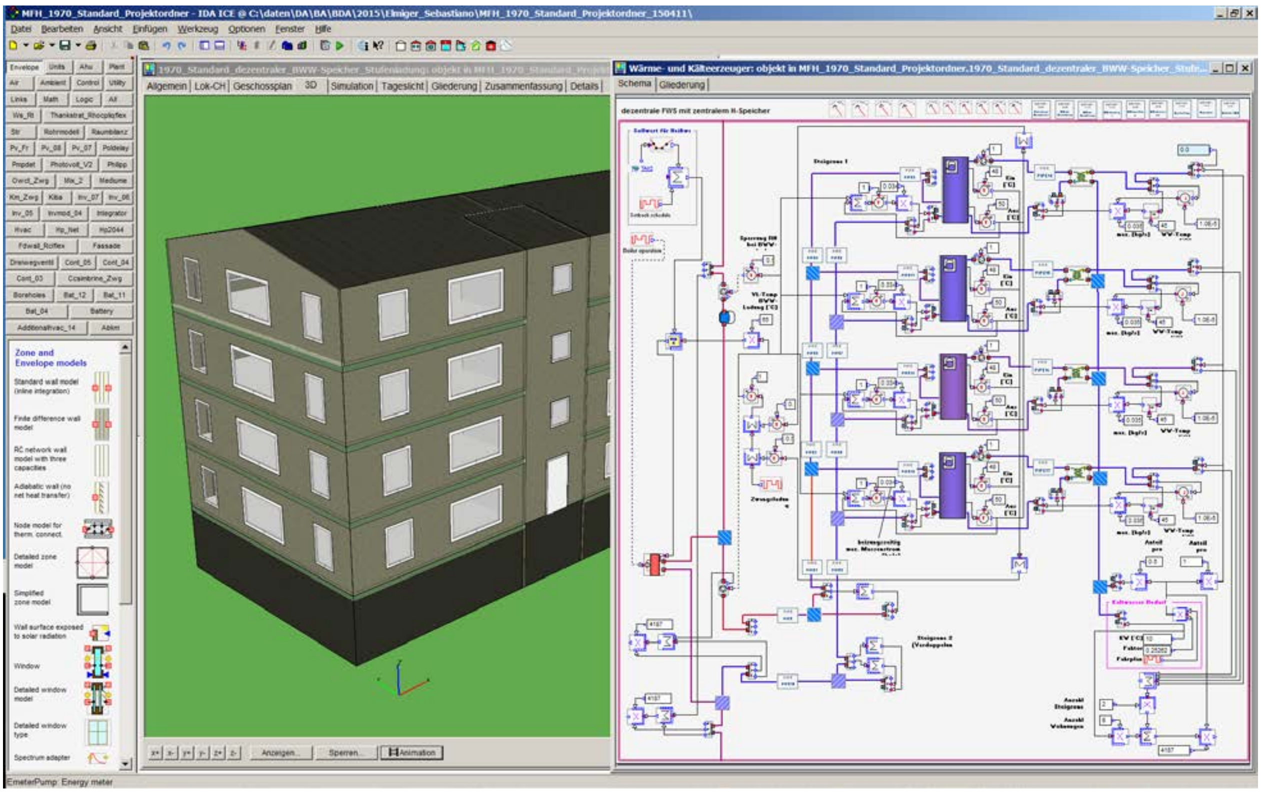

Figure 5 Example of an advanced HVAC model from the follow-up module

Running in the same semester in parallel, there is also an interdisciplinary module "Building Information Modelling (BIM)" offered, which has been developed and improved during the last 4 years. Students from all building related disciplines represented at the school: Architecture, Interior Architecture, Civil Engineering and Building Services Engineering (of both directions HVAC and electrical engineering) participate and work together in interdisciplinary teams. The emphasis is on the interoperability issue, and the groups try and experience data exchange between their native software via the IFC format.

One of the tasks performed by the building services students is to perform a simulation based on the architectural model from their colleague, by importing this in the simulation software. An example of a BIM based collaboration project with simulation software import is shown in figure 5.

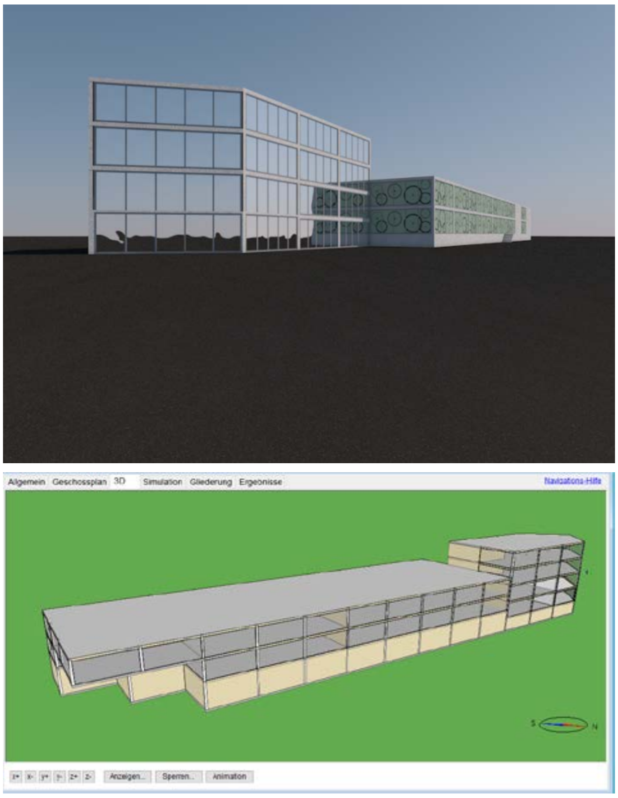

Figure 5: Example of a BIM project visualisation and simulation software import

This is one of the most advanced applications in the BIM area, and has been one of the initial motivations for development of IFC (Bazjanac 1997). Also, the main motivation for the author to spend a sabbatical in Finland in 2010 (Laine 2010) was the benefit for building simulation applications.

Finally, at the very end, an even deeper examination of advanced simulation is offered to students willing to enrol for a MSc program. In most cases, they go for optimisation topics, where they also get the accompanying lessons on statistics and stochastics. More than one IPBSA student competition award winners have evolved from this program (2011, 2015).

Conclusion

A method for teaching building simulation to building services engineering bachelor students has developed and optimised over many years.

The special education system needs to be considered, but this offers possibilities from a practical perspective.

The method will continuously be further optimised and adjusted to software developments. This also offers new perspectives.

A considerable part of dissemination of simulation into the building services industry has been reached and is still continuing by the students going out and transporting this experience.

Acknowledgement

Thanks are given to the Engineering and Architecture Department of the University of Applied Sciences and Arts for the support of the modules, especially the execution of the follow-up "Modelling and Simulation 2" module with small numbers of students, and also for supporting the presentation of this contribution.

Thanks are also expressed to the many students having attended these courses and having given feedback which lead to improvements, and also for their enthusiasm and curiosity they developed during the courses, while having fun.

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