Construction of a Modular Teaching System for the Building Physics Course under the Guidance of Green Building

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Abstract: *With the development of green buildings in recent years, new knowledge requirements have arisen for architecture professionals, and the traditional model of teaching building physics, which is divided into various sub-disciplines based on physical phenomena, can no longer meet the needs of green building design focused on comprehensive performance optimisation. Therefore, the purpose of this paper is to build a modular teaching system for the building physics course based on the concept of green buildings. First, this paper studies the necessary links among the goals of green building performance and the basic components of building physics, and puts forward that modern teaching should shift from "element decomposition" to "system integration". Therefore, a modular knowledge restructuring strategy based on problems and system integration is proposed, the construction logic of the key modules is explained, such as the integration of the thermal environment and energy consumption regulation, and the synergy of the light and sound environment with spatial quality is elaborated. In this paper, we will introduce the sequence of modules and dynamic teaching; at the same time, we will also study how to effectively integrate performance simulation tools into the design tasks. A few kinds of feedback will be given to help improve teaching knowledge, ability and way of thinking at the same time. The basis for building physics knowledge will change from individual calculations and verifications to a general ability and thinking system for new green building design.*

Keywords: *green building, building physics, modular teaching, teaching system, performance orientation*

Introduction

With the changing concept of green buildings, more and more people have begun to pay attention to regulating the physical environment inside buildings, and thus the basic problems of building physics have also drawn more attention. However, the traditional building physics course is still organised in its own disciplinary system, and there are separate modules for heat, light and sound; thus, there is a significant difference in both the teaching content and the mode of teaching compared with the multi-objective collaborative optimisation and performance-oriented integrated design put forward by green buildings. Therefore, although the students have learned the rules for sub-item calculation, they are unable to apply these rules together in complex design situations to solve practical problems of energy saving, environmental protection and comfort; thus, there is a gap between knowledge acquisition and application. Therefore, it is necessary to systematically reconstruct the current teaching system for building physics in light of the demands of green buildings at present. Given the problems mentioned above, this paper will build a modular teaching system to explore how to integrate the knowledge of building physics with other subjects organically and create teaching materials and capacity-building paths for green building design and innovation.

1. Analysis of the Intrinsic Relationship between the Concept of Green Building and the Teaching of Building Physics

1.1 The Physical Core Elements in the Performance Goals of Green Buildings

The performance goals of green buildings are to optimise energy and material exchange in the building system with the external environment, and this process is highly dependent on the accurate control of the physical elements of the building. The general ideas of thermal engineering, optics and acoustics taught in the course of building physics are directly related to the quality of the indoor environment and energy consumption of a building. For example, the heat transfer properties of the building envelope will directly affect the heating and cooling load of a building; to make good use of natural light and coordinate well with artificial light on cloudy days is to achieve both visual comfort and favourable lighting energy use; finally, the sound insulation ability of the components in the building against airborne and impact noise will provide a foundation for a quiet life.

Therefore, the goals of reducing energy consumption, saving materials and improving the health of the people in green buildings are no longer abstract ideals but have been turned into quantitative requirements for the physical performance parameters of buildings. The above performance indicators will be taken as a reference for the actual implementation of the green building concept in design, construction, and so on. Teaching the physics of building construction should clarify these necessary links and strengthen them to make them systematic limitations and motivators for innovation at all times in the Design Process; thus, the analysis of physical performance can serve as an early-stage technical tool to achieve the goal of green buildings, rather than just being used for evaluation at the end.

1.2 Analysis of the Differences Between Traditional Building Physics Teaching Content and the Requirements of Green Buildings

The traditional teaching system for building physics is generally linear in accordance with the principles of physics, and independent knowledge blocks, such as heat, light and sound, focus on explaining the mechanism and basic calculations of a single physical phenomenon. Although the model of vertical deepening in this field ensures the orderliness of the system of knowledge, it may be difficult to incorporate all the various physical environmental factors of teaching in practice. With the new demand for green buildings to achieve all-round optimisation through cooperation, the teaching content has not been updated accordingly; for example, we have seldom studied the dynamic coupling effect of natural ventilation and thermal inertia, and we have not investigated in detail how different strategies for natural lighting affect indoor heat gain and glare control[1].

