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The effect of air movement on the heat and moisture characteristics of building constructions

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Abstract: The paper presents the modeling and simulation of 2D heat and moisture transport with and without air movement for a building construction. The research focuses on the effect of air movement through building constructions. Although the typical air movement inside building constructions is quite small (velocity is of order ~10^{-5} m/s), this research shows it might have much more impact on the moisture characteristic as presumed so far. Our results indicate that especially vapor transport is in our case study very sensitive for air movement. As much as 40% Rh change at the inner surfaces of the building constructions are observed if we take air movement into account. Concerning the simulations tool, it is concluded that the use of the COMSOL Multiphysics software enables and simplifies the research of possible important effects that are not included in other standard heat and moisture simulation tools.

Keywords: Building, construction, air movement, modeling.

1. Introduction

The reduction of energy consumption related to buildings is of great importance. In order to calculate the energy consumption of a building, the heat transfer modeling of constructions is important [1, 2]. Moreover, some software tools also simulate moisture transport simultaneously to improve the design of building constructions. If we look more closely to these combined heat and moisture models, the effect of air movement inside the construction is not taking into account by almost all models. The main reasons are twofold: First, in practice it seems to have only a minor effect on the energy consumption. Second, the modeling and simulation of the air movement was quite complicated so far. The recent development of multiphysics software tools applied to building physics [3] give cause to revisit the following problem: How important is the effect of air movement on the heat- and especially the moisture characteristics of building constructions? The method of research was as follows: First, selection of a common building construction type. Second, modeling of the 2D heat and moisture transport model each with and without air movement based on the selected construction. The used internal and external boundary conditions (i.e. temperature, humidity and wind induced pressures) were based on a typical Dutch climate. This is provided in Sections 2. Third, simulation and evaluation of the results. This is presented in Section 3. The paper ends with some conclusions

2. The building construction model

We refer to earlier work of van Schijndel [4]. This paper presents a first modeling guide for the modeling and simulation of up to full 3D dynamic Heat, Air & Moisture (HAM) transport of building constructions using COMSOL with MatLab. Furthermore, all modeling files and results are public domain [5].

2.1 Geometry

We start with HAM2D construction model of [4]. Figure 1 presents this construction.

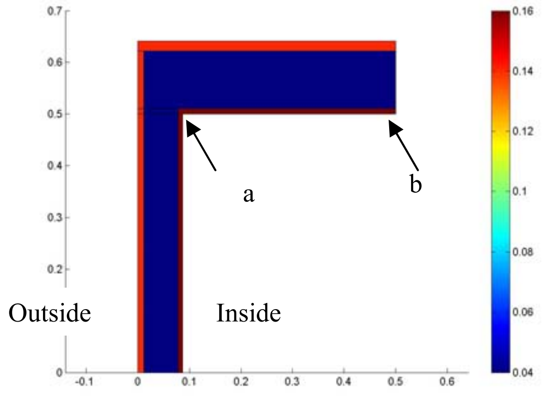


Figure 1. The 2D construction with the three materials.

2.2 Material properties

We take the same material properties as [4], see following Table I and II.

Table I. Material properties part 1

	λ W/mK	d m	U W/m^2 K
Exterior wall (inside to outside)			
Int. surf. coeff.			8.29
Wood panels	0.160	0.012	13.333
Cellulose ins.	0.040	0.066	0.606
Wood siding	0.140	0.009	15.556
Ext. surf. coeff			29.300
Total air-air			0.514
Roof (inside to outside)			
Int. surf coeff			8.29
Wood panels	0.160	0.010	16.000
Cellulose ins.	0.040	0.1118	0.358
Roof deck	0.140	0.019	7.368
Ext. surf. coeff			29.300
Total air-air			0.318

Table II. Material properties part 2

	R m^{2}K/ W	ρ kgm^3	C$_p$ J/kg K	K kg/ms Pa
Exterior wall (inside to outside)				
Int. surf. coeff.	0.121			
Wood panels	0.075	395	1880	10^{-9}
Cellulose ins.	1.650	55.0	1880	5.510^{-5}
Wood siding	0.064	530	900	10^{-9}
Ext. surf. coeff	0.034			
Total air-air	1.944			
Roof (inside to outside)				
Int. surf coeff	0.121			
Wood panels	0.063	395	1880	10^{-9}
Cellulose ins.	2.794	55.0	1880	5.510^{-5}
Roof deck	0.136	530	1880	10^{-9}
Ext. surf. coeff	0.034			
Total air-air	3.147			

Where λ is the heat conduction coefficient; d the thickness; U the U-value; R the heat resistance; ρ the density; Cp the heat capacity; K the air permeability.

