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EDUCATION OF PASSIVE SYSTEMS IN THE US ARCHITECTURE SCHOOLS: FROM THE CONCEPTUAL LEVEL TO THE LEVELS OF SIMULATION AND CALCULATION

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ABSTRACT

The purpose of this paper is to assess the current level of the education of building simulation for the design of passive/natural systems in the US architecture schools. Although an extensive list of publications about passive/natural systems exists, there are very few studies addressing their level of education with a particular focus on the simulation tools and their application. This paper will present and discuss parts of the results of the data that was collected through online survey questionnaires focused on educators in the US architecture schools. The education of passive/natural heating, cooling, ventilation, daylighting, and renewable energy systems was each compared on three levels of simulation, calculation, and concept. The findings indicate a low level of the education of passive systems' simulation, particularly for the systems that need complex designs. In this case, daylighting simulations were more regularly taught, while the education of passive cooling simulation was more common than passive heating simulation.

INTRODUCTION

Buildings consume a large portion of the total energy use in the US. The residential and commercial building sectors account for almost one-third of the end-use energy consumption and 40% of the total source energy consumption (LLNL, 2018). Using renewable energies and passive/natural systems in buildings could be an important strategy for designers to reduce the need for this purchased energy by drawing on the ambient condition for heating, cooling, and illuminating buildings. A high and proper application of passive systems in buildings needs to be supported by a proper level of education for applying these systems. Architecture schools can play an important role in defining and developing the level of this education.

Publications from the 1970s until the present have been continuously addressing/teaching passive design strategies by advocating their benefits and design procedures (Mazria, 1979; Balcomb, 1992; Sadatian et. al, 2012; Athienitis and Santamouris, 2013; Tian et. al, 2018). Many of these publications provided the basis of the educational sources for teaching passive design in architecture schools (Lechner, 2015; Grondzik and Kwok, 2018, 2015). However, the level of the education of passive systems have rarely been discussed, particularly with a focus on the simulation of passive systems and the tools applied by educators and students in class projects.

On a broader scope, although there are several studies on teaching building simulation in architecture schools, they rarely have a focus on the US. For example, the issue of quality has been addressed in courses which were taught at three levels at the Department of Architecture, Building and Planning of the Technische Universiteit Eindhoven. This study included second year undergraduate as well as first year and final year graduate students. The instructors realized that users' domain knowledge and simulation skills in combination with validated/verified building performance simulation software define the main components of quality assurance in these courses (Hansen and Radosevic, 2004). Another study has recommended that students during their education should be introduced to scientific and technical foundations for the use of simulation tools to learn how to integrate them in their own practice (Pedrini and Szokolay, 2005).

In one study at the University of Adelaide in Australia, Masters architecture students were asked to use a simulation program to evaluate the comfort and energy performance of their designs. This study revealed several key issues in teaching and using building simulation in class projects including: students' prior knowledge on building thermal performance, student's need for strong graphical interface, students' need for less numerical input, and students' unwillingness to change their designs based on simulation results (Soebarto, 2005).

In one of the few studies focused on US academic institutions, a survey revealed that Ecotect, Energy 10, HEED, and Radiance were the most frequent simulation tools at the time of the survey (Haberl, 2008). This study concluded that: first, IBPSA should find a more comprehensive survey of simulation use in architectural, engineering, and professional educations; and second, IBPSA should survey architectural and engineering firms to find out what simulation programs they prefer that were being taught in schools. Since the time of this study in 2008 many of the simulation tools became obsolete and replaced by more powerful and accurate simulation software, which justifies the need for a new survey.

In another experiment in a US academic institution focused on a class of architecture students, the researchers expressed that the key issue in building simulation is the unfamiliarity of architects with reading energy simulation results or incorporating the results into their designs. The authors defined a game-based teaching approach through which students were given several options to design the most energy-efficient building collaboratively within cost limits in 90 minutes. The result was a more engaged classroom with students who became more interested in simulation software and environmental design. The researchers suggested that such simulation games could be taught in two ways:

- Simple online, schematic, simulation software run by students
- Advanced programs run by simulation experts to inform students

In a context with such materials published on building simulation education in general, and with numerous publications on natural/passive systems in particular, it is reasonable to ask what is the actual level of teaching the simulation of these systems in architecture schools in the US and how we can promote it? Therefore, there is a need to assess the current level of the education of passive systems in the US architecture schools to discover its challenges/opportunities.