The reason is that the teaching goals have been changed. The purpose of traditional teaching is to help students learn about physical phenomena and acquire standard calculation methods; in contrast, with a green building orientation, one should start from the ultimate goal and work backward to integrate and apply all sorts of physics knowledge in this regard. Therefore, teaching should change from describing phenomena to solving problems, and from learning rules to maximising performance; thus, the focus of knowledge inheritance needs to be shifted away from calculating individual parameters and towards cultivating a holistic mind that can find optimal performance solutions under multiple objectives and many variables, breaking the traditional division of knowledge in other courses and achieving the systemic nature of green buildings.

1.3 Theoretical Paths for the Building Physics Knowledge System to Support Green Building Design

To build a theoretical foundation for applying building physics knowledge in the support of green building design, we should move from an "element decomposition" model to a "system integration" model. First, we need to organise the knowledge of building physics into "knowledge clusters" that are in line with the goals of green performance, rather than treating them as separate formulas and data. For example, to achieve the aim of "winter heat gain and thermal stability", this path can group and connect knowledge points such as calculation of solar radiation, heat transfer theory of building envelopes, the principle of thermal inertia and air-tightness design to form a goal-oriented knowledge unit.

The basic idea of the theoretical path above is to form a closed-loop connection among physical laws, quantitative analysis, design strategies and performance feedback. The class will show the students how to take the laws of nature and build a simple model, then repeatedly use the model for testing and improving an engineering design. That is to say, the building physics course should introduce performance-oriented design thinking and enable students to learn that physical calculations are not only used to verify results but can also be a source of design ideas. Based on the theoretical system above, knowledge of building physics can be employed in the design stage of green buildings to support the development of form innovation and make technical decisions.

2. Core Architecture and Content Restructuring of the Modular Teaching System

2.1 Principles for Dividing Modular Knowledge Units in Light of Green Performance Orientation

The Division of modular knowledge units should be based on the dual logic of the Design Process and performance goals. First of all, it is problem-oriented; that is, the main physical performance problems that occur in the green building design process are taken as the starting point for module construction, such as "low-energy design of the building envelope system" or "passive regulation of the indoor light and thermal environment". Each module should be a general performance problem and not only a single physical law. Second, the division of modules should be in line with the system integration; extract and organise knowledge points that are traditionally spread out in different areas, such as heat, light and sound, but ultimately aim for the same goal; thus, a logical knowledge system can be built, and the barriers among disciplines will be broken down[2].

The other is to set the scale and range of modules. The modules should be relatively independent and complete; that is to say, each module can be developed as an independent teaching unit, and clear interfaces need to be set up among the modules. The interface can be seen from the fact that the output of the previous module serves as the background or condition for the input of the next module; for example, the conclusions of the "solar radiation analysis and building heat gain" module will be directly used as input parameters for the "unsteady-state heat transfer and load calculation of the building envelope" module. The Division of modules should also be scalable and flexible; as new knowledge points or changes in the focus of the green building evaluation system and technology development occur, they can be added to the teaching system in a timely and modern way.

2.2 Integrated Knowledge Construction of the Thermal Environment Module and Building Energy Consumption Regulation

The primary reason for the restructuring of the thermal environment module is to strengthen the connection between the knowledge system of building thermal processes and the aim of dynamic regulation for building life-cycle energy consumption. The module needs to calculate the static heat transfer coefficient and build a complete knowledge chain; that is to say, it should start with the outdoor climate parameters and solar radiation analysis, then determine the unsteady-state heat transfer of the building envelope and natural ventilation potential, and finally predict the cooling and heating loads of the building, as well as energy consumption simulation. At this time, the traditional division of "building thermal engineering" and "building energy efficiency technology" has been broken, and the causal links and parameter transfers among all links are shown so that students can learn to analyze the whole process from physical mechanisms to energy consumption results.

