UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa

Air distribution in street canyons: a CFD study

BACHELOR FINAL THESIS

Document:
Annexes

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OpenFoam implementation

A.1 Turbulent kinetic energy (k)

```
/ *--------------------------------------------------------------*\
AIR DISTRIBUTION AND POLLUTANT TRANSPORT IN STREET CANYONS:
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                                        PAU GARCIA MORENO
                                                June, 2021
\*--------------------------------------------------------------*\

FoamFile
{
    version 2.0;
    format ascii;
    class volScalarField;
    location "0";
    object k;
}

dimensions [0 2 -2 0 0 0 0];
internalField uniform 0.19;

boundaryField
{
    TOP
    {
        type zeroGradient;
    }
    OUTLET
    {
        type zeroGradient;
```

```
    }
    INLET
    {
        type turbulentIntensityKineticEnergyInlet;
        intensity 0.05;
        value uniform 0.00375;
        U U;
        phi phi;
    }
    SYMMETRY
    {
        type empty;
    }
    CANYON
    {
        type kqRWallFunction;
        value uniform 0.19;
    }
}
```

A.2 Energy dissipation rate (ε)

```
/ *--------------------------------------------------------------*\
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\*--------------------------------------------------------------*\

FoamFile
{
    version 2.0;
    format ascii;
    class volScalarField;
    location "0";
    object epsilon;
}

dimensions [0 2 -3 0 0 0 0];
internalField uniform 5.57;

boundaryField
{
```

```
    TOP
    {
        type zeroGradient;
    }
    OUTLET
    {
        type zeroGradient;
    }
    INLET
    {
        type fixedValue;
        value uniform 5.57;
    }
    SYMMETRY
    {
        type empty;
    }
    CANYON
    {
        type epsilonWallFunction;
        value uniform 5.57;
    }
}
```

A.3 Velocity (U)

```
/ *--------------------------------------------------------------*\
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                                               June, 2021
\*--------------------------------------------------------------*\

FoamFile
{
    version 2.0;
    format ascii;
    class volVectorField;
    location "0";
    object U;
}

dimensions [0 1 -1 0 0 0 0];
```

```
internalField uniform ( 0 0 0 );

boundaryField
{
    TOP
    {
        type slip;
    }
    OUTLET
    {
        type zeroGradient;
    }
    INLET
    {
        type fixedValue;
        value uniform (1 0 0);
    }
    SYMMETRY
    {
        type empty;
    }
    CANYON
    {
        type fixedValue;
        value uniform (0 0 0);
    }
}
```

A.4 Pressure (p)

```
/ *--------------------------------------------------------------*\
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                                                June, 2021
\*--------------------------------------------------------------*\

FoamFile
{
    version 2.0;
    format ascii;
    class volScalarField;
    location "0";
```

```
14      object p;
15  }
16
17  dimensions [0 2 -2 0 0 0 0];
18  internalField uniform 0;
19
20  boundaryField
21  {
22      TOP
23      {
24          type zeroGradient;
25      }
26      OUTLET
27      {
28          type fixedValue;
29          value uniform 0;
30      }
31      INLET
32      {
33          type zeroGradient;
34      }
35      SYMMETRY
36      {
37          type empty;
38      }
39      CANYON
40      {
41          type zeroGradient;
42      }
43  }
```

A.5 Pollutant concentration (s)

```
1   / *--------------------------------------------------------------*\
2   AIR DISTRIBUTION AND POLLUTANT TRANSPORT IN STREET CANYONS:
3                       A CFD STUDY
4                                           PAU GARCIA MORENO
5                                                  June, 2021
6   \*--------------------------------------------------------------*\
7
8   FoamFile
9   {
10      version 2.0;
```

```
    format ascii;
    class volScalarField;
    location "0";
    object s;
}

dimensions [0 0 0 0 0 0 0];
internalField uniform 0;

boundaryField
{
    TOP
    {
        type zeroGradient;
    }
    OUTLET
    {
        type zeroGradient;
    }
    INLET
    {
        type zeroGradient;
    }
    SYMMETRY
    {
        type empty;
    }
    CANYON
    {
        type zeroGradient;
    }
    POLLUTANT
    {
        type fixedValue;
        value uniform 1.0;
    }
}
```

A.6 *controlDict*

```
/ *-------------------------------------------------------------*\
AIR DISTRIBUTION AND POLLUTANT TRANSPORT IN STREET CANYONS:
                    A CFD STUDY
```

```
4  |                                                PAU GARCIA MORENO
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6  |\*-------------------------------------------------------------*\
7  |
8  |FoamFile
9  |{
10 |    version 2.0;
11 |    format ascii;
12 |    class dictionary;
13 |    location "system";
14 |    object controlDict;
15 |}
16 |
17 |application pisoFoam;
18 |startFrom startTime;
19 |startTime 0;
20 |stopAt endTime;
21 |endTime 500;
22 |deltaT 0.005;
23 |writeControl timeStep;
24 |writeInterval 1000;
25 |purgeWrite 0;
26 |writeFormat ascii;
27 |writePrecision 6;
28 |writeCompression off;
29 |timeFormat general;
30 |timePrecision 6;
31 |graphFormat raw;
32 |runTimeModifiable true;
33 |adjustTimeStep off;
34 |maxCo 1;
35 |
36 |functions
37 |{
38 |    #includeFunc residuals
39 |    fieldAverage1
40 |    {
41 |        type fieldAverage;
42 |        libs ("libfieldFunctionObjects.so");
43 |        writeControl timeStep;
44 |        writeInterval 500;
45 |        fields
46 |            (
47 |                U
48 |                {
```

```
49                      mean on;
50                      prime2Mean on;
51                      base time;
52                  }
53                  p
54                  {
55                      mean on;
56                      prime2Mean on;
57                      base time;
58                  }
59              );
60      }
61      yPlus1
62      {
63          type yPlus;
64          libs ("libfieldFunctionObjects.so");
65          writeControl timeStep;
66          writeInterval 500;
67      }
68
69      scalar1
70      {
71
72      type scalarTransport;
73      functionObjectLibs ("libsolverFunctionObjects.so");
74      enabled true;
75      writeControl timeStep;
76      writeInterval 500;
77
78      field s;
79      nCorr 1;
80      D 0.000877;
81      schemesField U;
82
83      log yes;
84
85      }
86  }
```