This study considers those design strategies passive/natural that use the ambient energy sources (e.g. solar energy) instead of purchased energy (e.g. electricity) to heat, cool, ventilate, and illuminate buildings. This study excludes the strategies of continuous insulation, high R-value, and air-tightness of building envelope components from passive design strategies in the survey. These strategies were not the focus of this study and need a separate focused survey due to their significance and the required extensive scope of analysis. In the following sections, the status of teaching passive systems and renewable energies from conceptual to simulation and calculation levels has been measured and discussed.

EXPERIMENT

This research started with a broad review of the literature on passive systems and the potential issues for their application in the US. This review informed the content of the research methodology including the survey and analysis of the collected responses. As a part of the survey the education of the simulation of these systems was investigated.

The online survey questionnaire, using Qualtrics software, was designed to find answers in response to the issues found in the literature review on the application of passive design including the simulation of passive systems. The survey questionnaire was sent to academics and professionals in the field to ask for their feedback, which informed the content of the survey through several revisions.

The part of the survey that was measuring the teaching levels consisted of simple and tabular multiple choice questions, an image question, and a narrative question.

As a part of the survey the respondents were asked at what level—including simulation, calculation, and conceptual—they have been teaching the following design strategies in the last ten years:

- Renewable energy systems
- Passive/natural heating strategies
- Passive/natural cooling strategies
- Daylighting strategies
- Building envelope strategies

Educators were also asked about the tools they use for analyzing the feasibility of a passive system in their class projects. The selection of educators in architecture schools was based on the list of the top 50 architecture colleges and schools in the US (NICHE, 2019). At the end of the survey 36 useable survey responses were collected.

DISCUSSION AND RESULT ANALYSIS

Demographic analysis

The SBSE, ACSA, and LEED AP affiliations were the first three affiliations that educators selected. Of these choices about 66.7% of the respondents were SBSE, 50% were ACSA, 47.2% were LEED AP, 44.4% were AIA, and about 33.3% were ASHRAE members. About 55.6% of the educators had less than 20 years teaching experience and the remaining 44.4% of the educators had different ranges of teaching experience from 20 years to more than 34 years. The combination of old educators who had over 34 years teaching experience (13.9%) with young educators who had 5-14 years teaching experience (27.8%) formed the majority of the respondents. About 61.8% of the educators were licensed architects while 11.8% of the educators were Professional Engineers (PE).

The majority of the educators had a specialty in courses focused on sustainable building technologies (8.5% of the selection counts), which seems reasonable due to the current and growing interests in sustainability in architecture programs. The same can be said for courses in environmental control for passive systems (7.3%), building envelope (7%), and environmental control for active systems (6.7%). Teaching specialties exclusive to building simulation were ranked in the middle, from 11th to 13th, among the 20 claimed teaching specialties and included building energy optimization (5.6%), building simulation (5.0%), and building performance optimization (4.4%) respectively. The low percentage of building simulation specialties suggest that there is a need to promote the inclusion of building simulation courses in the US architecture schools' curriculums by hiring their required experts and instructors. An alternative interpretation on this result is that there may not be a large demand for these skills by architects, while these skills can considerably promote the performance of their building designs. Further research and a separate focused survey is required to validate one of the two mentioned hypothetical reasons on the low percentage of simulation specialties in architecture schools.

Based on the results, Masters of Architecture (27.9%), Bachelors of Architecture (26.2%), and PhD Degrees (16.4%) form the first top three degrees earned by educators who are active in the field of passive/natural systems. Master of Science (14.8%) and Bachelor of Science (8.2%) represent the fourth and fifth types of degrees pursued by educators. Given the third rank for educators with PhD degrees in the survey results, there is a potential to increase the number of faculty members in higher education who have PhD degrees related to the field of passive/natural systems if research for updating and promoting the old passive literature is desirable.

The following sections investigate the results of educators' responses to the teaching levels of renewable energy systems, passive/natural cooling and heating, and daylighting as well as their simulation tools.

