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Methods for Investigating Indoor Air Conditions of Ventilated Rooms

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Synopsis

The acquisition of temperatures and velocities is a permanent recurrent task for the investigation of air flow in ventilated rooms. On the one hand it is important to measure the temperature and velocity field with a high spatial resolution. On the other hand, in general, varying outdoor conditions prevent from reaching a steady state and an additonal demand consists in short measuring times.
Sometimes, the obtained measuring results are used both to supply appropriate boundary conditions for numerical computations and to verify the CFD-codes used. Therefore, the processing of received data has further importance.
In this paper the advantages and limitations of thermography, the usage of thermocouples and hot wire anemometry for temperature and velocity measurement is discussed. It is shown how the application of modern system components and data post processing in connection with these methods can satisfy better the already mentioned requirements.

List of symbols

T [°C] - temperature
U [V] - voltage
ε - emissivity

1 Introduction

Nowadays the investigation of temperature and flow in ventilated rooms is carried out by a variety of different methods. Each method shows advantages and disadvantages. Requirements related to a high resolution in space and time are commonly connected with extensive technical effort and high investments.
Therefore, the improvement of conventional methods for field measurements is focused on.

2 Temperature measurement

2.1 Thermography

Thermograhpy utilizes the emitted radiation in the infrared spectrum of a body to determine its temperature without contact. In contrast to pyrometry which records an average radiant density the thermography provides a radiant density distribution. Commonly, the emissivity of the measured object effects substantially (compared to other influences for instance reflection of background radiation, absorption in the air etc.) the conversion of radiant density into temperatures [1]. Using a one-point-calibration, the emissivity is easily calculated based on a local temperature measurement at the surface of the object under investigation (e.g. with a thermocouple). This emissivity is applied to the hole infrared picture. Errors occure, if this local emissivity varies along the measuring object. In most cases there is also no co-ordinate transformation which maps picture points onto object points.

These two disadvantages are removed by applying a suitable image post-processing* . Since the thermography system is used for temperature measurement in rooms with plane rectangular walls, the co-ordinate transformation can be reduced to a simple picture rectification. Objects recorded by the camera are distorted according to a central projection. Figure 1 shows a geometric method how a picture point P can be related to a point in the wall plane by repeated bisection.