A.7 *turbulentProperties*

```
1  / *-------------------------------------------------------------*\
2  AIR DISTRIBUTION AND POLLUTANT TRANSPORT IN STREET CANYONS:
```

```
3  |                     A CFD STUDY
4  |                                        PAU GARCIA MORENO
5  |                                                June, 2021
6  |\*-------------------------------------------------------------*\
7  |
8  |FoamFile
9  |{
10 |    version 2.0;
11 |    format ascii;
12 |    class dictionary;
13 |    location "constant";
14 |    object turbulenceProperties;
15 |}
16 |
17 |simulationType RAS;
18 |
19 |RAS
20 |{
21 |    RASModel RNGkEpsilon;
22 |    turbulence on;
23 |    printCoeffs on;
24 |}
```

A.8 *transportProperties*

```
1  |/ *-------------------------------------------------------------*\
2  |AIR DISTRIBUTION AND POLLUTANT TRANSPORT IN STREET CANYONS:
3  |                     A CFD STUDY
4  |                                        PAU GARCIA MORENO
5  |                                                June, 2021
6  |\*-------------------------------------------------------------*\
7  |
8  |FoamFile
9  |{
10 |    version 2.0;
11 |    format ascii;
12 |    class dictionary;
13 |    location "constant";
14 |    object transportProperties;
15 |}
16 |
17 |{
18 |    transportModel Newtonian;
```

```
19      nu nu [0 2 -1 0 0 0 0] 0.000083;
20  }
```

