PS-MATRICES AS COMPLEMENTARY INPUT FOR THERMAL COMFORT CONTROLLERS

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Abstract

An effective procedure of the *PS*-parameter evaluation for the indoor thermal environment of an enclosed space is presented. The *PS*-value as complementary thermal comfort quantity may serve as secondary input value into a controller of the indoor thermal environment. In order to get the *PS*-value on time for controlling purposes an efficient method of PS-index assessment obtained by both air velocity as well as operative temperature was proposed.

1 Indoor Thermal Environment Characteristics

Indoor Thermal Environment Characteristics include (1) substitution of 3-dimensional mapping of air mass movement with two-dimensional (2D) ones, and, (2) obtaining the operative temperature [1] by means of sensor(s) set up in convectional way used by any HVAC-equipment. The outcome of air mass recirculation in a rectangular enclosure was obtained through 2D-velocity field in its meridian [2]. As the means the CFD-calculation in Fortran code was employed with boundary conditions implemented for anisothermal surfaces (one heated wall). The 2D-temperature profile was obtained for air properties assumed to be constant within the computational grid, both spatial as well as the time step. The outcome formed *PS*-matrices above areas of range of velocities and operative temperatures of the occupied enclosed space. These matrices could be stored and updated in start/stop regime accordingly with the actual data measurement cycle.

2 PS-Index as Controller Quantity Input

The ability to adjust thermal comfort parameters, air velocity and air temperature in a ventilated/heated space could involve statistical parameters that include human thermal sensation acquired through (occupants') voting. These empirical, vote-based values will represent an average across occupants' possible differences. In control level, *PS*, or *a PI*-controller (*P*-proportional, *S*-sum part) output seeks to maintain desired value of effective temperature $T_{e,w}$ (pink area in Fig.1) [1] with quadratic criterion $I_{\min} = \sum_{k=0}^{\infty} e^2(k)$ where $e(k) = T_e(k) - T_{e,w}(k)$, $k = j.\Delta\tau$, j=0,1,2…, $\Delta\tau$ - sampling time in seconds while keeping the secondary thermal comfort parameter – either *PD* or *PS-index* - in a conjoined bay areas PD-T_e, PS-T_e or - in optimal case - in conjunction of all warded parameters – i.e. at area *TC*, Fig.1, graphically marked with acceptable margins (error band *e(k)* less than 5% around target *TC*-values).

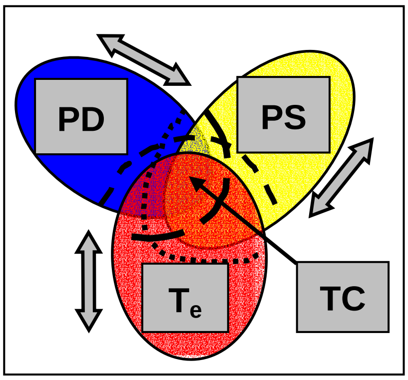


Figure 1: Control objective – *TC* area. Thermal comfort area (indicated in cross-section as *TC*) represents desired states of turbulence intensity (*PD*-index) and desired local air velocity (*PS*-index) chosen under given indoor thermal environment T_e – effective temperature). In joint areas are indicated also respective error bands (dashed lines).

The inclusion of empirical indices *PD* and *PS* would enhance control practice in terms of multi-input control regime: they might prevent thermally undesired states and in a focus on energy savings they will act as restricting parameters. Mathematically, their limit comfort area values

$$\left\{\overline{PD} \cap \overline{PS} \cap \overline{T_e(\tau)}\right\} \in \overline{TC(\tau)} \quad \wedge \quad T_e(\tau) = f\left[T_a(\tau), T_{MRT}(\tau)\right] \tag{1}$$

carve out a guarded area *TC* (Fig.1) of acceptable thermal states for which controllable parameters are being tuned for. Namely, mean radiant and air temperatures are checked continuously, at least with sampling time $\Delta\tau$ while *PD* and *PS*-indices yield as Navier-Stokes equations (NSE) calculation products for measured quasi-steady thermal state.

Adjustable air velocity represented by yellow *PS-index area* at Fig.1 requires known values in the immediate vicinity of occupant(s). That is possible by calculating them from velocity profiles obtained in both horizontal, as well as vertical directions (Fig.2) and to retrieve the maximal velocity magnitude in form of $|\vec{\mathbf{u}}(\xi,\chi)| = \sqrt{\mathrm{u}(\xi,\chi)^2 + \mathrm{v}(\xi,\chi)^2}$ there (ξ, χ – spatial coordinates).

