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# A PERFORMANCE COMPRISON OF ORDINARY AND CONTAINER CLASSROOMS IN AUSTRIA

P. Kaveh* and A. Mahdavi
Department of Building Physics and Building Ecology, Vienna University of Technology, Vienna, Austria.

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## ABSTRACT

This paper compares the indoor environment of ordinary and container classrooms in a number of schools in Austria. Temperature, relative humidity, and carbon dioxide concentration were measured. Moreover, teachers in each school were handed a questionnaire inquiring about factors such as ventilation practices, air quality, and thermal comfort in their classrooms. The results of the study suggest a slightly inferior indoor environmental performance of the container schools as compared to ordinary schools.

**Keywords:** Thermal comfort; container classrooms; monitoring; indoor climate; air quality.

## 1. INTRODUCTION

Besides being aesthetically pleasing, the human environment must provide adequate conditions from the health and comfort point of view. This contribution specifically compares thermal comfort and air quality issues in ordinary and container classrooms.

It has been known for a long time that the thermal comfort of a human being is not only a function of air temperature, but also of five other parameters; mean radiant temperature, relative air velocity, humidity, activity level, and the thermal resistance of clothing [1]. When combinations of these parameters satisfy the associated comfort equations, a majority of individuals are likely to be in a state of thermal neutrality [2]. Predicted Mean Vote (PMV) is a well-known thermal comfort indicator. Over the last decade, alternative higher resolution indicators employing thermo-physiological models have garnered interest. The adaptive thermal comfort standard (ATC), applying the indoor operative temperature in relation to the outdoor air temperature as the main performance indicator, represents likewise a more recent, though less complex approach [3].

The humidity in indoor air, which can be expressed in terms of temperature-dependent

* E-mail address of the corresponding author: paris_kw@yahoo.com (P. Kaveh)

relative humidity [4] or humidity ratio may directly or indirectly have an impact on the occupants. High air humidity, condensation or ingress of moisture stimulates the growth of moulds and other fungi etc. and causes allergies and malodours. Increased humidity may also augment the emission of chemicals like formaldehydes from construction materials [5]. Low humidity, on the other hand, may cause a sensation of dryness and irritation of skin and mucous membranes for some occupants [6]. Normally few problems occur when the relative humidity is between 30 and 70%, assuming that no condensation takes place [7, 8].

There are two basic requirements that must be met by the air quality in an enclosed and occupied space: First, the health risk associated with breathing the air should be negligible. Secondly, the air should be perceived as fresh and pleasant rather than stale, stuffy and irritating [9].

Humans produce carbon dioxide $CO_2$ in proportion to their metabolic rate. At low concentrations, $CO_2$ is harmless and it is not perceived by humans. Still it is a good indicator of the concentration of other human bioeffluents being perceived as a nuisance. As an indicator of human bioeffluents, $CO_2$ has been applied for more than a century [10].

According to ÖISS [11], the $CO_2$ concentration of classrooms should not exceed 1500 ppm. Studies suggest that the Pettenkofer aspired level of 1000 ppm is hard to achieve even in school buildings with mechanical ventilation systems. Attempts to reach very low concentrations may result in discomfort (due to draft) and high energy use. Rudnick and Milton [12] suggested that the risk of contraction of influenza in a classroom is greater at higher $CO_2$ concentration levels in classrooms.

The present paper as follows: The deployed method is described in Section 2. Section 3 entails the analysis of the results. Finally, Section 4 concludes the paper.

## 2. SECTECTED SCHOOLS AND MEASURED DATA

The selected five schools were located about twenty km south of Vienna in lower Austria (Baden) with a height of between 200 – 230 m above sea level. The largest distance between the schools was about 3.7 kilometres, so it could be assumed that these schools had comparable outdoor conditions. Two types of schools with ordinary classrooms (S1, S2 and S4) and container classrooms (S3, S5) were investigated. With ordinary classrooms we mean those in conventional multi-story buildings meant for permanent accommodation of school operation. The container classrooms are principally meant to be used on a temporary basis, for instance in cases where the main school building is undergoing retrofit measures. In reality, however, their period of operation is in many instances much longer than originally intended. In the present case, container schools were assembled in one or two stories from four containers aligned together in the length direction.