Appendix B

Matlab post-processing

B.1 Velocity and second order terms validation

```
/ *-------------------------------------------------------------*\
AIR DISTRIBUTION AND POLLUTANT TRANSPORT IN STREET CANYONS:
                    A CFD STUDY
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                                                June, 2021

       Note: code provided by Ivette Maria Rodriguez Perez
             and modified by the author of this thesis
\*-------------------------------------------------------------*\

clear
close all
N=40;
pos=[25,5,75];
varU=true;
varV=true;
BL=false;
Uinf=1.41;
Re=12000;

for k=drange(1:numel(pos))
    for n=drange(1:N)
        filename=sprintf('m2/mesh_x0%d_%d.csv',pos(k),n-1);
        disp(filename)
        M=csvread(filename,1,0);
        U(n,:)=M(:,4);
        V(n,:)=M(:,5);
        UU(n,:)=M(:,1);
```

```
        VV(n,:)=M(:,2);
        Y(n,:)=M(:,10);

    end
    lineX{k}.uu=sqrt(mean(UU-U.*U));
    lineX{k}.vv=sqrt(mean(VV-V.*V));
    lineX{k}.u=mean(U);
    lineX{k}.v=mean(V);
    lineX{k}.y=Y(1,:);


end

clear U;
    clear V;
    clear UU;
    clear VV;
    clear M;
    clear X;

for k=drange(1:numel(pos))
    for n=drange(1:N)
        filename=sprintf('m2/mesh_y0%d_%d.csv',pos(k),n-1);
        disp(filename)
        M=csvread(filename,2,0);
        U(n,:)=M(:,4);
        V(n,:)=M(:,5);
        UU(n,:)=M(:,1);
        VV(n,:)=M(:,2);
        X(n,:)=M(:,9);
    end

    lineY{k}.uu=sqrt(mean(UU-U.*U));
    lineY{k}.vv=sqrt(mean(VV-V.*V));
    lineY{k}.u=mean(U);
    lineY{k}.v=mean(V);
    lineY{k}.y=X(1,:);

    end

for k=drange(1:numel(pos))
    clear E;
    clear L;

    filename=sprintf('U_exp_x0%d.csv',pos(k));
```

```
74      E=csvread(filename,0,0);
75      ref1{k}.EU(:)=E(:,1);
76      ref1{k}.EY(:)=E(:,2);
77
78      filename=sprintf('UU_exp_x0%d.csv',pos(k));
79      E=csvread(filename,0,0);
80      ref1{k}.EUU(:)=E(:,1);
81      ref1{k}.EYU(:)=E(:,2);
82
83      filename=sprintf('V_exp_x0%d.csv',pos(k));
84      E=csvread(filename,0,0);
85      ref1{k}.EV(:)=E(:,1);
86      ref1{k}.EX(:)=E(:,2);
87
88      filename=sprintf('VV_exp_x0%d.csv',pos(k));
89      E=csvread(filename,0,0);
90      ref1{k}.EVV(:)=E(:,1);
91      ref1{k}.EXV(:)=E(:,2);
92
93      filename=sprintf('U_0%d_LES_Liu.csv',pos(k));
94      L=csvread(filename,0,0);
95      ref2{k}.LU(:)=L(:,1);
96      ref2{k}.LY(:)=L(:,2);
97
98      filename=sprintf('UU_0%d_LES_Liu.csv',pos(k));
99      L=csvread(filename,0,0);
100     ref2{k}.LUU(:)=L(:,1);
101     ref2{k}.LYU(:)=L(:,2);
102
103     filename=sprintf('V_0%d_LES_Liu.csv',pos(k));
104     L=csvread(filename,0,0);
105     ref2{k}.LV(:)=L(:,1);
106     ref2{k}.LX(:)=L(:,2);
107
108     filename=sprintf('VV_0%d_LES_Liu.csv',pos(k));
109     L=csvread(filename,0,0);
110     ref2{k}.LVV(:)=L(:,1);
111     ref2{k}.LXV(:)=L(:,2);
112 end
113
114     clear U;
115     clear Y;
116     clear P;
117
118     P=csvread('x050_04.csv',1,0);
```

```
119
120     Urans(:)=P(:,1);
121     Yrans(:)=P(:,22);
122     Vrans(:)=P(:, 2);
123     Xrans(:)=P(:, 21);
124     UUrans(:)=P(:, 4);
125     VVrans(:)=P(:,5);
126
127     VVrans=sqrt(VVrans);
128     UUrans=sqrt(UUrans);
129     Urans = Urans';
130     Yrans = Yrans';
131     Vrans = Vrans';
132     Xrans = Xrans';
133     UUrans = UUrans';
134     VVrans = VVrans';
135
136     clear U;
137     clear Y;
138     clear P;
139
140     PP=csvread('x050_imp.csv',1,0);
141
142     Urans1(:)=PP(:,1);
143     Yrans1(:)=PP(:,19);
144     Vrans1(:)=PP(:, 2);
145     Xrans1(:)=PP(:, 18);
146     UUrans1(:)=PP(:, 4);
147     VVrans1(:)=PP(:,5);
148
149     VVrans1=sqrt(VVrans1);
150     UUrans1=sqrt(UUrans1);
151     Urans1 = Urans1';
152     Yrans1 = Yrans1';
153     Vrans1 = Vrans1';
154     Xrans1 = Xrans1';
155     UUrans1 = UUrans1';
156     VVrans1 = VVrans1';
157
158     clear U;
159     clear Y;
160     clear P;
161     clear K;
162     clear PP;
163
```

```
164     K=csvread('x025_04.csv',1,0);
165
166     Urans025(:)=K(:,1);
167     Yrans025(:)=K(:,22);
168     Vrans025(:)=K(:, 2);
169     Xrans025(:)=K(:, 21);
170     UUrans025(:)=K(:, 4);
171     VVrans025(:)=K(:, 5);
172
173     VVrans025=sqrt(VVrans025);
174     UUrans025=sqrt(UUrans025);
175     Urans025 = Urans025';
176     Yrans025 = Yrans025';
177     Vrans025 = Vrans025';
178     Xrans025 = Xrans025';
179     UUrans025 = UUrans025';
180     VVrans025 = VVrans025';
181
182     clear U;
183     clear Y;
184     clear P;
185     clear K;
186     clear PP;
187
188     KK=csvread('x025_imp.csv',1,0);
189
190     Urans0251(:)=KK(:,1);
191     Yrans0251(:)=KK(:,19);
192     Vrans0251(:)=KK(:, 2);
193     Xrans0251(:)=KK(:, 18);
194     UUrans0251(:)=KK(:, 4);
195     VVrans0251(:)=KK(:, 5);
196
197     VVrans0251=sqrt(VVrans0251);
198     UUrans0251=sqrt(UUrans0251);
199     Urans0251 = Urans0251';
200     Yrans0251 = Yrans0251';
201     Vrans0251 = Vrans0251';
202     Xrans0251 = Xrans0251';
203     UUrans0251 = UUrans0251';
204     VVrans0251 = VVrans0251';
205
206     clear U;
207     clear Y;
208     clear P;
```

```
209     clear K;
210     clear H;
211     clear PP;
212     clear KK;
213
214     H=csvread('x075_04.csv',1,0);
215
216     Urans075(:)=H(:,1);
217     Yrans075(:)=H(:,22);
218     Vrans075(:)=H(:, 2);
219     Xrans075(:)=H(:, 21);
220     UUrans075(:)=H(:, 4);
221     VVrans075(:)=H(: ,5);
222
223     VVrans075=sqrt(VVrans075);
224     UUrans075=sqrt(UUrans075);
225     Urans075 = Urans075';
226     Yrans075 = Yrans075';
227     Vrans075 = Vrans075';
228     Xrans075 = Xrans075';
229     UUrans075 = UUrans075';
230     VVrans075 = VVrans075';
231
232     clear U;
233     clear Y;
234     clear P;
235     clear K;
236     clear H;
237     clear KK;
238     clear PP;
239
240     HH=csvread('x075_imp.csv',1,0);
241
242     Urans0751(:)=HH(:,1);
243     Yrans0751(:)=HH(:,19);
244     Vrans0751(:)=HH(:, 2);
245     Xrans0751(:)=HH(:, 18);
246     UUrans0751(:)=HH(:, 4);
247     VVrans0751(:)=HH(: ,5);
248
249     VVrans0751=sqrt(VVrans0751);
250     UUrans0751=sqrt(UUrans0751);
251     Urans0751 = Urans0751';
252     Yrans0751 = Yrans0751';
253     Vrans0751 = Vrans0751';
```

```
254     Xrans0751 = Xrans0751';
255     UUrans0751 = UUrans0751';
256     VVrans0751 = VVrans0751';
257
258     A=csvread('x_050_u_jordi.csv', 1, 0);
259
260     Ucomp050(:)=A(:,1);
261     Ycomp050(:)=A(:, 2);
262     Ucomp050=Ucomp050';
263     Ycomp050=Ycomp050';
264
265     B=csvread('x_025_u_jordi.csv', 1, 0);
266
267     Ucomp025(:)=B(:,1);
268     Ycomp025(:)=B(:, 2);
269
270     Ucomp025=Ucomp025';
271     Ycomp025=Ycomp025';
272
273     C=csvread('x_025_v_jordi.csv', 1, 0);
274
275     Vcomp025(:)=C(:,1);
276     Ycompv025(:)=C(:, 2);
277
278     Vcomp025=Vcomp025';
279     Ycompv025=Ycompv025';
280
281     D=csvread('x_025_v_jordi.csv', 1, 0);
282
283     UUcomp025(:)=D(:,1);
284     Ycompuu025(:)=D(:, 2);
285
286     UUcomp025=UUcomp025';
287     Ycompuu025=Ycompuu025';
288
289     D=csvread('x_025_vv_jordi.csv', 1, 0);
290
291     VVcomp025(:)=D(:,1);
292     Ycompvv025(:)=D(:, 2);
293
294     VVcomp025=VVcomp025';
295     Ycompvv025=Ycompvv025';
296
297     E=csvread('x_050_uu_jordi.csv', 1, 0);
298
```

```
299     UUcomp050(:)=E(:,1);
300     Ycompuu050(:)=E(:, 2);
301
302     UUcomp050=UUcomp050';
303     Ycompuu050=Ycompuu050';
304
305     F=csvread('x_050_v_jordi.csv', 1, 0);
306
307     Vcomp050(:)=F(:,1);
308     Ycompv050(:)=F(:, 2);
309
310     Vcomp050=Vcomp050';
311     Ycompv050=Ycompv050';
312
313     G=csvread('x_050_vv_jordi.csv', 1, 0);
314
315     VVcomp050(:)=G(:,1);
316     Ycompvv050(:)=G(:, 2);
317
318     VVcomp050=VVcomp050';
319     Ycompvv050=Ycompvv050';
320
321     H=csvread('x_075_u_jordi.csv', 1, 0);
322
323     Ucomp075(:)=H(:,1);
324     Ycompu075(:)=H(:, 2);
325
326     Ucomp075=Ucomp075';
327     Ycompu075=Ycompu075';
328
329     I=csvread('x_075_uu_jordi.csv', 1, 0);
330
331     UUcomp075(:)=I(:,1);
332     Ycompuu075(:)=I(:, 2);
333
334     UUcomp075=UUcomp075';
335     Ycompuu075=Ycompuu075';
336
337     J=csvread('x_075_v_jordi.csv', 1, 0);
338
339     Vcomp075(:)=J(:,1);
340     Ycompv075(:)=J(:, 2);
341
342     Vcomp075=Vcomp075';
343     Ycompv075=Ycompv075';
```

```
344
345     L=csvread('x_075_vv_jordi.csv', 1, 0);
346
347     VVcomp075(:)=L(:,1);
348     Ycompvv075(:)=L(:, 2);
349
350     VVcomp075=VVcomp075';
351     Ycompvv075=Ycompvv075';
352
353
354 /*************************************************************\
355 %U
356
357 figure
358 text1=sprintf('x/W_s = 0.25 ');
359 text2=sprintf('x/W_s = 0.50 ');
360 text3=sprintf('x/W_s = 0.75 ');
361 ------------------------------------------------------------------
362 subplot(1,3,1)
363 hold on
364
365 plot(lineX{1,1}.u/Uinf,lineX{1,1}.y,'k-','LineWidth',2)
366 plot(ref1{1,1}.EU,ref1{1,1}.EY,'ro')
367 plot(ref2{1,1}.LU,ref2{1,1}.LY,'k--')
368
369 r=plot(Urans025(:,1), Yrans025(:,1),'r:', 'LineWidth', 2)
370 r.Color= 'b';
371 p=plot(Ucomp025(:,1), Ycomp025(:,1),'-.','LineWidth', 2)
372 p.Color= '[0.2 0.9 0]';
373 pp=plot(Urans0251(:,1), Yrans0251(:,1),'-.','LineWidth', 2)
374 pp.Color= 'r';
375
376 ax = gca;
377 ax.FontSize=18;
378 xlabel('$$\overline{u}/U_{ref}$$', 'Interpreter', 'Latex');
379 ylabel('$y/H$', 'Interpreter', 'Latex');
380 ax.XLim=[-0.35 1.05];
381 ax.Box='on';
382 text(-0.2,1.25,text1,'FontSize',18);
383 ------------------------------------------------------------------
384 subplot(1,3,2)
385 hold on
386
387 plot(lineX{1,2}.u/Uinf,lineX{1,2}.y,'k-','LineWidth',2)
388 plot(ref1{1,2}.EU,ref1{1,2}.EY,'ro')
```

```
plot(ref2{1,2}.LU,ref2{1,2}.LY,'k--')


r=plot(Urans(:,1), Yrans(:,1),'r:', 'LineWidth', 2)
r.Color= 'b';
pl=plot(Ucomp050(:,1), Ycomp050(:,1),'-.','LineWidth', 2)
pl.Color= '[0.2 0.9 0]'
pp=plot(Urans1(:,1), Yrans1(:,1),'-.','LineWidth', 2)
pp.Color= 'r';

ax = gca;
ax.FontSize=18;
xlabel('$$\overline{u}/U_{ref}$$', 'Interpreter', 'Latex');
ylabel('$y/H$', 'Interpreter', 'Latex');
ax.XLim=[-0.35 1.05];
ax.Box='on';
text(-0.2,1.45,text2,'FontSize',18);
-----------------------------------------------------------------
subplot(1,3,3)
hold on

plot(lineX{1,3}.u/Uinf,lineX{1,2}.y,'k-','LineWidth',2)
plot(ref1{1,3}.EU,ref1{1,3}.EY,'ro')
plot(ref2{1,3}.LU,ref2{1,3}.LY,'k--')

r=plot(Urans075(:,1), Yrans075(:,1),'r:', 'LineWidth', 2)
r.Color= 'b';
p=plot(Ucomp075(:,1), Ycompu075(:,1),'r:', 'LineWidth', 2)
p.Color= '[0.2 0.9 0]';
pp=plot(Urans0751(:,1), Yrans0751(:,1),'-.','LineWidth', 2)
pp.Color= 'r';

ax = gca;
ax.FontSize=18;
xlabel('$$\overline{u}/U_{ref}$$', 'Interpreter', 'Latex');
ylabel('$y/H$', 'Interpreter', 'Latex');


columnlegend(1,{'m2','Exp','LES'}, 'location', 'south');
lgd = legend('m2','Exp','LES', 'RANS1', 'RANS2', 'RANS3');
lgd.FontSize = 20;
ax.Box='on';
text(-0.2,1.25,text3,'FontSize',18);
/*************************************************************\
%UU
```

```
434
435 figure
436 text1=sprintf('x/W_s = 0.25 ');
437 text2=sprintf('x/W_s = 0.5 ');
438 text3=sprintf('x/W_s = 0.75 ');
439
440 subplot(1,3,1)
441 hold on
442
443 plot(lineX{1,1}.uu/(Uinf*Uinf),lineX{1,1}.y,'k-','LineWidth',2)
444 plot(ref1{1,1}.EUU,ref1{1,1}.EYU,'ro')
445 plot(ref2{1,1}.LUU,ref2{1,1}.LYU,'k--')
446
447 r=plot(UUrans025(:,1), Yrans025(:,1) ,'r:', 'LineWidth', 2)
448 r.Color= 'b';
449 p=plot(UUcomp025(:,1), Ycompuu025(:,1),'-.','LineWidth', 2)
450 p.Color= '[0.2 0.9 0]';
451 pp=plot(UUrans0251(:,1), Yrans0251(:,1),'-.','LineWidth', 2)
452 pp.Color= 'r';
453
454 ax = gca;
455 ax.FontSize=18;
456 xlabel('$\overline{u"u"}/U_{ref}^{2}$','Interpreter','Latex');
457 ylabel('$y/H$', 'Interpreter', 'Latex');
458
459 ax.Box='on';
460 text(.02,1.25,text1,'FontSize',18);
461 ----------------------------------------------------------------
462 subplot(1,3,2)
463 hold on
464
465 plot(lineX{1,2}.uu/(Uinf*Uinf),lineX{1,2}.y,'k-','LineWidth',2)
466 plot(ref1{1,2}.EUU,ref1{1,2}.EYU,'ro')
467 plot(ref2{1,2}.LUU,ref2{1,2}.LYU,'k--')
468
469 r=plot(UUrans(:,1), Yrans(:,1),'r:', 'LineWidth', 2)
470 r.Color= 'b';
471 p=plot(UUcomp050(:,1), Ycompuu050(:,1),'-.', 'LineWidth', 2)
472 p.Color= '[0.2 0.9 0]';
473 pp=plot(UUrans1(:,1), Yrans1(:,1),'-.','LineWidth', 2)
474 pp.Color= 'r';
475
476 ax = gca;
477 ax.FontSize=18;
478 xlabel('$\overline{u"u"}/U_{ref}^{2}$','Interpreter','Latex');
```

```
ylabel('$y/H$', 'Interpreter', 'Latex');

ax.Box='on';
text(.02,1.25,text2,'FontSize',18);
-----------------------------------------------------------------
subplot(1,3,3)
hold on

plot(lineX{1,3}.uu/(Uinf*Uinf),lineX{1,2}.y,'k-','LineWidth',2)
plot(ref1{1,3}.EUU,ref1{1,3}.EYU,'ro')
plot(ref2{1,3}.LUU,ref2{1,3}.LYU,'k--')

r=plot(UUrans075(:,1), Yrans075(:,1),'r:', 'LineWidth', 2)
r.Color= 'b';
p=plot(UUcomp075(:,1), Ycompuu075(:,1),'-.', 'LineWidth', 2)
p.Color= '[0.2 0.9 0]';
pp=plot(UUrans0751(:,1), Yrans0751(:,1),'-.','LineWidth', 2)
pp.Color= 'r';

ax = gca;
ax.FontSize=18;
xlabel('$\overline{u"u"}/U_{ref}^{2}$','Interpreter','Latex');
ylabel('$y/H$', 'Interpreter', 'Latex');

columnlegend(1,{'m2','Exp','LES'}, 'location', 'south');
ax.Box='on';
text(.02,1.25,text3,'FontSize',18);

lgd = legend('m2','Exp','LES', 'RANS1', 'RANS2', 'RANS3');
lgd.FontSize = 20;
/*********************************************************\
%V
figure
text1=sprintf('y/W_s = 0.25 ');
text2=sprintf('y/W_s = 0.5 ');
text3=sprintf('y/W_s = 0.75 ');

subplot(1,3,1)
hold on

plot(lineX{1,1}.v/Uinf,lineX{1,1}.y,'k-','LineWidth',2)
plot(ref1{1,1}.EV,ref1{1,1}.EX,'ro')
plot(ref2{1,1}.LV,ref2{1,1}.LX,'k--')

r=plot(Vrans025(:,1), Yrans025(:,1),'r:', 'LineWidth', 2)
```

```
r.Color= 'b';
p=plot(Vcomp025(:,1), Ycompv025(:,1),'-.', 'LineWidth', 2)
p.Color='[0.2 0.9 0]';
pp=plot(Vrans0251(:,1), Yrans0251(:,1),'-.','LineWidth', 2)
pp.Color= 'r';

ax = gca;
ax.FontSize=18;
xlabel('$$\overline{v}/U_{ref}$$', 'Interpreter', 'Latex');
ylabel('$y/H$', 'Interpreter', 'Latex');

ax.XLim=[-0.3 0.3];
ax.Box='on';
text(-0.2,1.25,text1,'FontSize',18);
------------------------------------------------------------------
subplot(1,3,2)
hold on

plot(lineX{1,2}.v/Uinf,lineX{1,2}.y,'k-','LineWidth',2)
plot(ref1{1,2}.EV,ref1{1,2}.EX,'ro')
plot(ref2{1,2}.LV,ref2{1,2}.LX,'k--')

r=plot(Vrans(:,1), Yrans(:,1),'r:', 'LineWidth', 2)
r.Color= 'b';
p=plot(Vcomp050(:,1), Ycompv050(:,1),'-.', 'LineWidth', 2)
p.Color= '[0.2 0.9 0]';
pp=plot(Vrans1(:,1), Yrans1(:,1),'-.','LineWidth', 2)
pp.Color= 'r';

ax = gca;
ax.FontSize=18;
xlabel('$$\overline{v}/U_{ref}$$', 'Interpreter', 'Latex');
ylabel('$y/H$', 'Interpreter', 'Latex');
ax.XLim=[-0.3 0.3];
ax.Box='on';
text(-0.2,1.45,text2,'FontSize',18);
------------------------------------------------------------------
subplot(1,3,3)
hold on

plot(lineX{1,3}.v/Uinf,lineX{1,2}.y,'k-','LineWidth',2)
plot(ref1{1,3}.EV,ref1{1,3}.EX,'ro')
plot(ref2{1,3}.LV,ref2{1,3}.LX,'k--')

r=plot(Vrans075(:,1), Yrans075(:,1),'r:', 'LineWidth', 2)
```

```
r.Color= 'b';
p=plot(Vcomp075(:,1), Ycompv075(:,1),'-.', 'LineWidth', 2)
p.Color= '[0.2 0.9 0]';
pp=plot(Vrans0751(:,1), Yrans0751(:,1),'-.','LineWidth', 2)
pp.Color= 'r';

ax = gca;
ax.FontSize=18;
xlabel('$$\overline{v}/U_{ref}$$', 'Interpreter', 'Latex');
ylabel('$y/H$', 'Interpreter', 'Latex');
columnlegend(1,{'m2','Exp','LES'}, 'location', 'south');
ax.Box='on';

ax.XLim=[-0.3 0.3];
text(-0.2,1.25,text3,'FontSize',18);
lgd = legend('m2','Exp','LES', 'RANS1', 'RANS2', 'RANS3');
lgd.FontSize = 20;

/************************************************************\
%VV

figure
text1=sprintf('y/W_s = 0.25 ');
text2=sprintf('y/W_s = 0.5 ');
text3=sprintf('y/W_s = 0.75 ');

subplot(1,3,1)
hold on

plot(lineX{1,1}.vv/(Uinf*Uinf),lineX{1,1}.y,'k-','LineWidth',2)
plot(ref1{1,1}.EVV,ref1{1,1}.EXV,'ro')
plot(ref2{1,1}.LVV,ref2{1,1}.LXV,'k--')

r=plot(VVrans025(:,1), Yrans025(:,1),'r:', 'LineWidth', 2)
r.Color= 'b';
p=plot(VVcomp025(:,1), Ycompvv025(:,1),'-.', 'LineWidth', 2)
p.Color= '[0.2 0.9 0]';
pp=plot(VVrans0251(:,1), Yrans0251(:,1),'-.','LineWidth', 2)
pp.Color= 'r';

ax = gca;
ax.FontSize=18;
xlabel('$$\overline{v"v"}/U_{ref}^{2}$$', 'Interpreter', 'Latex');
ylabel('$y/H$', 'Interpreter', 'Latex');