2.3 Boundary Values

The internal and external conditions are provided in figure 2-4.

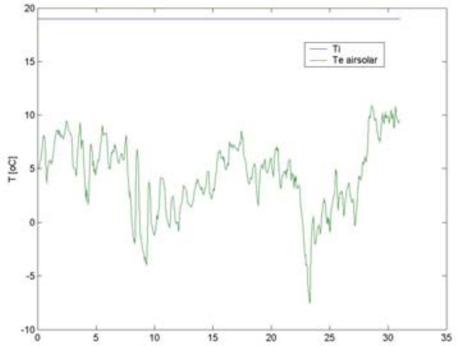


Figure 2. The temperature

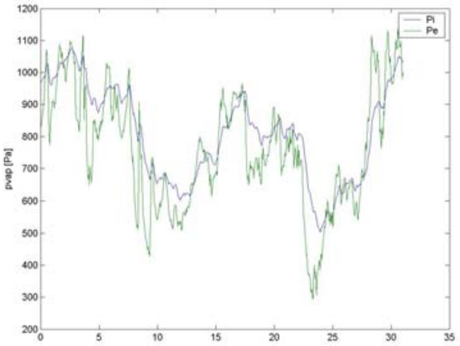


Figure 3. The vapor pressure

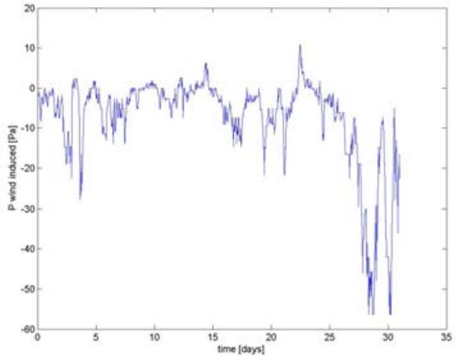


Figure 4. The wind induced pressure

The changes to the HAM2D model of [4] were twofold: (1) Internal and external boundary conditions of temperature (figure 2) and humidity (figure 3) are now based on a typical Dutch climate instead of the more or less extreme climate of Denver; (2) In [4] the wind induced pressure was steady, thus also the airflow through the construction was steady during the simulation period. However, in this paper, the wind induced pressure is dynamic (figure 4) and thus also the airflow through the construction.

2.4 Implementation using COMSOL

2.4.1 Boundary settings

See figure 5 and table III.

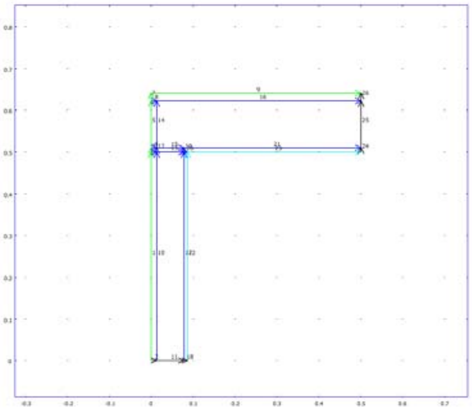


Figure 5. Boundary numbers

Table III. Boundary setting

Boundary	*1, 5, 7, 9*	*2-3, 11, 18, 24-26*
Type	Heat flux	Thermal insulation
(h)	29.3	0
(Tinf)	te(t)	273.15

Boundary	22-23
Type	Heat flux
(h)	8.29
(Tinf)	ti(t)

Boundary	*2, 11, 18, 24-26*	*1, 3, 5, 7, 9*
Type	Insulation/Symmetry	Flux
Inward flux (N)	0	8e-8*(pe(t)-c)

Boundary	22-23
Type	Flux
Inward flux (N)	2e-8*(pi(t)-c)

Boundary	*2, 11, 18, 24-26*	*1, 3, 5, 7, 9*
Type	Insulation/Symmetry	Pressure condition
Pressure (p0)	0	pwind(t)

Boundary	*22-23*
Type	Pressure condition
Pressure (p0)	0

2.4.2 Subdomain settings

See figure 6 and Table IV.