In order to capture the thermal and air quality conditions in the selected schools, data loggers were installed in each school. Temperature and relative humidity sensors were installed in four classrooms of each school. $CO_2$ sensors were installed in two classrooms of the ordinary schools and three classrooms of the container schools. The measurements of temperature and humidity were taken from February until the end of June 2011. Carbon dioxide values were obtained for the month of June 2011. Information about the selected schools is provided in Table 1. Table 2 contains details of the three types of sensors deployed.

Table 1: Information regarding the selected schools

| Schools | School type | Building type | Construction year | Refurbishment year | Orientation |
|---|---|---|---|---|---|
| **S1** | Primary | Ordinary | 1904 | 2002-2005 | Southeast-northwest |
| **S2** | Primary | Ordinary | 1970 | 2010 | South |
| **S3** | Primary | Container | 2010 | - | Southeast-northwest |
| **S4** | Secondary | Ordinary | 1970 | 2009-2011 | South and east |
| **S5** | Secondary | Container | 2004 | - | East-west |

Table 2: Sensor information

| Device | Measuring | Measurement range | Accuracy |
|---|---|---|---|
| **Hobo U12 a** | Temp | -20° to 70°C | ± 0.35°C from 0° to 50°C |
| **Hobo U12 b** | Temp | -20° to 70°C | ± 0.35°C from 0° to 50°C |
| | RH | 5% to 95% | ±2.5% from 10% to 90% |
| **Wöhler** | $CO_2$ | 0 - 6.000 ppm | 50 ppm, ± 5 % of reading |
| | Temp | -10 °C to +60 °C | ± 0.6 °C |
| | RH | 5% to 95% | ± 3 % (10 - 90 %) |

To obtain an interpretative context for the data, the teachers in each school were handed a questionnaire at the end of school semester in June 2011. Inter alia information such as ventilation practices, air quality (and related health issues), visual quality, and thermal comfort were subjects of enquiry.

## 3. ANALYSIS OF DATA AND RESULTS

The main results of the study are presented in the following in terms of a number of graphs. They summarize the results of the temperature, relative humidity, and carbon dioxide concentration measurements in the selected classrooms. Thereby, the focus lies on the month of February (representative of the winter period) and June (representative of the summer period).

Figure 1 entails the cumulative frequency distribution of the measured indoor temperatures in the five schools during the school hours (8:00-13:00) in February 2011. The information in this Figure suggests that in February (heating season) the temperatures of the two container schools S3 and S5 were higher than 25°C about 33% and 42% of the time respectively. The temperature in these classroom is thus maintained at a higher than necessary level during a considerable fraction of time. The reason for this circumstance cannot be attributed to the thermal quality of the container wall envelope and its possible effect on the mean radiant temperature in the room. The estimation of the mean radiant temperature for a rather cold reference day resulted in a deviation of the mean radiant temperature from the room temperature of only 1.2 K. It may be speculated that the smaller window sizes of the container schools result in lower daylight levels and – psychologically speaking – in a darker and colder impression. Occupants may conceivably compensate for this impression through maintaining higher temperatures. While this speculation cannot be verified, it does receive some support from the statements in the questionnaires. A more likely contributor to the persistence of high temperatures is an inadequate heating control regime, as discussed below.