```

```
ax.Box='on';
text(.02,1.25,text1,'FontSize',18);
-----------------------------------------------------------------
subplot(1,3,2)
hold on

plot(lineX{1,2}.vv/(Uinf*Uinf),lineX{1,2}.y,'k-','LineWidth',2)
plot(ref1{1,2}.EVV,ref1{1,2}.EXV,'ro')
plot(ref2{1,2}.LVV,ref2{1,2}.LXV,'k--')

r=plot(VVrans(:,1), Yrans(:,1),'r:', 'LineWidth', 2)
r.Color= 'b';
p=plot(VVcomp050(:,1), Ycompvv050(:,1),'-.', 'LineWidth', 2)
p.Color= '[0.2 0.9 0]';
pp=plot(VVrans1(:,1), Yrans1(:,1),'-.','LineWidth', 2)
pp.Color= 'r';

ax = gca;
ax.FontSize=18;
xlabel('$\overline{v"v"}/U_{ref}^{2}$','Interpreter','Latex');
ylabel('$y/H$', 'Interpreter', 'Latex');

ax.Box='on';
text(.02,1.45,text2,'FontSize',18);
-----------------------------------------------------------------
subplot(1,3,3)
hold on

plot(lineX{1,3}.vv/(Uinf*Uinf),lineX{1,2}.y,'k-','LineWidth',2)
plot(ref1{1,3}.EVV,ref1{1,3}.EXV,'ro')
plot(ref2{1,3}.LVV,ref2{1,3}.LXV,'k--')

r=plot(VVrans075(:,1), Yrans075(:,1),'r:', 'LineWidth', 2)
r.Color= 'b';
p=plot(VVcomp075(:,1), Ycompvv075(:,1),'-.', 'LineWidth', 2)
p.Color= '[0.2 0.9 0]';
pp=plot(VVrans0751(:,1), Yrans0751(:,1),'-.','LineWidth', 2)
pp.Color= 'r';

ax = gca;
ax.FontSize=18;
xlabel('$\overline{v"v"}/U_{ref}^{2}$','Interpreter','Latex');
ylabel('$y/H$', 'Interpreter', 'Latex');
columnlegend(1,{'m2','Exp','LES'}, 'location', 'south');
ax.Box='on';
```

```
659 text(.02,1.25,text3,'FontSize',18);
660
661 lgd = legend('m2','Exp','LES', 'RANS1', 'RANS2', 'RANS3');
662 lgd.FontSize = 20;
```