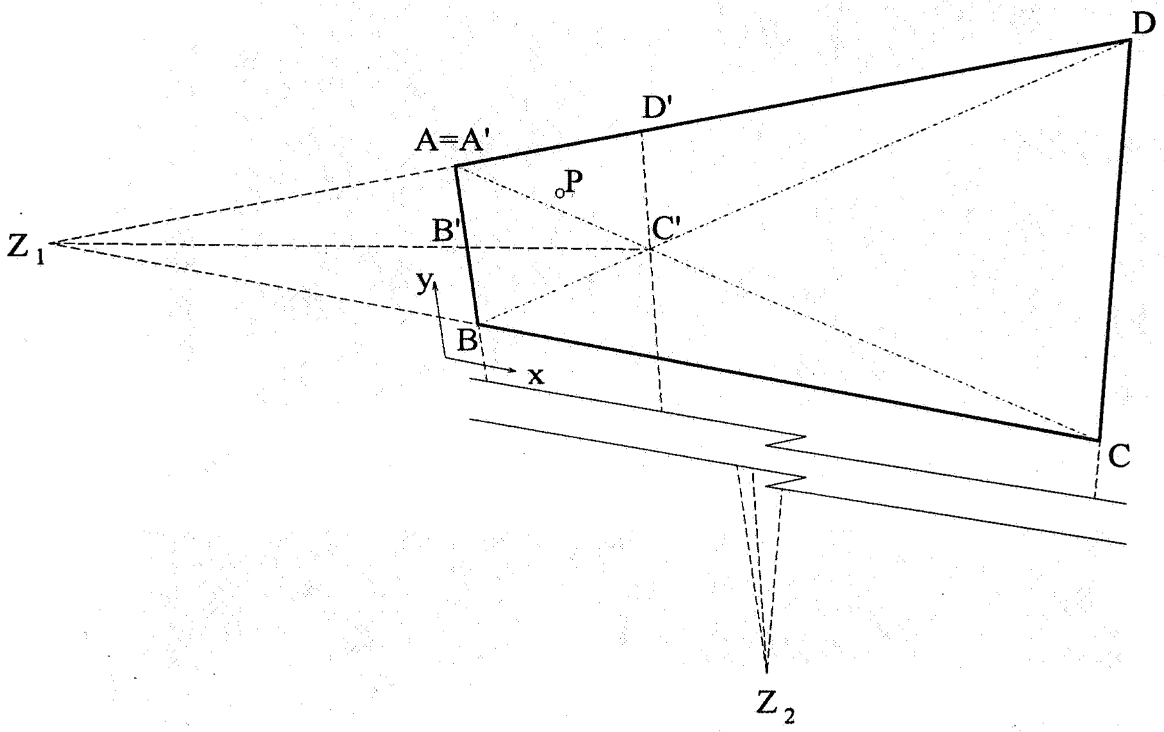

Figure 1: Rectification of a plane rectangular wall using a simple geometric bisection method

For the rectangle ABCD in the wall plane as well the wall as the picture co-ordinates are known. The intersection of the two diagonals defines an additional point. The two connecting lines between this point and the projection centres Z_1 and Z_2 split the region into four subregions. It follows the determination of the subregion (A'B'C'D') in which the considered point P is located. Afterwards, the process of bisection is restarted and continued as long as the subregion reaches the picture resolution. Because a lot of picture points have to be mapped, sophisticated programming allows to reduce the computing costs per point.
The particular advantage of this method is that neither the camera position nor the camera orientation need to be known. Only four picture points forming a rectangle in the wall plane have to be indentified by their wall co-ordinates.
If required, local emissivities for different regions (e.g. windows) can be read in from an external geometry file. These emissivities can be either obtained by the one-point-calibration mentioned above or they are already known. Finally, the corrected temperatures are available in dependence on the wall co-ordinates,
Figure 2 shows the original infrared picture of an inside wall with 3 windows of a gymnasium [2]. Picture rectification and emissivity correction as described above lead to figure 3.

* The presented algorithm is implemented in a selfmade image post-processing software

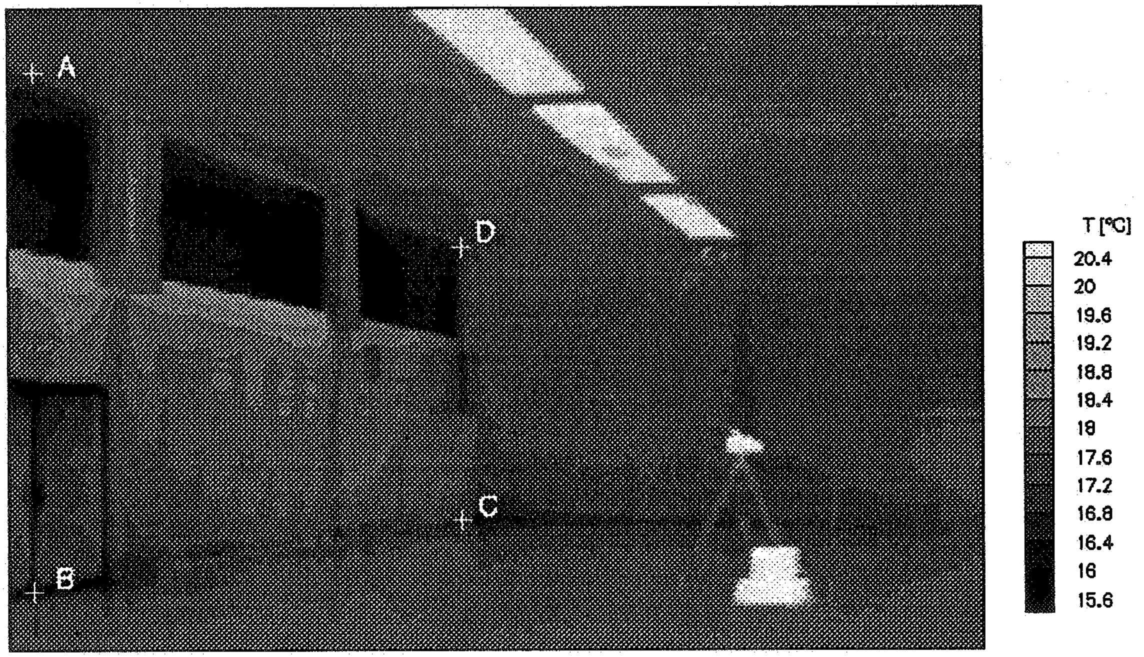

Figure 2: Original infrared picture with corner points A, B, C and D for rectification