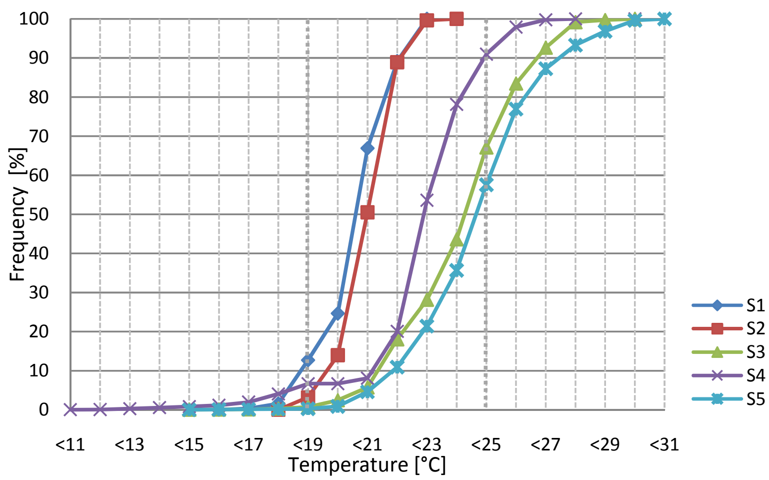


Figure 2. Cumulative frequency graph of temperature for five schools (8:00-13:00) in February 2011.

Figure 2 shows for a reference day in February (derived based on the medians of hourly temperatures during the month of February) the indoor air temperature in the five schools. During the operation hours, the indoor temperature noticeably increases in the ordinary schools. This circumstance is plausible, given the increase in internal (occupants and lights) and – to a lesser extent – solar gains. However, the rate of temperature increase in S3 is rather modest and in S5 the indoor temperature actually falls. As Figure 2 illustrates, there is practically no night-time temperature reduction in the container schools, pointing to the absence of a scheduled temperature regulation. It appears thus that – especially in the case of S5 – the occupants reduce at times the room temperature via excessive (continuous) ventilation.

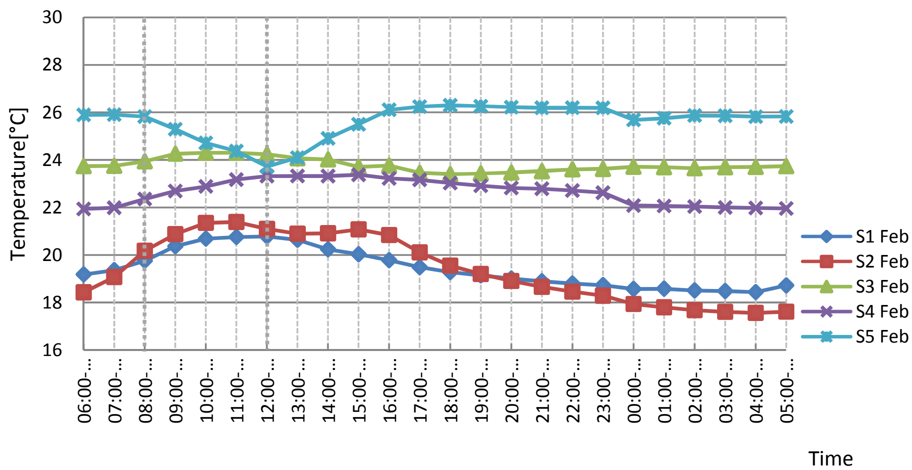


Figure 3. Temperature median of a reference day representing the month of February.

Figure 3 shows the cumulative frequency distribution of the relative humidity in the five schools during the operation hours in the month of February. The somewhat lower values of the container school S5 may be attributed in part to the generally high indoor air temperatures. The same observation explains the somewhat higher relative humidity levels in S1 and S2.