B.2 Air exchange rate (ACH)

```
1  / *------------------------------------------------------------*\
2  AIR DISTRIBUTION AND POLLUTANT TRANSPORT IN STREET CANYONS:
3                      A CFD STUDY
4                                          PAU GARCIA MORENO
5                                                  June, 2021
6  \*------------------------------------------------------------*\
7
8  clear
9  close all
10
11 M=csvread('y100_poll_ar050.csv', 1, 0);
12 VV5(:)=M(:,2);
13 X5(:)=M(:,14);
14 X5(:)=X5(:);
15
16 M=csvread('y100_imp.csv', 1, 0);
17 VV(:)=M(:,5); %5
18 X(:)=M(:,18); %18
19 ;
20
21 M=csvread('y100_poll_ar200.csv', 1, 0);
22 VV2(:)=M(:,2);
23 X2(:)=M(:,14);
24
25 figure
26 title('y/H=1')
27
28 hold on
29
30 plot((X5-12)/2, VV5, 'k', 'linewidth', 2);
31 plot(X-12, VV, 'r', 'linewidth', 2);
32 plot((X2-12)*2, VV2, 'b', 'linewidth', 2);
33
34 lgd = legend('AR=0.50','AR=1.00','AR=2.00');
35 lgd.FontSize = 20;
36 xlabel('$$X/w$$', 'Interpreter', 'Latex');
```

```
37 ylabel('$\overline{v"v"}/U_{ref}$', 'Interpreter', 'Latex');
38
39
40 ACH1=(trapz(X5, sqrt(VV5)))/4;
41 ACH2=(trapz(X, sqrt(VV)))/2;
42 ACH3=(trapz(X2, sqrt(VV2)));
```