Renewable energies

The most frequently taught renewable systems by educators in the US, in order, included Photovoltaics (33.5%), solar thermal collectors for domestic hot water (17.9%), geothermal (18.4%), solar thermal collectors for space heating (16.8%), and wind turbines (10.6%). However, the distribution of the level of teaching varies for each system from conceptual to simulation and calculation. In particular, except for photovoltaics, the majority of teaching levels remain in the conceptual level as shown in Figure 1. The simulation of wind turbines has not been taught by any of the respondents. Teaching the simulation of geothermal and solar thermal collectors are almost on the same level, although at a much lower level compared with the teaching of PV systems' simulations.

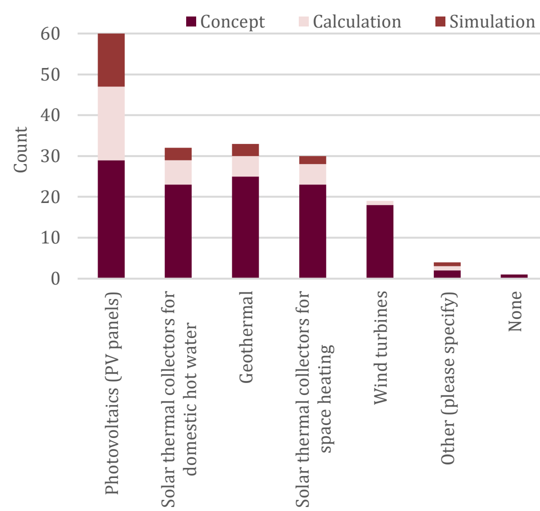

Figure 1 Renewable energy systems' teaching level/frequency

One reason for such a large difference could be the availability of many simulation tools exclusively tuned for the design of PV systems, which are rarely available for other renewable energy systems. Most of these tools are accessible online or through cloud-based platforms. Additionally, the concept of PV panels seems to be more familiar to architecture students and educators, due to its currently widespread application as well as easier design/installation procedures. There is a need for further investigations to clarify if these hypothetical reasons support the wide use of simulation tools at schools for PV design.

Passive/natural cooling

External shading devices (9.5% of selection counts), cross ventilation (7.6%), and stack ventilation (6.9%) are the educators' top three taught topics among passive cooling strategies. As shown in Figure 2 the teaching of the simulation/calculation of a system reduces as the system becomes more complex. For example, roof pond or downdraft cooling systems are not simulated at all by the respondents. On the other hand, shading devices and natural ventilation systems in a range from external/internal to dynamic, and from cross/natural ventilation to natural ventilation with thermal mass, are the most frequently taught systems in the simulation and calculation levels. Double roof and earth contact are two of the passive cooling strategies that are not taught at the calculation level. This could be, hypothetically, due to the complexity of the calculation required for these systems, such as the ground temperature calculations.

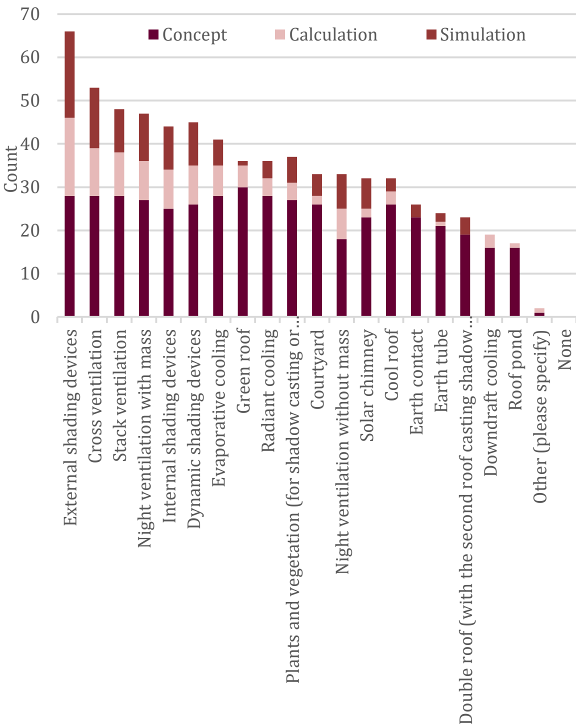

Figure 2 Passive cooling systems' teaching level/frequency

Based on the educators' professional registration as an architect or engineer, the results show that licensed architects do not teach simulation of the passive cooling strategies that contain earth as one of their design elements as in the case of earth tube or earth contact. Roof pond is one of the strategies which is only being taught at the conceptual level by both engineers and architects. Overall, the survey results show that simulation of passive cooling strategies, except for shading devices and cross ventilation, are receiving a low level of attention in education.