The first need of an integrated knowledge system is to have a closed-loop design and a quantitative assessment method. Teachers can have students use dynamic simulation tools to quickly iterate on and compare the thermal performance and energy consumption of various building envelope design schemes, shading devices, other ways to promote natural ventilation, and so on. Therefore, the Design Elements of material thermophysical properties, construction detail design and spatial form should be directly converted into calculable physical model parameters. Therefore, the knowledge of thermal engineering will no longer be used only for post-construction evaluation; instead, it will be actively applied to guide all stages of design, optimise building shapes and construction processes at the conceptual design stage, and achieve true integration with the process of energy-saving design and implementation.

2.3 Collaborative Teaching Design for the Light and Sound Environment Module and Building Spatial Quality

The teaching plan for the light and sound environment module aims to improve the quality of collaboration in visual and auditory perception, and this is one of the goals of improving the indoor environmental quality of green buildings. This module should move away from the old way of treating daylighting, lighting and architectural acoustics as separate problems and study the interaction effect and joint optimisation path of the two in spatial design. Many factors affect the Design of windows at the same time, such as natural light and view, noise insulation, indoor reverberation time, etc.; the selection of interior surface materials is also related to the distribution of reflected light and the properties of sound wave absorption. Teachers should have students observe how these cross-physical-domain correlation mechanisms work and learn to incorporate all the design ideas.

The goal of cooperative teaching is to create a system for multi-physics coupled analysis and jointly carry out the analysis of spatial quality parameters. The teacher will teach the method of performance-based parametric analysis, and the students will be able to simulate all kinds of indices under different building shapes, window-to-wall ratios and interior material arrangements, such as lighting uniformity, glare index, background noise level and speech intelligibility. Based on all the above indicators and adjusting them according to different goals, teachers can help students learn how design choices affect the combined effect of light and sound in a particular place, and when to use them together or separately. A teaching model can help students learn how light and sound are produced by themselves and create their own worlds with these means[3].

3. Implementation Path and Quality Evaluation of the Modular Teaching System

3.1 Logical Connection of Module Sequences and Dynamic Organization of the Teaching Process

The order of the module sequences is in line with the natural logic that building design and physical performance analysis are interdependent. The first part of the teaching will be "environmental analysis and goal setting" to establish the foundation for climate response and performance standards, and then we will move on to "principles and methods of passive regulation" to learn how to regulate various environmental factors such as heat, light and wind. Based on the knowledge foundation provided in the previous lesson, the following teaching sequence will cover all parts of the advanced modules "active system coordination" and "comprehensive performance simulation and evaluation", starting with the basic rules and then moving on to combined applications and single-performance scenarios. Therefore, the output of the previous module will be taken as the foundation for cognition and technical support in the next module to achieve a spiral expansion of knowledge and skills.

The organisation of the teaching process should no longer be in the form of a fixed sequence; instead, it should be dynamic and flexible, with the goal of achieving learning objectives. Generally speaking, a short teaching cycle should be established to integrate the theoretical knowledge, tools and methods for teaching, design application, etc., closely and be able to iterate quickly. Teach each part of the core knowledge (e.g., dynamic thermal response of the building envelope), and immediately after teaching it, have students practice with the corresponding parametric analysis tool or a simplified simulation method. Next, a particular Design Task closely related to the theory (e.g., improving the performance of a window in a certain direction) will be given, and students need to immediately apply what they have learned in analysis and decision-making. Based on the common cognitive biases or technical problems students may encounter in the course of completing the task, teachers can provide timely group feedback or supplementary explanations to flexibly adjust the speed and content of teaching according to the current cognitive state of the students. Organisers will change the mode of teaching to be more interactive, allow students to learn in groups, and have their peers guide and support one another[4].