Appendix C

Results validation

C.1 Dimensionless mean velocities

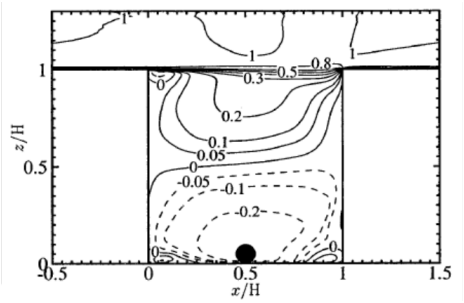

Figure C.1: Spatial variation of dimensionless stream-wise velocity, AR=1.00[1]

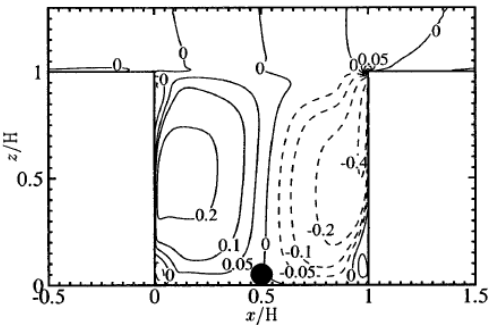

Figure C.2: Spatial variation of dimensionless vertical velocity, AR=1.00[1]

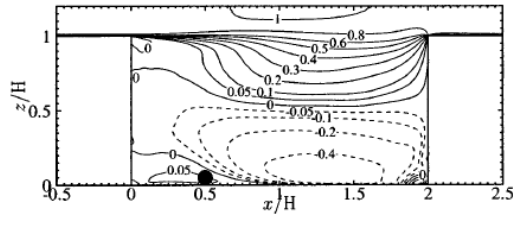

Figure C.3: Spatial variation of dimensionless stream-wise velocity, AR=0.50[1]

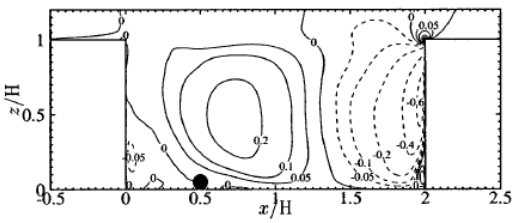

Figure C.4: Spatial variation of dimensionless vertical velocity, AR=0.50[1]

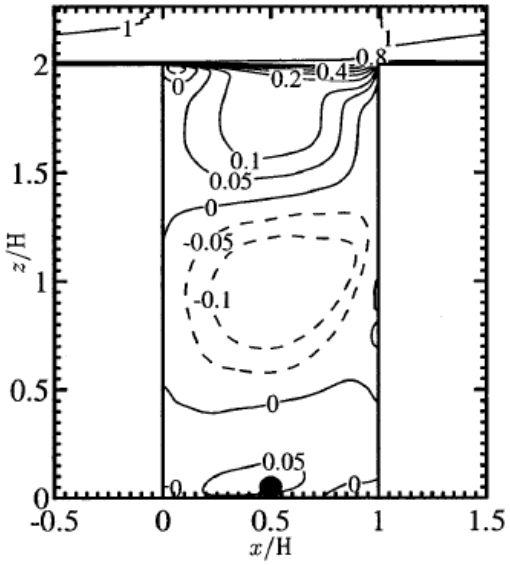

Figure C.5: Spatial variation of dimensionless stream-wise velocity, AR=2.00[1]