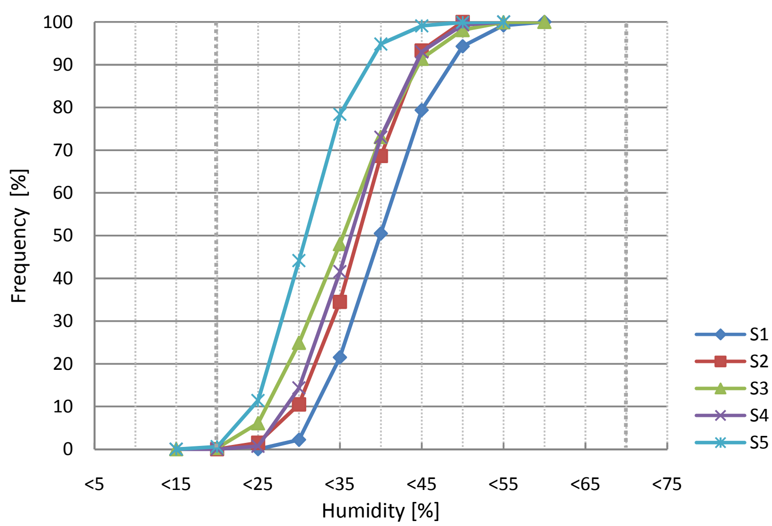


Figure 4. Cumulative frequency graph of indoor relative humidity of 5 schools (8:00-13:00) in February.

Figure 4 entails the cumulative frequency distribution of the measured indoor temperatures in four of the five schools during the school hours (8:00-13:00) in June 2011.

This Figure suggests that, as compared to the ordinary schools, in June the indoor temperature in the container schools is actually lower. For example, S3 and S5 are 65% and 58% of the time under 25°C, whereas S2 and S1 are 47% and 20% of the time under 25°C. This circumstance may be in part due to smaller windows and the associated lower solar gains in container schools. Moreover, the shading level of the container school windows due to other buildings was higher as compared to the ordinary schools.

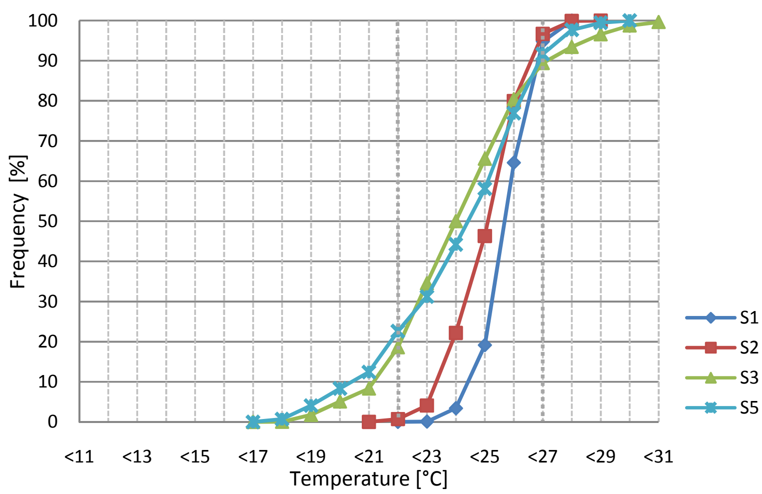


Figure 4. Cumulative frequency graph of temperature for four of the five schools (8:00-13:00) in June 2011.

Figure 5 shows the cumulative frequency distribution of the absolute humidity levels in the five schools during the month of June. These levels could be said to be in the proper range (lower than 14 g/m³) most of the time.

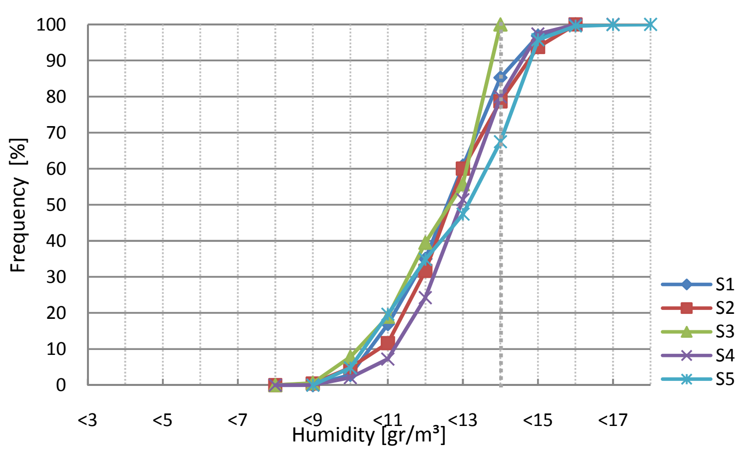


Figure 5. Cumulative frequency distribution of absolute humidity of five schools (8:00-13:00) in June 2011.

