The 9th International Joint IWA/IAHR Conference on
URBAN DRAINAGE MODELLING
3 - 7 September 2012
Belgrade, Serbia
University of Belgrade, Faculty of Civil Engineering

Specialist Conferences
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DESIGNING DOMESTIC RAINWATER HARVESTING SYSTEMS UNDER DIFFERENT CLIMATE REGIMES IN ITALY

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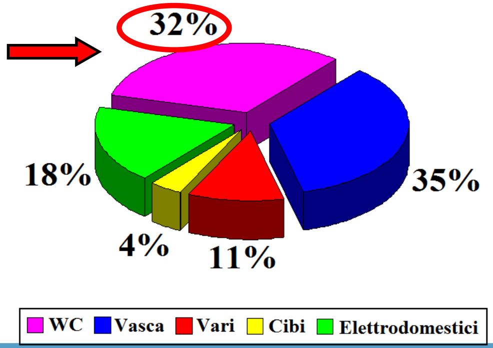
INTRODUCTION (I)

Domestic Rain Water Harvesting DRWH
defines the small-scale concentration, collection, storage and use of rainwater from impervious surfaces for domestic use [EPA, 2004]

- Worldwide diffusion of DRWH systems to harvest and domestic use of rain water coming from building rooftop [Donati, 1995; Fewkes, 1999]
- Rain water replacing water from mains in case of domestic uses requiring lower quality in comparison to potable water (toilet flushing, garden watering, etc.) [Vickers, 2001]
- Various researches have shown that the house demand for toilet flushing can achieve up to 30% of household consumptions [Butler et al., 1995; Lazarova et al., 2003]
- Most immediate addressing of rooftop rain water to the flush of toilets