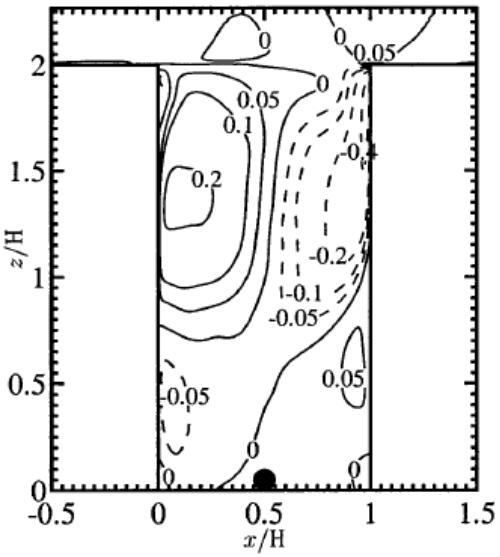

Figure C.6: Spatial variation of dimensionless vertical velocity, AR=2.00[1]

C.2 Dimensionless stream-functions

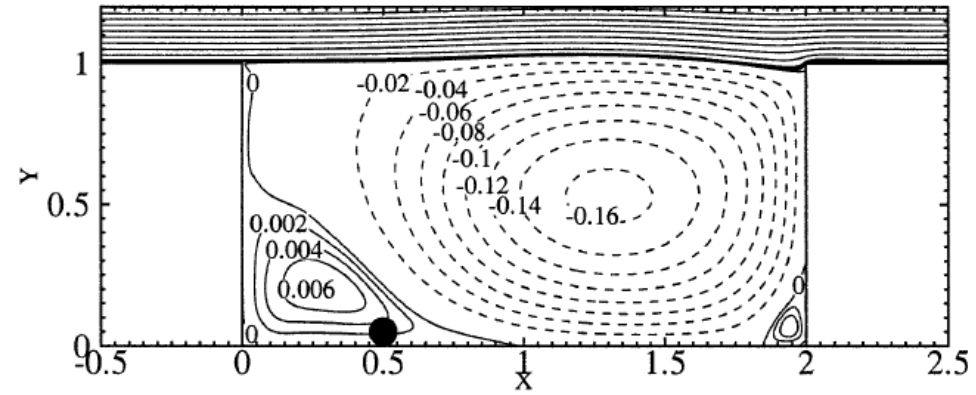

Figure C.7: Spatial variation of dimensionless stream-function, AR=0.50[1]

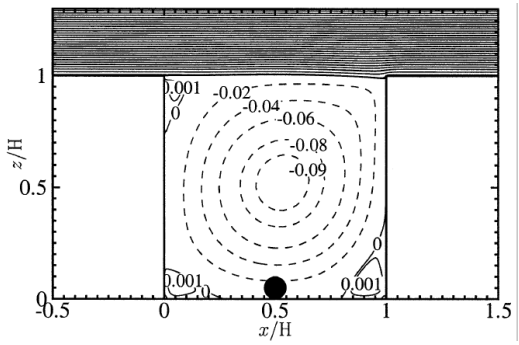

Figure C.8: Spatial variation of dimensionless stream-function, AR=1.00[1]

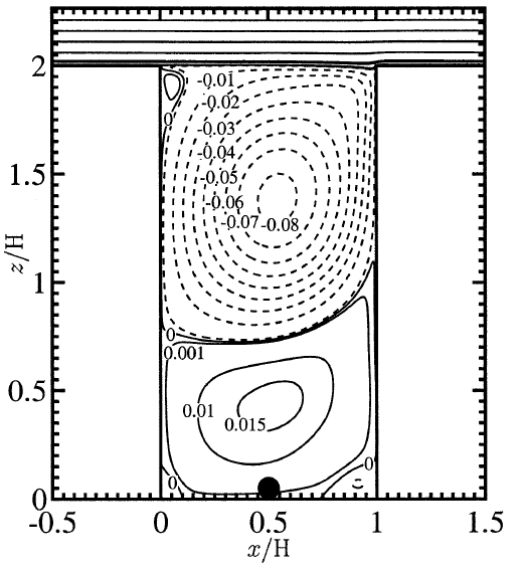

Figure C.9: Spatial variation of dimensionless stream-function, AR=2.00[1]

C.3 Dimensionless mean pollutant concentration

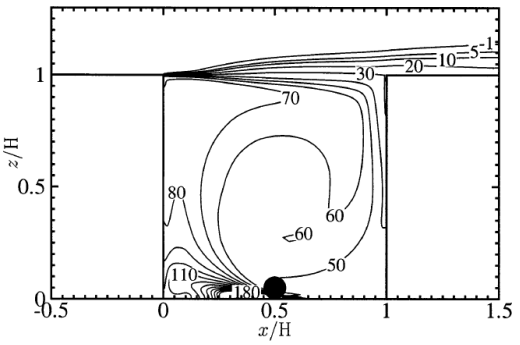

Figure C.10: Spatial variation of dimensionless mean pollutant concentration, AR=1.00[1]

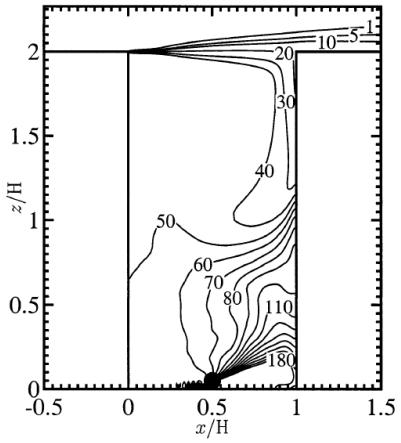

Figure C.11: Spatial variation of dimensionless mean pollutant concentration, AR=2.00[1]

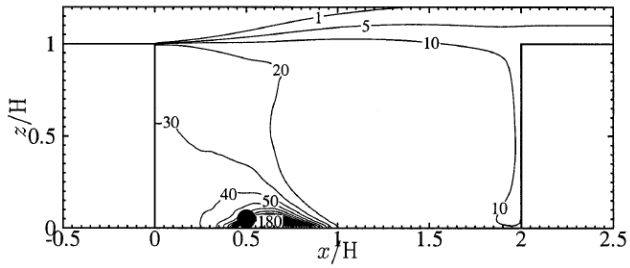

Figure C.12: Spatial variation of dimensionless pollutant concentration, AR=0.50[1]

C.4 Dimensionless turbulent kinetic energy contours

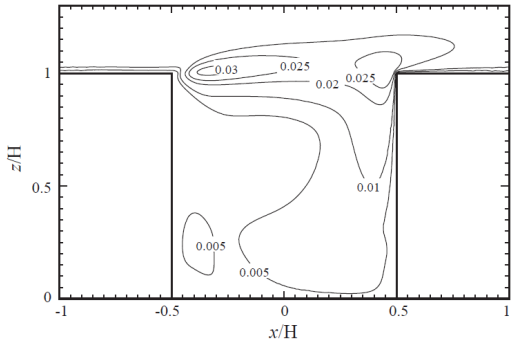

Figure C.13: Spatial contours of the dimensionless turbulent kinetic energy using *RNG* $K-\varepsilon$, AR=1.00[2]

