Teaching indoor thermal comfort using computer technologies with inexpensive instruments

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ABSTRACT: As an eligible architect, one should be aware of the physical phenomena affecting buildings, in order to be able to improve design concepts to create comfortable indoor conditions. This article suggests an innovative solution combining computer technologies and inexpensive instruments to improve teaching in building indoor thermal comfort. This solution is compared with expensive and less available instruments in Chinese universities and complex manual calculations. Its advantage is obvious and its effectiveness has been validated by students' examination results.

INTRODUCTION

Building physics is a course that helps students understand the physics behind the acoustics, day lighting and thermal behaviour of a building. Many complex equations may challenge students since they focus on building design (a kind of art) and are not familiar with mathematical calculations. Therefore, teaching building physics requires experiments to improve students' understanding.

A number of pieces of experimental apparatus were developed for building physics. They play a significant role in helping students' absorption of knowledge about the complex phenomena involved in building physics. However, some of these instruments are too expensive and many universities in China cannot afford to buy them or can buy only one or two, which makes it difficult to improve teaching quality. For example, PMV-PPD is an important index in building physics, used to evaluate indoor thermal comfort. It can be measured by an instrument called WinIAQ (as shown in Figure 1) developed by a European company.

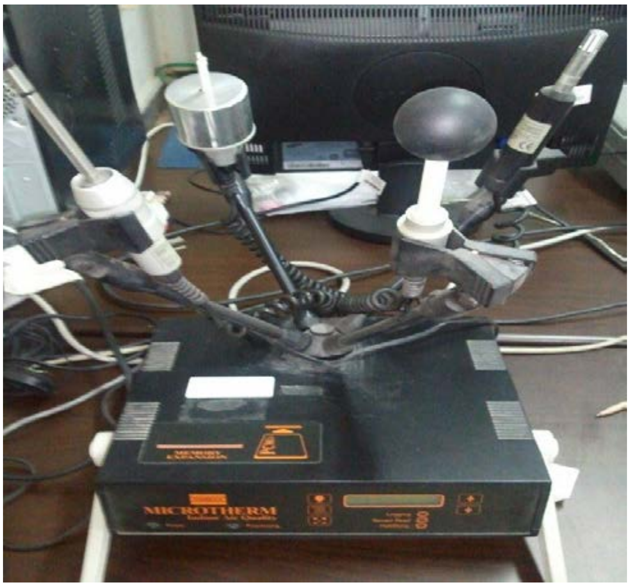

Figure 1: The picture of WinIAQ.

The price of this instrument can reach 1 million Yuan (the Chinese currency; 1 US Dollar is about 6.3 Chinese Yuan), which is far higher than regular temperature instruments and, thus, only a few universities bought this instrument due to the limited availability of educational funds. This leads to classroom teaching being restricted to the theory of building physics, with few and simple experiments as the main teaching method. Students, therefore, have limited opportunities to do experiments. Hence, there is a great need for innovation in teaching of building physics to enhance the teaching quality.

The literature on teaching improvement in building physics has computer technologies as its focus. Some researchers have reported on computer aided teaching solutions, such as those that can be obtained by using Ecotect [1], Matlab [2], etc.

However, some experiments, such as indoor thermal comfort tests require field measurement using expensive and not readily available instruments, and computer technologies alone cannot address this demand. This article provides an illustration of improvements in the teaching indoor thermal comfort (PMV-PPD index) in order to improve students' understanding about thermal comfort and its main influencing factors, through the innovative solution of using computer technologies with inexpensive instruments.

INDOOR THERMAL COMFORT EVALUATION

Indoor thermal comfort is an important aspect in building physics teaching. Many factors, such as room temperature, relative humidity, air velocity, etc, affect indoor thermal comfort. When evaluating indoor thermal comfort, the predicted mean vote (PMV) and predicted percent dissatisfied (PPD) were widely adopted as the principal indexes, which were established by Fanger in 1970 [3].