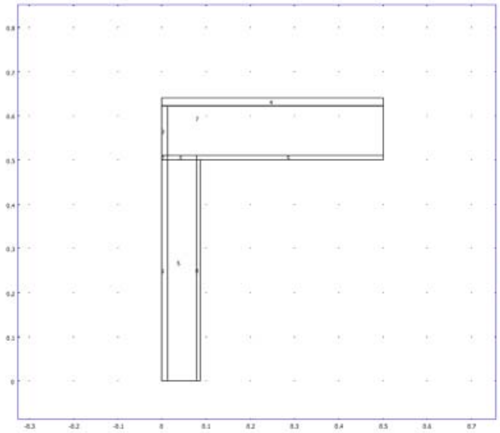


Figure 6. Subdomain numbers

Table IV. Subdomain settings

Subdomain	*1-4*	*5-7*	*8-9*
(convOn)	1	1	1
(k)	0.14	0.04	0.16
(rho)	530	55	395
(C)	1880	1880	1880
x-velocity (u)	u_chdl*1e-5	u_chdl*1e-5	u_chdl*1e-5
y-velocity (v)	v_chdl*1e-5	v_chdl*1e-5	v_chdl*1e-5

Subdomain	*1-4*	*5-7*
Diffusion coefficient (D)	psatf(T)*1.8e-10/(120*95)	psatf(T)*1.8e-10/(14*1.4)
x-velocity (u)	u_chdl*1e-5	u_chdl*1e-5
y-velocity (v)	v_chdl*1e-5	v_chdl*1e-5
(idon)	1	0

Subdomain	*8-9*
Diffusion coefficient (D)	psatf(T)*1.8e-10/(101*2.1)
x-velocity (u)	u_chdl*1e-5
y-velocity (v)	v_chdl*1e-5
(idon)	0

Subdomain	*1-4, 8-9*	*5-7*
Permeability (k)	1e-4	5.5
(eta)	1	1

3. Simulation results

We considered three cases concerning ΔP : the wind induced pressure difference between internal and external :
(1) $\Delta P = 0$;
(2) ΔP = P wind induced (see figure 4) and
(3) ΔP = - P wind induced.

The simulation results are visualized in three ways:

(a) Movies (downloadable from http://sts.bwk.tue.nl/hamlab/)

(b) Snapshots of the temperature and relative humidity distributions of each case at specific times, which are presented in Appendix A

(c) Time series for temperature, vapor pressure and relative humidity at the indoor surface at cross sections a and b (figure 1) are presented in the following figures 7-9.

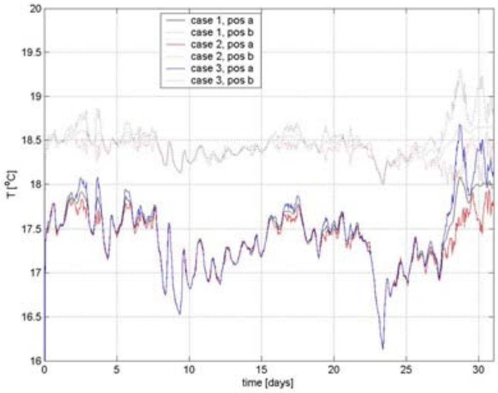


Figure 7. Time series temperature.

The results of indoor surface temperatures (figure 7) show that the multi-dimensional effect is far more dominant than the effect of airflow through the construction. Only at high pressure differences (for example day 28) the latter has some significant effect.

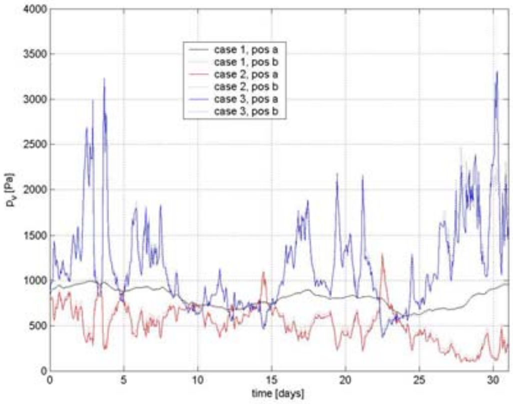


Figure 8. Time series vapor pressure.