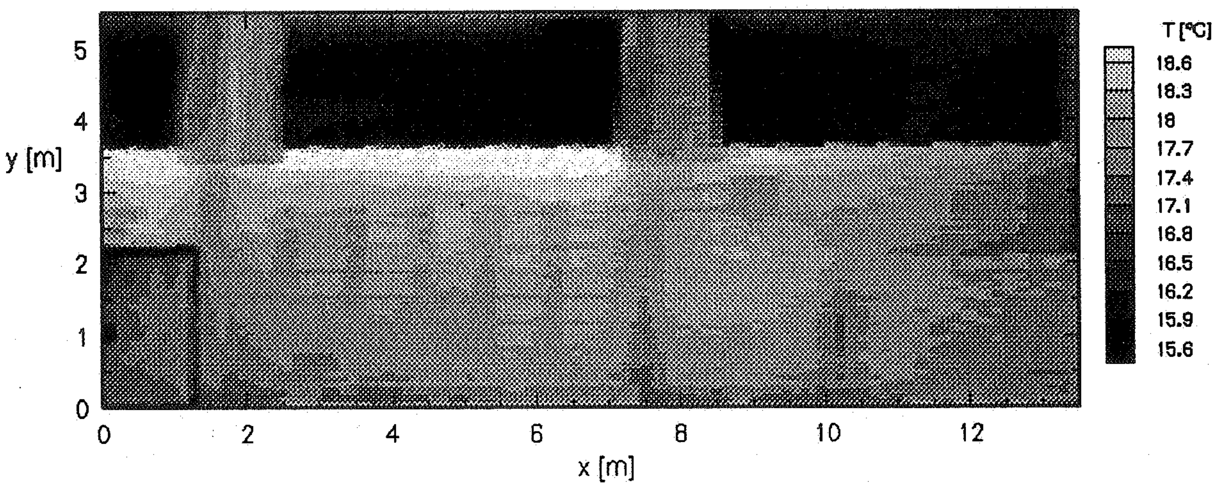

Figure 3: Obtained picture after rectification and ε-correction from figure 2

The applied camera (Jenoptik LW1011) is equipped with only one infrared sensitive element and generates its pictures using a two-dimensional reflector scanner with a resolution of 300x200. This results in costs which are much lower than for alternative systems [3]. The lower picture repetition frequency of approximately 2 Hz seems to be sufficient for this application and should not be viewed as a disadvantage.
The temperature data can also be used as boundary conditions for numerical computations. An interpolation onto the underlying grid seems to be sufficient (see figure 4).