The PMV-PPD index can be calculated according to the following equations:

$$\begin{aligned} PMV &= F(T_a, \phi, T_r, V, M, I_r) \\ &= (0.028 + 0.3033e^{-0.036M}) \times \{(M - W) - 3.05[5.733 \\ &-0.000699(M - W) - Pa] - 0.42[(M - W) - 58.15] \\ &-0.0173M(5.867 - Pa) - 0.0014M(34 - T_a) - 3.96 \\ &\times 10^8 \times fcl[(T_{cl} + 273)^4 - (T_r + 273)^4] - fcl \times h_c(T_{cl} - T_a)\} \end{aligned}$$

Where:

$$\begin{aligned} T_{cl} &= 35.7 - 0.028(M - W) - 0.155I_r\{3.96 \times 10^{-8} \\ &\times fcl[(T_{cl} + 273)^4 - (T_r + 273)^4] - fcl \times h_c(T_{cl} - T_a)\} \end{aligned}$$

$$h_c = \begin{cases} 2.38(T_{cl} - T_a)^{0.25}, for(T_{cl} + T_a)^{0.25} \geq 12.1\sqrt{V} \\ 12.1\sqrt{V}, for(T_{cl} + T_a)^{0.25} \leq 12.1\sqrt{V} \end{cases}$$

Then PPD can be expressed as a function of PMV:

$$PPD = 100 - 95\exp[-(0.03353PMV^4 + 0.2179PMV^2)]$$

The relationship between PMV and thermal sensation is depicted in Table 1.

Table 1: The relationship between PMV and thermal sensation.

PMV	Thermal sensation	PPD (%)
+3	Hot	100
+2	Warm	75
+1	Slightly warm	25
0	Neutral	5
-1	Slightly cool	25
-2	Cool	75
-3	Cold	100

According to the above equations, it is clear that students may find it difficult or too time-consuming to do a manual calculation of PMV-PPD. Therefore, students may find it hard to acquire the required knowledge about indoor thermal comfort for the following two reasons:

- PMV-PPD testing instruments are too expensive to be widely used in Chinese universities;
- Complex manual calculation of PMV-PPD is too difficult to be grasped by students.

TEACHING INNOVATION AND ITS EFFECT

To overcome the above two problems, an innovative solution combining computer technologies and inexpensive instruments was developed, and in this article, it is illustrated in Figure 2. The main idea of this solution is to use inexpensive instruments to obtain basic environmental parameters (including air temperature, relative humidity, air velocity, etc) and, then, calculate the PMV-PPD index based on these data and pre-assumed values for occupant activity, etc, through a developed visual basic tool as shown in Figure 3.

The advantage of this solution, compared with PMV-PPD testing instruments, is that the required instruments are inexpensive and, thus, can be widely used by students. Moreover, students can easily change the measurement values to obtain its influence on PMV-PPD (the red dot as shown in Figure 3). This means students will have a better understanding of which parameters have a significant impact on indoor thermal comfort and which value is optimal. Compared with complex manual calculations, this solution is much faster and does not require sophisticated mathematical knowledge but, more importantly, manual calculations cannot be used to test a room. The advantages of this solution are summarised in Table 2.

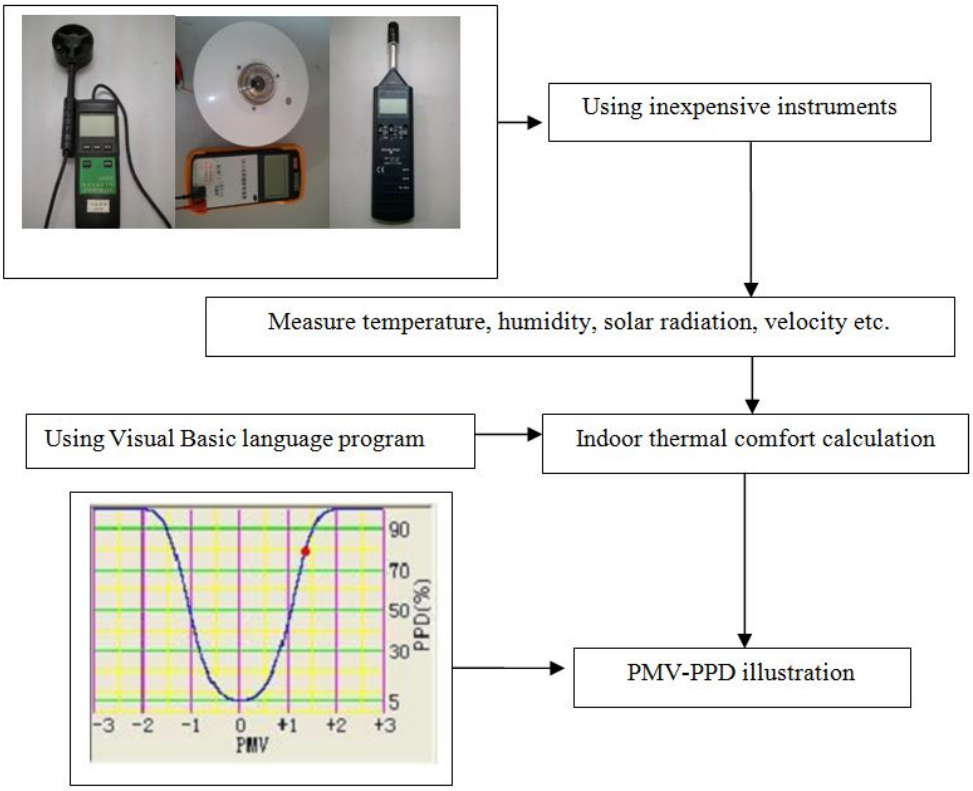

Figure 2: The flowchart of the innovative PMV-PPD teaching solution.