Passive/natural heating

Direct solar gain (20.2%), isolated solar gain (12.5%), indirect solar gain in Trombe' wall with water (11.3%), and indirect solar gain in Trombe' wall with non-water thermal mass (11.3%) represent the most selected teaching topics for passive heating respectively.

Figure 3 shows the frequency of teaching passive heating strategies by educators in the three levels of concept, calculation, and simulation. The results show except for the direct solar gain system, teaching simulation and calculation of other passive heating strategies is not a usual teaching practice. In this case, simulation and calculation of isolated gain systems, indirect gain systems, and solar chimneys are being taught more than other systems. More precisely, simulation of the isolated gain systems, indirect gain systems, and solar chimneys vary from 37% to 20% of each system's corresponding conceptual teaching level. Transpired wall system is the rarest teaching topic at the simulation level (0.3%).

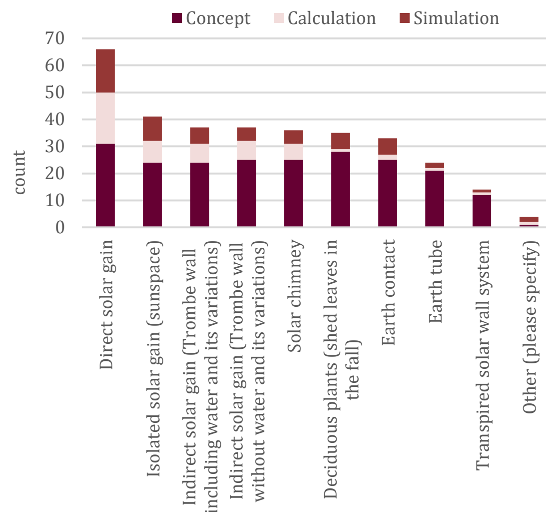

Figure 3 Passive heating systems' teaching level/frequency

Based on the results, teaching the calculation of passive heating systems is of higher interest compared to their simulation for the top five topics taught. These topics include direct, isolated, and indirect solar gain systems (Trombe' walls with/without water) and solar chimneys.

Overall, based on the survey results, with the exception of direct solar gain systems, simulation of passive heating systems is rarely taught at architecture schools. The teaching frequency of the simulation of passive heating systems is even lower than the teaching frequency of the simulation of passive cooling systems. This might indicate losing a great opportunity to prepare students for the design of these systems in the future, where at least half of the country has a cold climate.

Daylighting systems

As show in Figure 4 the top choices of educators for teaching daylighting systems included skylights (12.9%), light shelves (12.9%), clerestory windows (12.2%), sidelights (12%), and atriums (9.8%).

Similar to passive/natural design strategies, simulation and calculation of daylighting systems are being taught with a lower frequency compared to their conceptual teaching. Frequency of teaching the simulation of light pipe, light duct, and dynamic daylighting systems are the lowest with 1% to 0.7% for their simulation in each case.

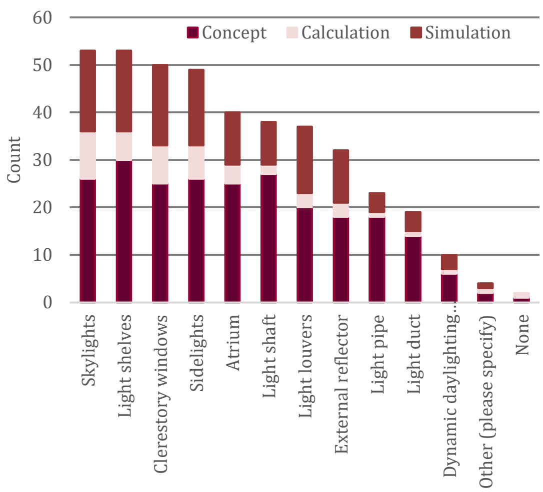

Figure 4 Daylighting systems' teaching level frequency

Compared with the education of other passive systems, simulation/calculation of daylighting systems has been taught more frequently in architecture schools. The concept, simulation, and calculation of skylights, light shelves, clerestory windows, and sidelights are better taught in architectural schools compared with other daylighting systems. The frequent design application of these systems, compared to other daylighting systems, could be a hypothetical reason for their higher teaching frequency, which needs a separate survey to be verified. Atrium and light louvers ranked next or lower regarding their simulation/calculation teaching frequency, thereby calling for further attention in teaching simulation courses due to their unique building performance contributions in designs.