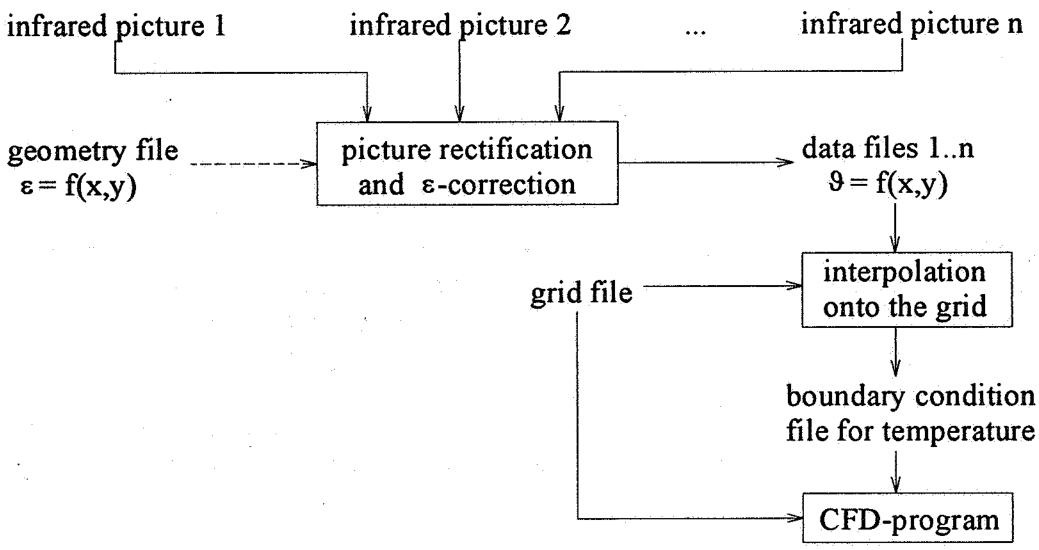

Figure 4: Structure of the infrared picture processing

2.2 Thermocouples

Methods for direct registration of a two-dimensional air temperature distribution (e.g. holographic interferometry [4]) are connected with high technical effort and high costs. They are therefore unsuitable for the practical investigation of large enclosures. Because of this the temperature field is constructed of a number of single measuring points.
Themocouples utilize the Seebeck effect after which in a closed circuit made of two materials a thermoelectric voltage is generated in dependence on the used materials and the temperature difference at the junctions [5]. The application of multiplexers (MUX) with cold-junction compensation (CJC) allows to connect a great number of thermocouples. The thermoelectric voltage is amplified and via an analogue-digital converter (ADC) read into a computer (Figure 5).

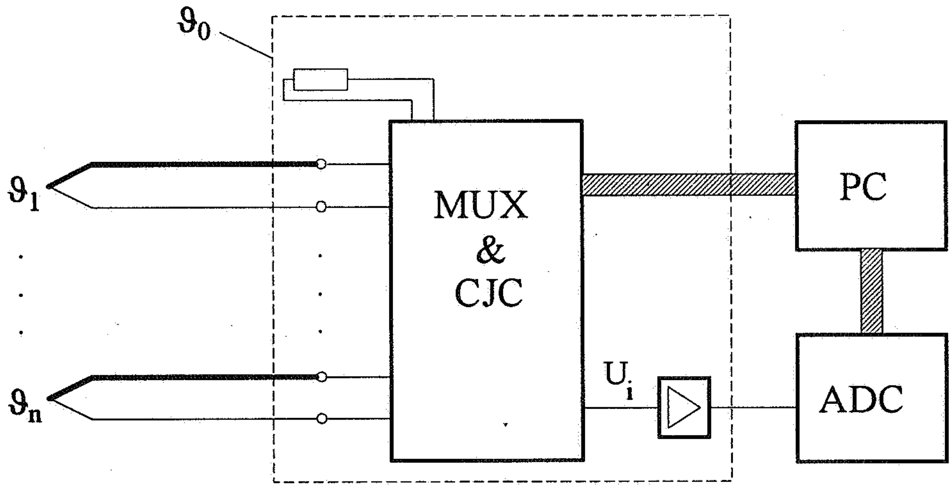

Figure 5: Measuring chain for temperature acquisition

A resistance thermometer measures the cold-junction temperature ϑ_0. For high accuracy, the multiplexer and amplifier must have the same temperature ϑ_0, because they are made also of different materials. Therefore, all these devices are placed in a thermically isolated box. The applied ADC is equiped with difference inputs causing noise reduction. Its resolution of 16 bit in connection with a polynomial function for the conversion of thermoelectric voltages into temperatures causes an accuracy of ± 0.1°C using iron-constantan thermcouples.
The thermocouples are placed in polished brass tubes protected from radiation and mounted in desired distances on a portable bar. This permits to measure the temperature along the bar nearly simultaneously. Moving the bar in a two-dimensional mesh leads to a three-dimensional temperature field. The pausing time at a point before starting the data acquisition is determined by the time constant of the thermocouples and influences the measuring time.
In any case the development of a reference temperature (e.g. intake air) should be recorded during the whole measuring process to check the constant boundary conditions or to apply a suitable correction.