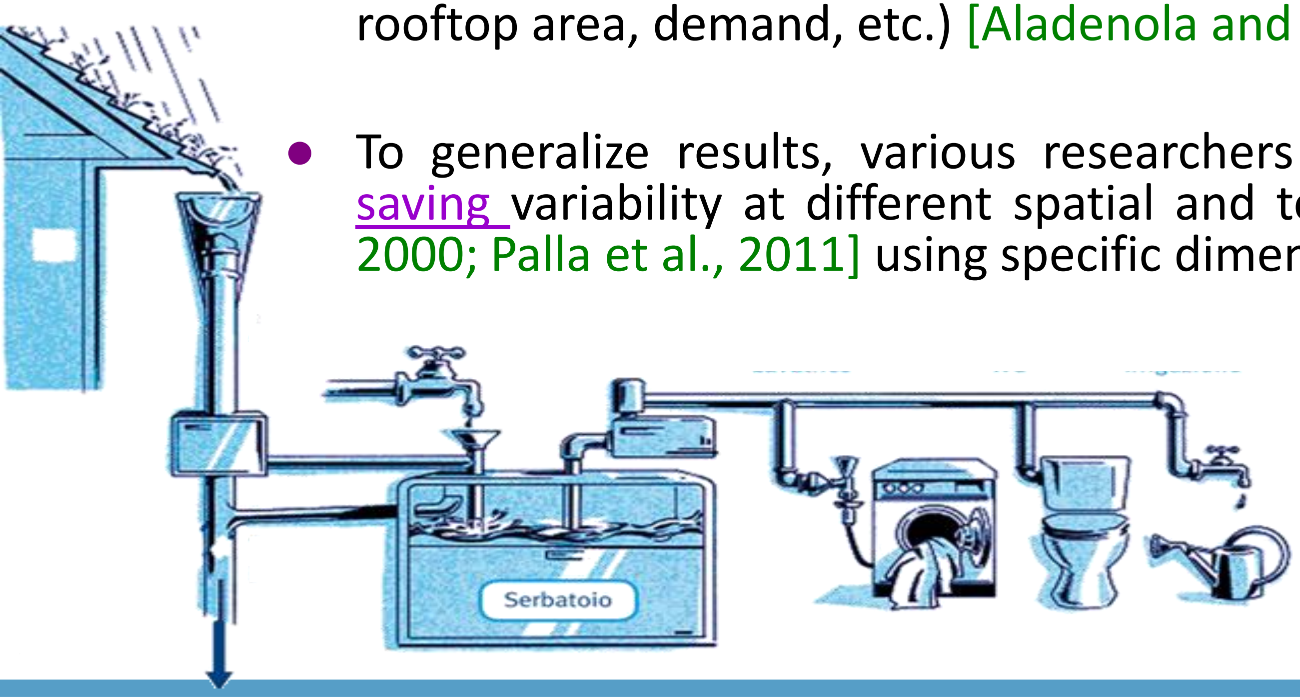


INTRODUCTION (II)

- Many studies focusing on the assessment of water-saving efficiency carried out with different approaches based on water balance simulation [Fewkes and Butler, 2000; Ghisi et al., 2007], probabilistic methods [Lee et al., 2000; Guo and Baetz, 2007] and economic approaches [Sturm et al., 2009]

- Tank capacity depends on local variables (precipitation patterns, rooftop area, demand, etc.) [Aladenola and Adeboye, 2009]

- To generalize results, various researchers investigated the water saving variability at different spatial and temporal scales [Fewkes, 2000; Palla et al., 2011] using specific dimensionless parameters



INTRODUCTION (III)

STUDY AIM

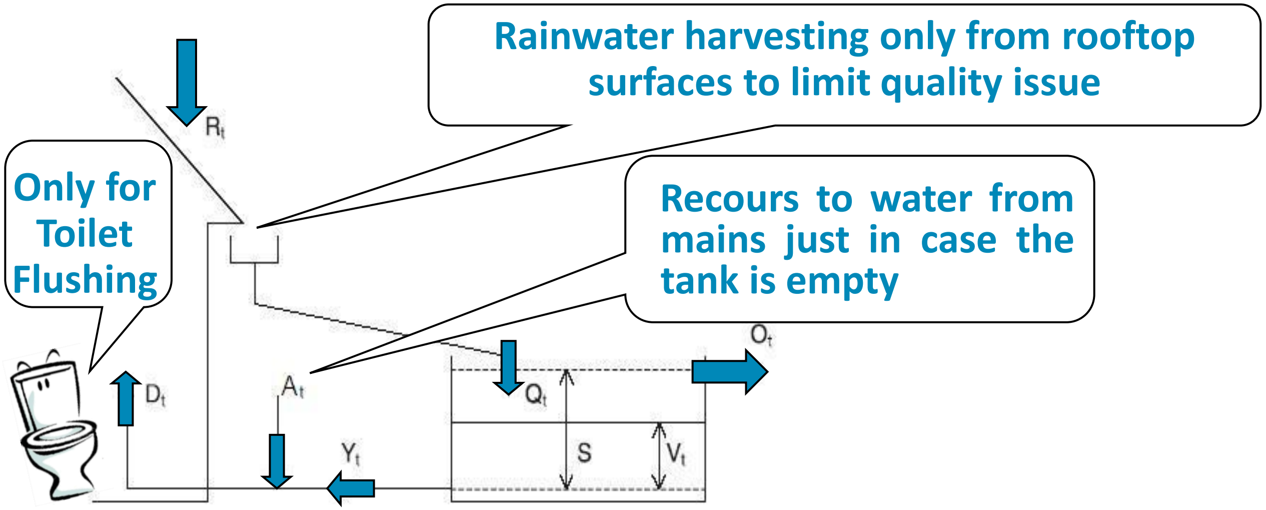
In 2011, a joint research program between Universities of Catania and Genoa (Italy) to evaluate potential water-saving provided by rooftop rain water harvesting for domestic use.

- To define a methodology (based on daily water balance simulations) to cost-effective design DRWH systems at national scale.