Figure 6 shows the cumulative frequency distribution of the measured $CO_2$ concentrations in the five schools for the month of June. Note that in this case the data is provided for the individual classrooms in each school (two classrooms in S1, S2 and S4 and one classroom in S3 and S5). These results suggest that container school classrooms display a higher carbon dioxide concentration than the other schools. A contributing factor to this circumstance may be the higher occupancy rate (number of pupils per unit area or unit volume) in the container schools. The occupancy density in the container schools was roughly 40% higher than ordinary schools. Generally speaking, the concentration rate was in all schools less than 1500 ppm in at least 80% of the time.

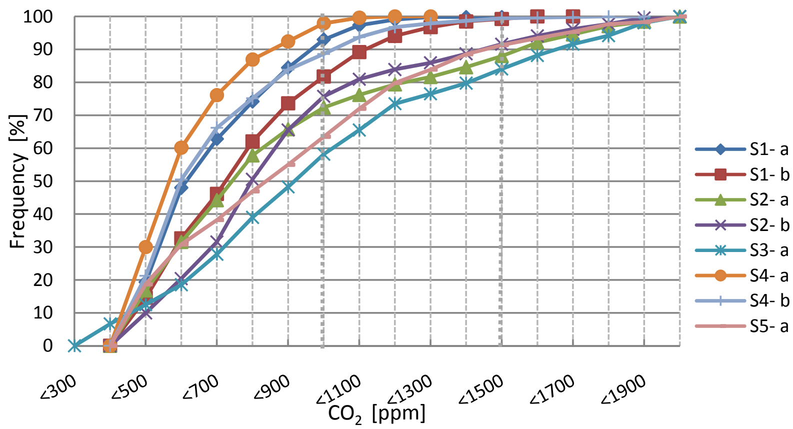


Figure 6. Cumulative frequency distribution of $CO_2$ concentration levels in June 2011 (8:00-13:00) in eight classrooms of the five schools.

## 4. CONCLUDING REMARKS

A comparison of ordinary schools and container schools in Baden, Austria was performed. Within the framework of the study, indoor environmental conditions were monitored (from February to June 2011), obtaining data including dry bulb temperature, relative humidity, and $CO_2$ concentration levels. Moreover, measurements were used to derive further data as absolute humidity and radiant and operative temperatures. In addition to data monitoring, a number of users (teachers) were requested to provide subjective evaluations of the indoor conditions.

The results point to the prevalence of unnecessarily high temperatures in the winter season in the container schools, resulting in energy wastage and higher heating cost. This circumstance is a result of inadequate temperature control. In the ordinary schools the Indoor temperature values in winter were found to be in the proper range most of the time.

Contrary to the initial expectation, summer time temperatures in the container classroom were found to be somewhat lower than in the ordinary schools. Smaller window sizes and higher shading levels (due to external obstructions) might have contributed to this circumstance. Absolute humidity levels in all schools displayed similar ranges and are mostly within acceptable ranges. However, $CO_2$ concentration levels in June in container classrooms were found to be higher than those in ordinary classrooms. A plausible explanation for this circumstance is the higher occupancy density in the container schools.

Overall the results suggest a slightly inferior indoor environmental performance of the container schools as compared to ordinary schools. Future studies need to address the differences in more detail. Moreover, additional evaluation criteria with regard to overall spatial quality of the classrooms need to be taken into consideration.

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