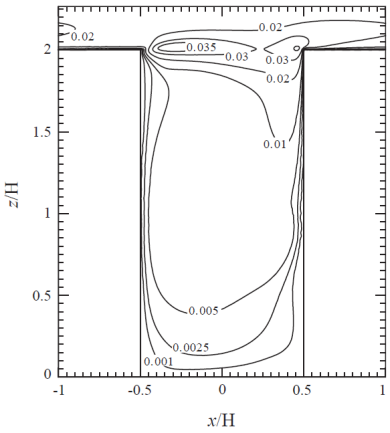

Figure C.14: Spatial contours of the dimensionless turbulent kinetic energy using *RNG* $K-\varepsilon$, AR=2.00[2]

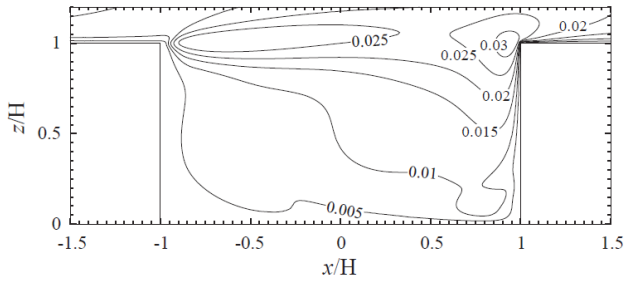

Figure C.15: Spatial contours of the dimensionless turbulent kinetic energy using *RNG* $K-\varepsilon$, AR=050[2]

C.5 Dimensionless mean pollutant fluxes

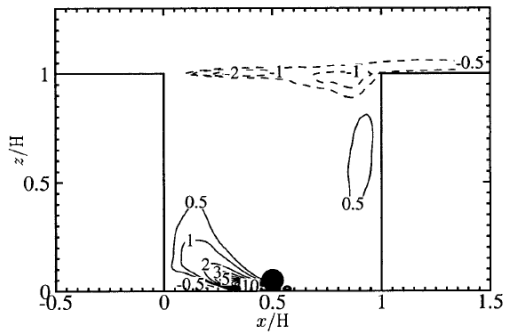

Figure C.16: Spatial variation of the dimensionless mean stream-wise pollutant flux, AR=1.00[1]

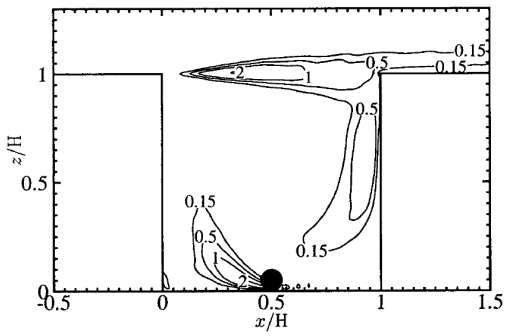

Figure C.17: Spatial variation of the dimensionless mean vertical pollutant flux, AR=1.00[1]

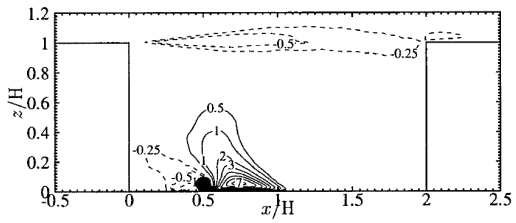

Figure C.18: Spatial variation of the dimensionless mean stream-wise pollutant flux, AR=0.50[1]

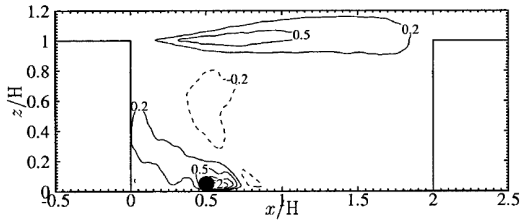

Figure C.19: Spatial variation of the dimensionless mean vertical pollutant flux, AR=0.50[1]

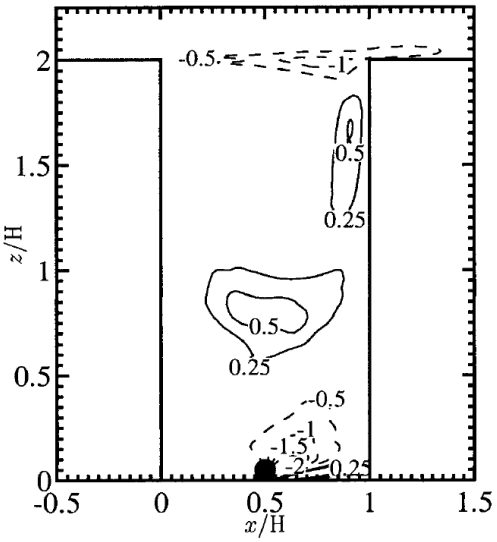

Figure C.20: Spatial variation of the dimensionless mean stream-wise pollutant flux, AR=2.00[1]

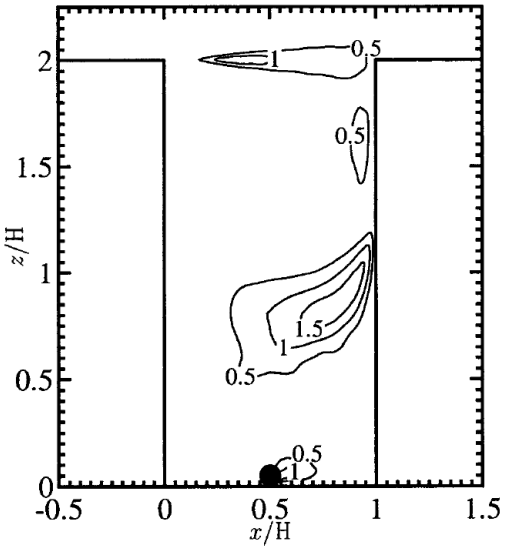

Figure C.21: Spatial variation of the dimensionless mean vertical pollutant flux, AR=2.00[1]

Bibliography

[1] Mary C. Leung Dennis Y.C. Liu, Chun Ho Barth. Large-eddy simulation of flow and pollutant transport in street canyons of different building-height-to-street-width ratios. pages 1410–1424, 2004.

[2] Dennis Y.C. Leung Xian-Xiang Li, Chun-Ho Liu. Development of a k-ε*model for the determination of air exchange rates for street canyons*. 39 : 7285 − −7296, 2005.

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Air distribution in street canyons: a CFD study

Thesis submitted in partial fulfillment of the requirements for the degree

of

Bachelor's degree in Industrial Technologies Engineering

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