→ To identify performance of DRWH systems under different precipitation regimes in Italy

→ To set up simple regression relationships to be used in order to suitably size the DRWH systems according to the required water saving performance

METHODOLOGY (I)



- **R_t →** **Rainfall**
- **Q_t →** **Inflow**
- **D_t →** **Water Demad**
- **S →** **Tank capacity**
- **V_t →** **Stored volume**
- **O_t →** **Overflow volume**
- **Y_t →** **Rainwater supply**
- **A_t →** **Main supply**

Daily mass balance equation

$$V_t = Q_t + V_{t-1} - Y_t - O_t$$

YAS Operating Rule

- ✓ Conservative irrespective of the model time scale (Fewks, 2000)
- ✓ Less sensitive to system capacity and water demand variation (Mitchell, 2007)

$$Y_t = \min \begin{cases} D_t \\ V_{t-1} \end{cases}$$

The stored volume V_t is evaluated after spillage .

$$V_t = \min \begin{cases} V_{t-1} + Q_t - Y_t \\ S - Y_t \end{cases}$$

METHODOLOGY (II)

To analyse the performance of the DRWH system under various climate and operational condition the following two dimensionless parameters were used [Campisano et al., 2012]:

Storage fraction s_m

$$s_m = \frac{S}{D/365 \cdot n_D / n_R}$$

Demand fraction d

$$d = \frac{D}{Q}$$

- S = rain water tank storage capacity
- D = annual water demand for toilet flushing
- n_D = number of dry weather days in the year
- n_R = number of rainy days in the year
- Q = annual inflow volume

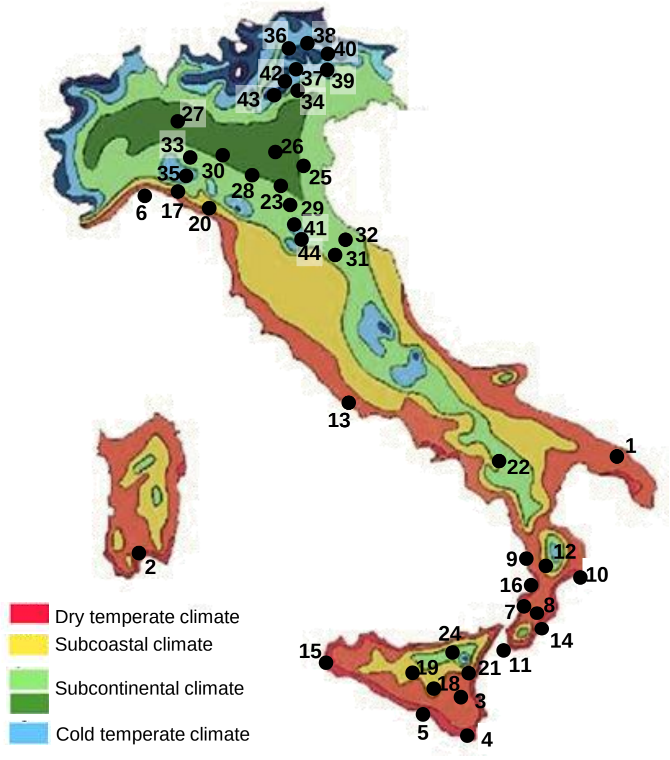
DRWH performance assessment is performed by means of a non-dimensional index:

Water – saving efficiency E

defined as the ratio between the supplied volume of rainwater and the water demand during the entire simulation period.