Passive building envelope strategies

For passive building envelope strategies, educators selected the double skin façade (34.8%), phase change materials (26.1%), movable insulation (24.3%), and non-motorized kinetic façade (12.2%) as their frequently taught topics. Among these choices, the most frequently taught strategy included the phase change material at the calculation level and the double skin façade at the simulation level. As shown in Figure 5, non-motorized kinetic façade is the least taught topic in all three levels of concept, simulation, and calculation. The results imply that recent passive envelope strategies such as kinetic facades as well as advanced passive systems such as double skin facades require a better education at the simulation level.

Simulation tools

Educators were asked about more than 36 manual and digital tools for analyzing the feasibility of passive systems in their class projects. After reassigning the category of "other" tools based on the survey responses, 41 different digital and manual tools were collected from the responses as shown in Figure 6. Climate Consultant (10.4%), Sefaira (7.4%), Manual tables, charts, and protractors (7.0%) were the top three choices used by educators in their class projects.

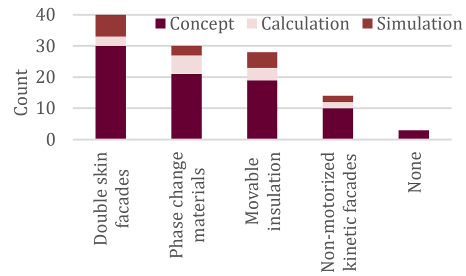

Figure 5 Building envelope systems' teaching level/frequency

The survey did not ask respondents why they chose a certain tool over the other, although hypothetical interpretations can be made based on their tool selections. These interpretations need separate surveys to be validated. For example, the high frequency of using Climate Consultant and Sefaira could be due to their friendly and fast grasping interface as well as the possibility of integrating them with modeling software such as SktechUp and Revit, which are easier for architecture students to learn. As another hypothetical reason, the high use of manual tools by educators in class may imply that the majority of educators consider it a learning requirement for students. From another perspective, the additional time required for instructors/students to learn a new software could be a reason for the inclusion of manual tools among the educators' top three choices. A separate survey focused on these hypothetical claims can find the actual reason.

The next set of tools, among the top ten tools being used by educators, included Diva for Rhino (6.5%) Energy Plus (6.1%), Ladybug/Honeybee plugins for Rhino (6.1%), Spreadsheets (6.1%), Radiance (4.3%), WUFI (3.9%), Therm (3.9%), Revit Tools/Plugins (3.5%), eQuest/DOE2 (3.0%), HEED (3.0%) OpenStudio (3.0%), COMFEN (3.0%), Daysim (3.0%), DesignBuilder (3.0%), and Autodesk Flow (1.7%).

Other tools being used by educators included BeOpt (1.3%) Autodesk CFD (0.9%), HAP (0.9%), Passive House Planning Package or PHPP (0.9%), TRNSYS (0.9%), Personal or In-house Software (0.9%), and Archsim (0.9%). F-Chart and Ansys Flow with 0.4% are the least frequent tools used by educators. Despite the potential power of TRNSYS for exclusive analysis of passive systems in buildings, educators have rarely used this tool (0.9%). This lack of tool application or low application could be the result of educators' and students' unfamiliarity with the tools due to difficult