3 Hot wire anemometry

Hot wire anemometry holds a special position under the numerous methods for velocity measurement [6]. Particular in turbulence research this method is often applied and although laser-optical techniques become more and more important it will be used furthermore. These are the main reasons:

- equipment for hot wire anemometry is still much lower priced than for laseroptical methods
- hot wire probes are easy to handle and can provide a high resolution in space and time
- hot wire anemometry enables to analyze momentary and average velocity vector, turbulence intensity, energy spectrum and correlations in space and time

Apart from these advantages there are also following limitations:

- disturbance of flow field → probes have to be very small
- cut-off frequency of about 10 kHz
- high mechanical sensitivity
- limitation of the spatial resolution due to wire dimension

Nowadays, the effective application of this conventional method is achieved using computer controlled system components. For example, the abilities of hot wire anemometry can be enlarged using fast ADC as following:

- functions of time with a sampling rate of 80kHz and more can be recorded
- average values, fluctuating values etc. can be investigated in nearly aribitrary time intervals
- if the ADC is equiped with simultaneous sample & hold inputs (SS&H) several probes can be measured at the same time allowing to compute multi-point correlations or velocity vectors (3- and 4-wire probes)

Figure 6 shows our applied configuration for velocity measurement, whereby up to 7 probes can be sampled simultaneously.

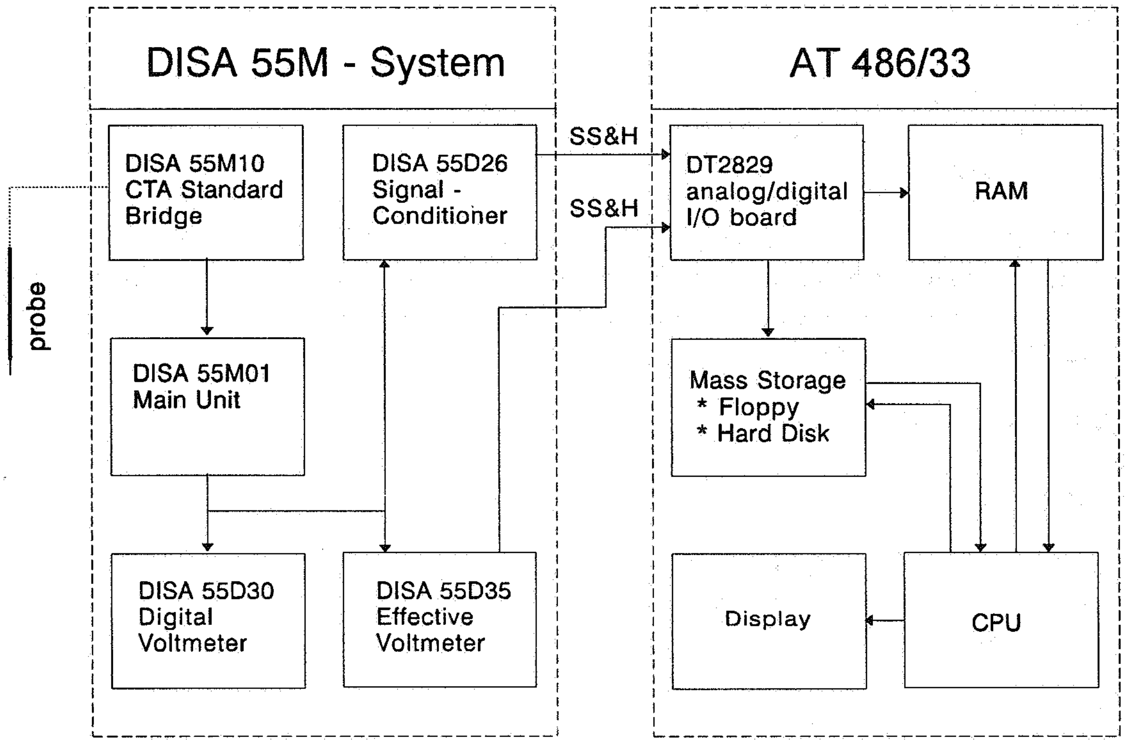

Figure 6: Measuring chain for velocity acquisition (only 1 probe shown)

A further automation is reached using positioning systems. This allows computer controlled measurement along axes, in planes and in chambers with high spatial resolution.
After processing of the numerous row data the results are easily visualized applying standard software (e.g. Tecplot™).

4 Conclusions

Thermography has a special advantage, because it supplies a complete temperature distribution. A method is presented allowing information from infrared pictures to be easily imported as temperature boundary condition into a CFD-code.
Computer controlled devices like ADC and positioning systems allow to improve and automate conventional measuring methods. Difficulties appear if thermocouples and hot wire anemometry are applied for field measurements with varying boundary conditions in time.

5 Acknowledgement

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