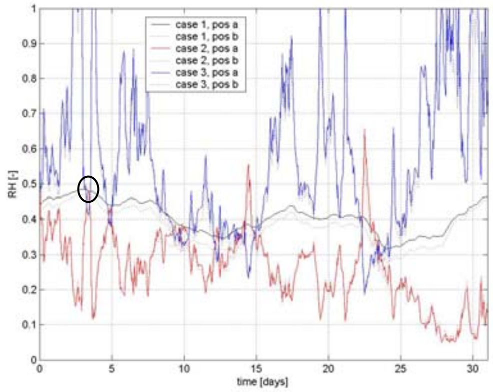


Figure 9. Time series relative humidity.

The results of the surface vapor pressures and Rh (figure 8-9) show the opposite effect. The airflow through the construction has far more impact than the multidimensional effect. More important, the airflow effect seems to be quite significant also at relative low wind pressure differences. For example at day 4 (see encircled area) the relative humidity (RH) at inner surface points a and b are almost equal (~ 48%) at low wind speed. A few hours later and depending on the wind induced pressure this RH could be as small as 15% or above 95%(!) The latter can easily cause condensation. If air movement is not taking into account then the RH remains about 48%.

4. Discussion

The preliminary results show that (as expected) the heat characteristic of the studied building construction is only minor affected by air movement.

However, the slightest air movement through the construction might have more impact on the moisture characteristic as presumed so far. Our case study shows that an RH, at the internal surface of a building construction and simulated without air movement inside the construction, of 50%, can drop to less than 20% or rise above 95% if air movement is taking into account.

Limitations
Currently, the moisture transport is based on vapor transport, so for example rain penetration and condensation are not included. This means that the results are not accurate for RH above 0.90.

More (experimental) results are needed to confirm or contradict our computational findings on the impact of airflow.

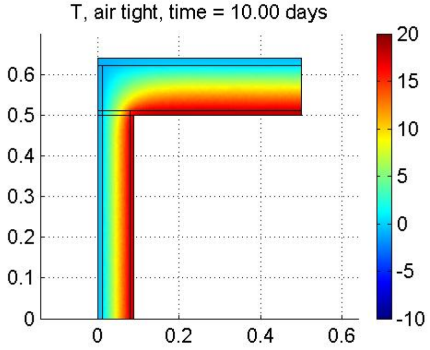
6. References

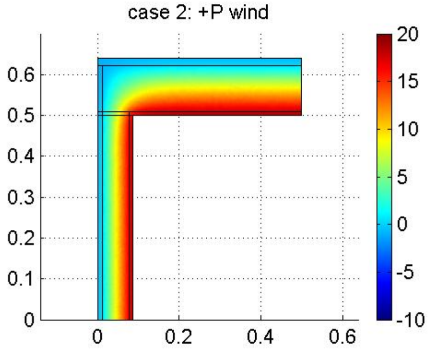
1. IEA Annex 41,
http://www.ecbcs.org/annexes/annex41.htm
(visited Aug 2007)
2.U.S. Department of Energy,
http://www.eere.energy.gov (visited Aug 2007)
3. A.W.M. van Schijndel, Integrated Heat Air and Moisture Modeling and Simulation, *PhD thesis*, **ISBN: 90-6814-604-1,** (2007)
4. A.W.M. van Schijndel, HAM Construction modeling using COMSOL with MatLab, Modeling guide version 1.0, *Proceedings of the COMSOL Users Conference 2006 Eindhoven* (2006)
5. HAMLAB, Heat Air and Moisture LABoratory,
http://sts.bwk.tue.nl/hamlab/ (visited Aug 2007)