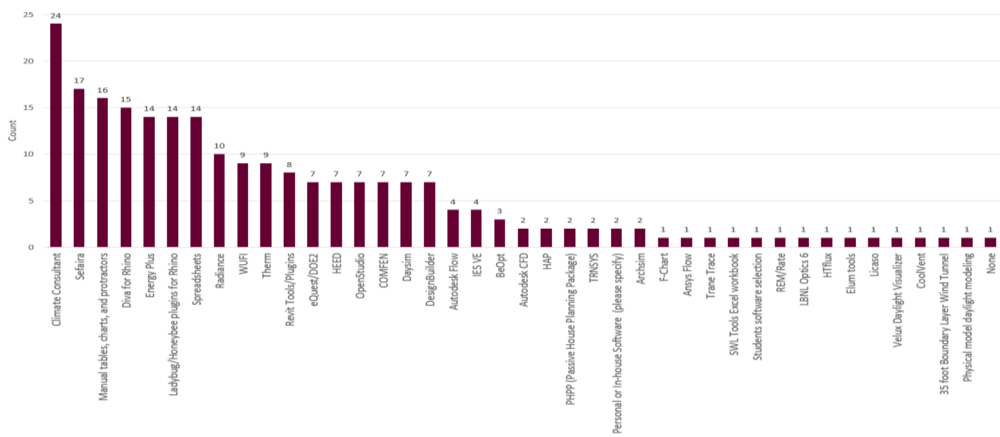

Figure 6 Simulation tools used by educators

accessibility to open source and comprehensive training resources. All of these hypothetical claims need separate surveys to find/clarify the actual reasons.

Each of the other tools that educators specified had 0.4% application frequency, which included tools such as Trane Trace, Excel workbook, REM/Rate, LBNL Optics 6, HTflux, Elum tools, Licaso, Velux Daylight Visualizer, CoolVent, and software tools open to students' decision for class use.

Among the daylighting tools, Diva for Rhino, Ladybug/Honeybee plugins for Rhino, Radiance, and Daysim were the educators most frequently used tools respectively. These tools were followed by the tools specified in the other category including LBNL Optics 6, Licaso, Elum tools, and Velux Daylight Visualizer. Availability of Diva and Ladybug/Honeybee tools and their training resources to students/educators, and their integration with Rhino as a powerful design software could be a reason for their frequent application.

Similarly, availability of Autodesk performance analysis tools, their free available training resources, and their possible integration with other design/BIM tools such as Revit could be a main reason for their higher selection by educators for exclusive CFD analysis. However, due to the required expertise for using the interface of these CFD software packages, it seems that students and educators mostly use plugin tools, such as Rhino plugins, for the natural ventilation simulations. A separate survey is required to validate this hypothetical claim.

Discussion of the open-ended text question

Among the responses to the open-ended text question of the survey, several responses had a focus on the simulation of passive systems. Some of the educators believed that learning the concepts, in comparison to simulation/calculation, is the key in teaching passive systems to students. Some other educators added that learning/teaching basic rules of thumb for various passive design strategies—with respect to overall limits on size, massing, scale, and other features of a building or its zones—is a critical first step in implementing many passive design strategies.

However, the author believes these approaches while useful for the teaching of passive systems are not enough for taking students to the level of the implementation of these systems after graduation. The students' conceptual perception needs to be developed to an ability for analyzing these systems' performance. Changes in the existing educational requirements in architecture schools, which is defined by NAAB (National Architectural Accrediting Board), may expand students' perceptions of building performance simulations. The author's belief in the usefulness of this change is based on the content of the NCARB (National Council of Architectural Registration Boards) Education Standard, which is the approximation of the requirements of a professional degree program accredited by NAAB (NCARB, 2018). It includes a minimum of 150 semester credit hours in six subject areas of general education.

Among these subjects, courses in Environmental Control Systems and Building Enclosure Systems are part of the requirements for a NAAB-accredited program, which may provide opportunities for teaching building performance simulations. However, these courses comprise about only 6% of the total required credit hours. In addition to design studios, which may rarely provide opportunities for learning building simulations depending on the instructors' knowledge, these courses are the only opportunities for a systematic teaching focused on the simulation of passive systems. Therefore, it seems that educators have a very limited opportunity to teach the concept, calculation, and simulation of passive design to students. In this case, large architecture schools, architecture schools in close collaboration with engineering departments, and schools with sustainable building technology programs, seem to hold a stronger position in teaching the simulation of these systems.

Some of the respondents mentioned that it should be kept in mind that architects, with some rare exceptions, are responsible to design and integrate systems, but not to calculate their performance. This group maintained that generally speaking engineers are responsible for the calculations of buildings heating and cooling loads. They extended that the use of passive systems is driven partly by the client's responsiveness to include these systems, for which simulations need to consider the lifecycle costs associated with energy benefits to find the value over a client's interested period of time.