3.2 Embedding Strategy for Simulation Analysis and Performance-Oriented Design Tasks

An introduction to the Performance Simulation Analysis Tool should be added to the transformation plan for using the modular knowledge system in the actual design. In short, we want to change the purpose of simulation from the old way of checking results after completion to that of an active reasoner that introduces concepts early in the design stage, compares and selects schemes in the middle stage, and carries out fine-tuning in the final stage. THSWare Green Building Performance Simulation Software can be employed for parametric and visual dynamic tests of the actual performance of the design scheme in the Design stage. For instance, in a project to study the effect of spatial form on natural ventilation, students need to construct several massing models, simulate and analyse the arrangement of indoor air flow and wind speed distribution under different conditions of opening position, size and spatial connectivity, and then apply the results of the simulation to directly modify the spatial form. Thus, Design Thinking will be informed by data and facts, and a direct link can be drawn between the Design process and the desired outcomes.

The organisation of design tasks should specify the aim of achieving them and avoid using only one way to implement so as to motivate students to think flexibly and be more creative. The task brief should set a number of main performance goals (e.g., the number of hours per day of indoor illuminance meets the standard, the maximum rate of annual thermal discomfort dissatisfaction) as the required conditions for the design plan, but it should not specify particular construction methods or technical systems. Students should be able to independently collect and integrate the principles and methods of all the knowledge modules (e.g., thermal environment, light environment, sound environment) to conduct multi-objective trade-offs and optimisations. Together, they will learn how to use high-performance glazing, phase-change materials and adaptive shading systems to solve the problems of daylighting and heat gain; or, they can combine the Design of open spaces with sound-absorbing materials to achieve both acoustic privacy and visual openness. After several rounds of "design - simulation - evaluation - optimisation", students have learned an organised way to study and can use performance data to provide feedback for continuous improvement in their design choices; thus, they are able to learn actively rather than passively[5].

3.3 Multi-dimensional Feedback of Modular Teaching Effectiveness and System Optimisation Mechanism

From all sides and at different times, evaluate the effect of the modular teaching system; do not rely solely on the results of the final-term examination. The three types of assessment for learning in this system are knowledge, skills and thinking. Modular formative tests and concept maps will be used at this time to find out how well students have grasped the basic ideas and connections among them. To determine how well students can apply the theoretical knowledge in technical operation and tool-use skills to solve specific environmental performance problems, the evaluation criteria will be the application level of skills in process documents, simulation analysis reports and the final optimised scheme submitted by students for the design task of each module. To develop all-round thinking, the research projects or the final defence presentations in the system will be divided into several modules to systematically observe the high-level thinking abilities of the students, integrate knowledge from all areas of physics, make trade-off decisions, and find new ways to solve complex design problems under various conditions. Combine the feedback data from the three areas to show the general situation of the students' learning results.

All of the above will be taken to improve the closed-loop system. At the bottom of this mechanism is regular, organised analysis of teaching feedback data to find weak links in each module in terms of the transmission of knowledge, training of skills and cultivation of thinking. Some Optimisation measures are taken to adjust some links in the teaching chain, such as changing the proportion of theoretical depth and breadth for a particular module, updating the performance parameters and constraints of design tasks, or adding a more efficient chain of simulation analysis tools. In this way, the modular teaching system will be able to self-renew and develop, meet the new demands for technological progress in the area of green buildings and talent education, and create a dynamic and flexible environment for curriculum construction[6].

Conclusion

Build a modular teaching system for the building physics course based on green building performance and organise it systematically in this paper. First, given the inherent relationships among the knowledge, a new type of teaching based on problems will be introduced. Then, in line with the Design Process and performance goals, this system will be organised in a modular way, its core knowledge in thermal engineering, light and sound, etc., will be innovated, and the focus will be on integrating energy consumption regulation with the synergy of spatial quality. At the level of implementation, this paper puts forward a logically progressive module sequence and a dynamic and flexible teaching organisation method to enable the application of theory in the design ability through the integration of simulation analysis tools and performance-oriented design tasks. Based on the above feedback, we have made some adjustments to improve the teaching system's flexibility and quality. The goals, content and methods of teaching and learning in Building Physics will all be revised, as will the assessment system. In the future, more research will be conducted to expand the application of new simulation tools and digital platforms, strengthen the development of cross-module comprehensive design projects, carry out longitudinal empirical studies on the impact of this teaching system on students' design thinking and professional ability cultivation, etc.

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