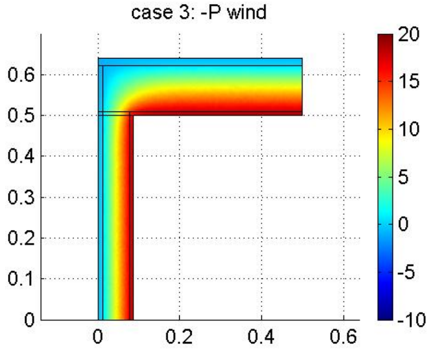
7. Acknowledgements

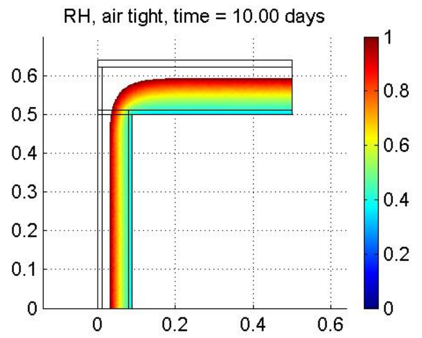
The contribution of the IEA Annex 41 team members is acknowledged.

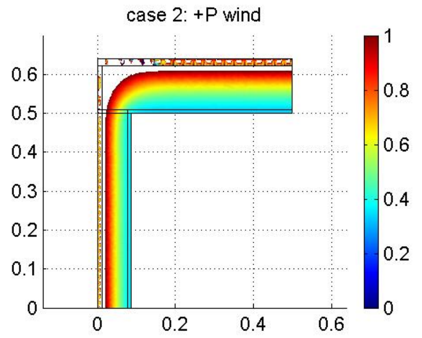
8. Appendix snapshots

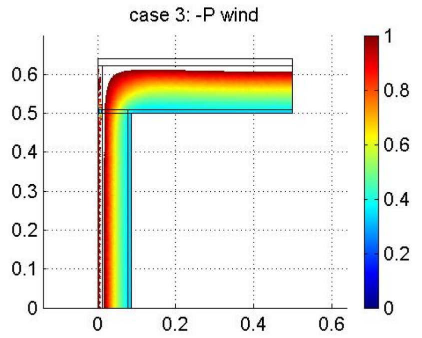

T, air tight, time = 10.00 days

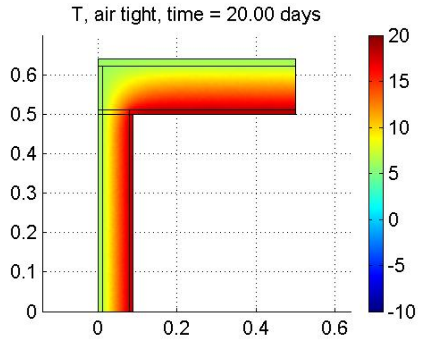

case 2: +P wind

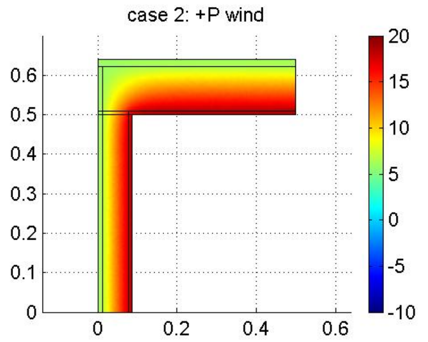

case 3: -P wind

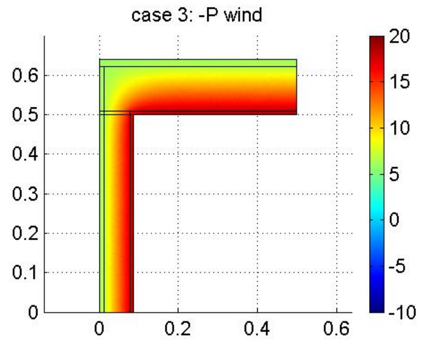

RH, air tight, time = 10.00 days
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
1
0.8
0.6
0.4
0.2
0