Importance of simulation

To find out about the top challenges/opportunities that can increase the use of passive systems in buildings educators were asked to select three choices from a proposed list of eleven challenges/opportunities in the application/implementation of passive systems. The educators' top three choices included "simulation tools with capabilities for analyzing passive systems" (16.7%) "building codes and rating systems" (15.7%), and "experience of the project team in the design, implementation, and integration of passive systems" (10.2%). Another choice sharing the third place was "clients' desire and collaboration to include passive systems" with 10.2% selection. Giving the highest priority by educators to simulation tools capable of analyzing the use of passive systems indicates that there is a need for such tools and the required training to promote the teaching and application of passive systems.

Recommendations

Certain strategies can be adopted to promote the education of passive systems' simulation in architecture schools, form which several examples will be described here. Beyond conceptual education, the calculation and simulation of passive systems need to be taught through both individual course modules and courses integrated with topics on active systems. Passive systems should be taught also as integrated parts of design studios. Design studios, such as integrated studios, among other courses represent valuable opportunities for students in architecture schools to gain experience on the integrated application of simulation techniques in a design process. Teaching the calculation and simulation of passive systems to architecture students should be through simple methods to be easily understood and applicable. Therefore, teaching approaches should avoid asking architecture students to calculate the complicated equations of these systems. Instead, simple tools can make considerable contributions if the tools and their training resources become accessible to students through online platforms similar to Autodesk tools.

Strong connection between the academia and the building industry with a focus on passive design/simulation can facilitate students' and educators' access to these required resources. Meanwhile, this connection through real and funded projects promotes educators'/students' motivations on teaching/learning simulation of these systems and increases the chance of collaboration between the academia and the industry.

Developing user-friendly simulation tools with passive simulation capabilities and updating the legacy passive systems with today technologies can pave the way for this collaboration. As mentioned above, these simulation tools should simplify the complicated, less frequently applied passive systems revealed by the survey (e.g. downdraft cooling systems). Based on the responses to the open-ended text question, these simulation tools and their education in architecture schools should be developed to include the level of lifecycle analyses, as in the case of lifecycle cost analysis.

CONCLUSION

In this paper the education of passive/natural systems were compared on three levels of simulation, calculation, and concept. Overall passive systems in architecture schools are being taught mostly at the conceptual level and rarely at the level of simulation and calculation. The findings indicate a low level of the education of passive systems' simulation, particularly for the systems that need complex designs. In this case, daylighting simulations were more regularly taught, while the education of passive cooling simulation was more common than that of passive heating simulation.

The survey results showed that the simulation of passive cooling strategies, except for shading devices and cross ventilation, receives a low level of attention in education. Similarly, except for direct solar gain systems, simulation and calculation of passive heating systems are rarely taught at architecture schools. In the case of daylighting systems, education of the top selected systems by educators (i.e. skylights, light shelves, clerestory windows, and sidelights) are better expanded in all three levels of concept, simulation, and calculation. However, there are concepts such as light pipes and dynamic daylighting systems that are the least taught daylighting systems at the level of simulation, which need more educational considerations. Except for photovoltaics, the majority of teaching levels for renewable energies has remained at the level of concept. The availability of many simulation tools exclusively tuned for the design of PV systems and their online public availability could be a reason for a higher level of their simulation education. Further investigations and surveys are required to validate this reason.

Availability of simulation training programs and simulation tools for students, particularly validated open source tools, can increase their application in class projects. This increase can be linked with opportunities for including more courses related to building simulation in architectural curriculums. Courses on building energy optimization, building simulation, building performance optimization, green building design studios, and energy systems could provide such opportunities considering the survey results, which show the low/medium level of teaching attention focused on these courses.

Educators, who mostly stated they have practiced in passive design, considered the simulation tools with capabilities for analyzing passive systems the main factor in increasing the use of passive systems in buildings. This may indicate that there is a need for further work on promoting the level of teaching these systems focused on their simulation. This demands architecture schools' timely attention to invest for the required expertise and tools in their programs. Providing simplified and user-friendly simulation tools, their integration into design studios and exclusive simulation courses, and including life-cycle analysis in teaching these tools could be examples of such an investment.

The findings of this survey was limited to 36 responses received from educators during the course of two months. Certainly, a larger sample size can provide more concrete findings on the teaching status of passive systems as well as their levels of teaching. The survey results discussed in this paper was an opening on the importance of teaching simulation in the US architecture schools, which opens up opportunities for future surveys, such as surveys focused on the cause of not using some of the simulation tools in architecture schools or surveys about other passive systems not discussed in this paper.

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