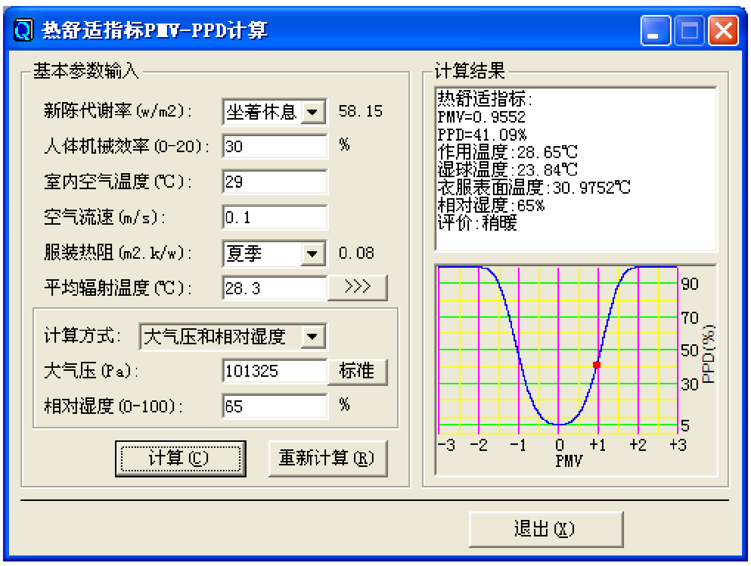

Figure 3: A demonstration of the PMV-PPD calculation tool.

Table 2: The summary of the advantage of this solution.

Type	This innovative solution	PMV-PPD testing instruments	Manual calculation
Students availability	Widely	Limited	Limited
Portability	Very good	Good	None
Price	Cheap	Expensive	None
Understandability	Easy	Hard	Hard
Interactivity	Very good	Poor	Poor

The effectiveness of this innovative tool in improving teaching in building physics was validated in a comparison of two examinations before and after using this solution. Figure 4 presents this comparison. It can be seen that students' scores improved after using this solution, especially for those students with scores between 60 and 70.

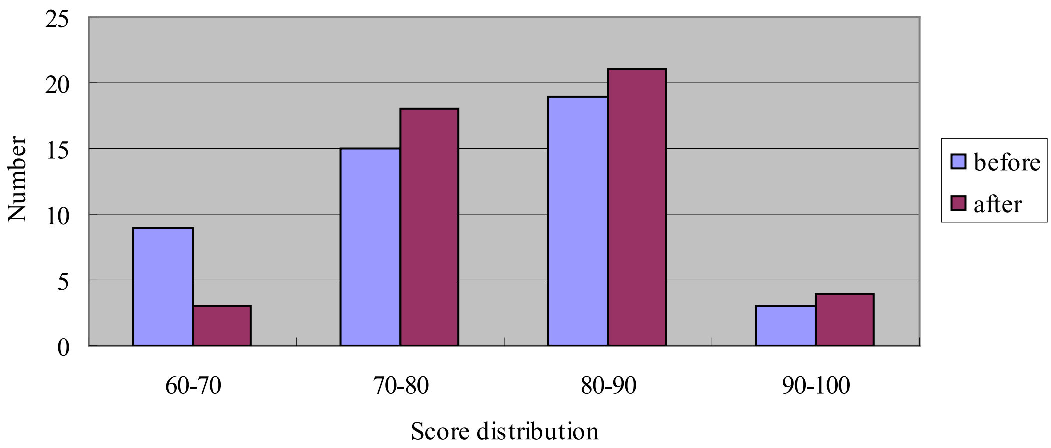

Figure 4: Students' score distribution before and after using this innovative solution.

CONCLUSIONS

Scientific knowledge of the physical phenomena affecting buildings is a necessity for students in learning building physics. This article describes an innovative solution combining computer technologies and inexpensive instruments to improve teaching in building indoor thermal comfort. This solution was compared with expensive and less available instruments and complex manual calculations. Its advantage is obvious and its effectiveness has been validated by students' examination results.

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