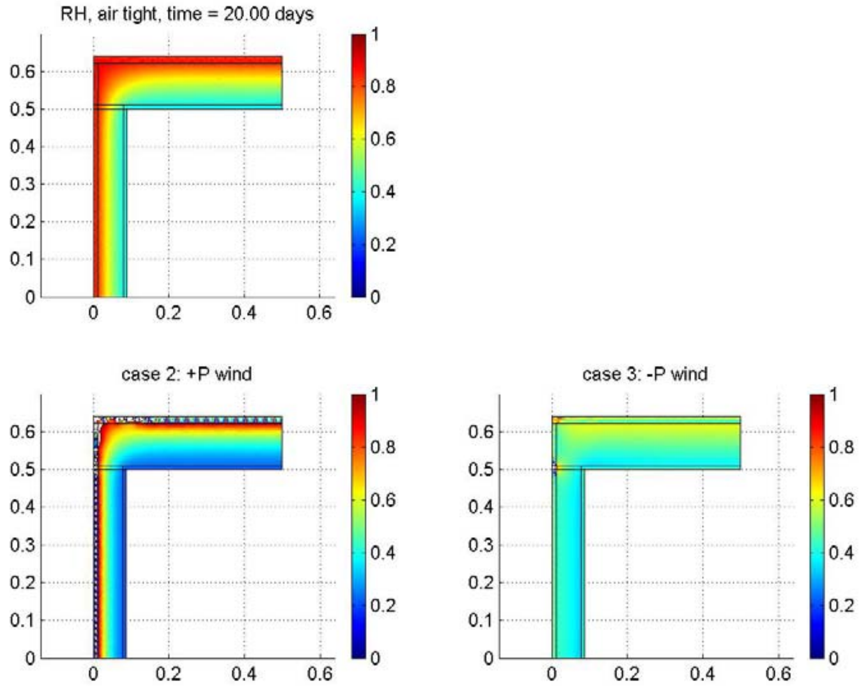

case 2: +P wind
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
1
0.8
0.6
0.4
0.2
0


case 3: -P wind
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
1
0.8
0.6
0.4
0.2
0


T, air tight, time = 20.00 days
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
20
15
10
5
0
-5
-10


case 2: +P wind
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
20
15
10
5
0
-5
-10


case 3: -P wind
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
20
15
10
5
0
-5
-10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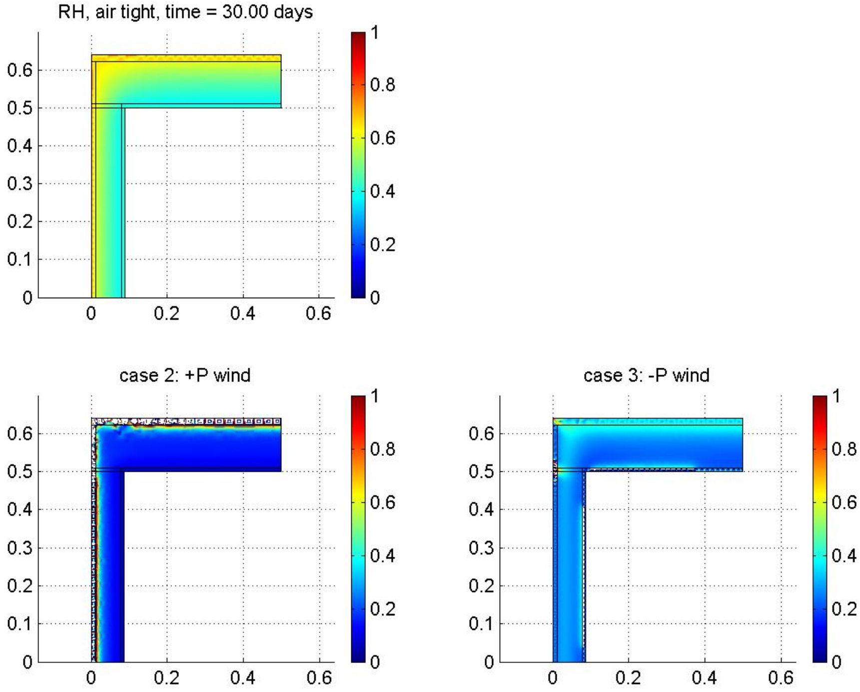
case 2: +P wind
case 3: -P wind
0
0.1
0.2
0.3
0.4
0.5
0.6
0
0.2
0.4
0.6
0
0.2
0.4
0.6
0.8
1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case 3: -P wind
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0.2
0.3
0.4
0.5
0.6
0
0.2
0.4
0.6
0
0.2
0.4
0.6
0.8
1