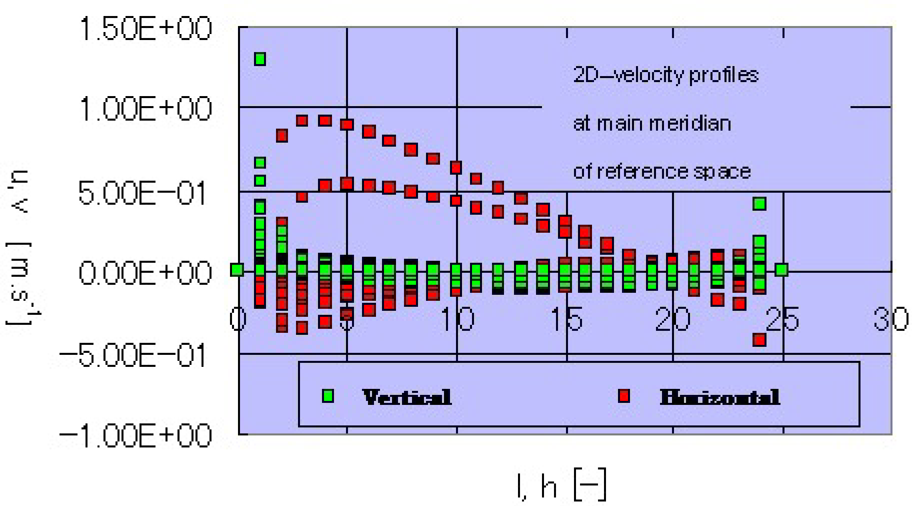
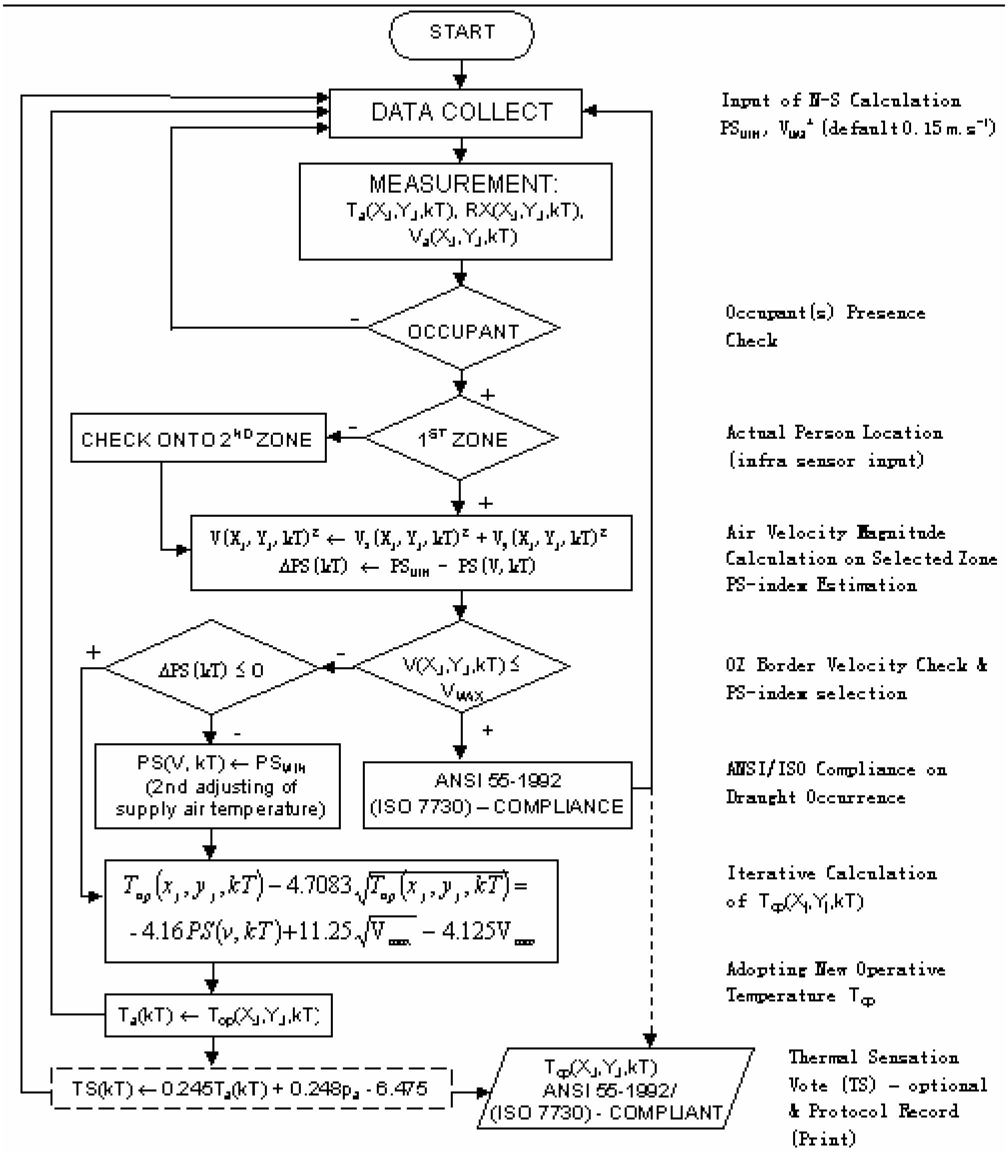


Figure 2: Indoor air velocity profiles in investigated space's main meridian cross-cut induced by thermal buoyancy. 2D-velocity field of air movement; *ACH* = 2.0.

3 Results

Unlike the computational fluid dynamics code, Fluent, used in [3], Fortran source code was employed to solve the compressible two-dimensional Navier-Stokes equations (NSE) for the air-recirculating flow in ventilated space. Further, was took an advantage of the interior's spatial symmetry in order to compute fluid parameters in its main vertical cut – the meridian. With the air velocity magnitude is needed only the last – third parameter – the air temperature T_a at occupant's nearest vicinity (at the same level above the floor) in order to determinate the recommended indoor thermal comfort area *TC* as indicated in Fig.1.

These three parameters were evaluated with numerical procedure written in MATLAB environment and flow diagram for *PS*-index evaluation shows Fig. 3.



$$T_{op}(x_J, y_J, kT) - 4.7083\sqrt{T_{op}(x_J, y_J, kT)} = -4.16\,PS(v, kT) + 11.25\sqrt{V_{max}} - 4.125V_{max}$$

Selected results of wavelet transform use in environmental engineering are given in Table 1.

Figure 3: Flow-chart of Thermal Sensation Vote Calculation (*TS*) parameter. *TS*-parameter is set up in *kT*-time period cycle (*k*=0,1,2…) employing *PS*-Index equation in two-zonal enclosure.

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