METHODOLOGY (III)

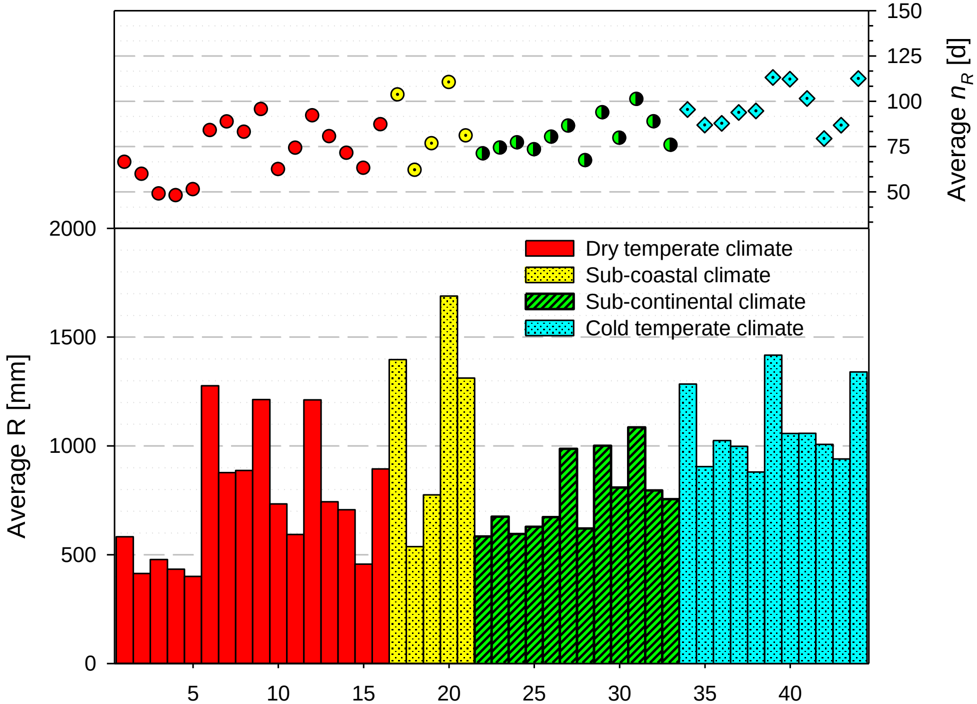
- Use of Köppen-Geiger classification to identify the main different climates zone within the Italian territory (Cs and Cf) and by considering the specific morphology of the Italian territory, further classification in two sub-zones within each Köppen class:
    - dry temperate climate (Cs_1);
    - sub-coastal climate (Cs_2);
    - sub-continental climate (Cf_1);
    - cold temperate climate (Cf_2).



- Selection of 44 sites within the 4 climate zones to examine the impact of climate conditions on the performance of RWH systems.

- For each site rainfall data are available with daily resolution and the precipitation series is at least 30 years long [Palla et al., 2011].

CLIMATIC ZONING in ITALY



Dry temperate
1. Brindisi
2. Cagliari
3. Catania
4. Cozzo Spadaro
5. Gela
6. Genova
7. Gioia Tauro
8. Gioiosa Ionica
9. Guardia Piemontese
10. Isola di Capo Rizzuto
11. Reggio Calabria
12. Rende
13. Roma Ciampino
14. Siderno Marina
15. Trapani
16. Vibo Valentia

Sub-coastal
17. Bedonia
18. Caltagirone
19. Enna
20. Ligonchio Centrale
21. Zafferana Etnea

Sub-continental
22. Ariano
23. Bologna
24. Bronte
25. Ferrara
26. Mantova
27. Milano
28. Modena
29. Monzuno
30. Parma
31. Pennabilli
32. San Marino
33. Sarmato

Cold temperate
34. Ala Ronchi
35. Bobbio
36. Passo Mendola
37. Borgo Valsugana
38. Predazzo
39. Caoria Centrale
40. Pian Fedaia Diga
41. Santa Sofia
42. Mezzolombardo
43. Trento Laste
44. Verghereto

- Average yearly precipitation in the range 420-1700 mm
- Variability mainly associated with the dry temperate and sub-coastal climate precipitation (Cs_1 and Cs_2)
- n_R values tends to increase from an average value of 73 days (dry temperate sites) to 95 days (cold climate sites)

DRWH SYSTEM PERFOMANCE (I)

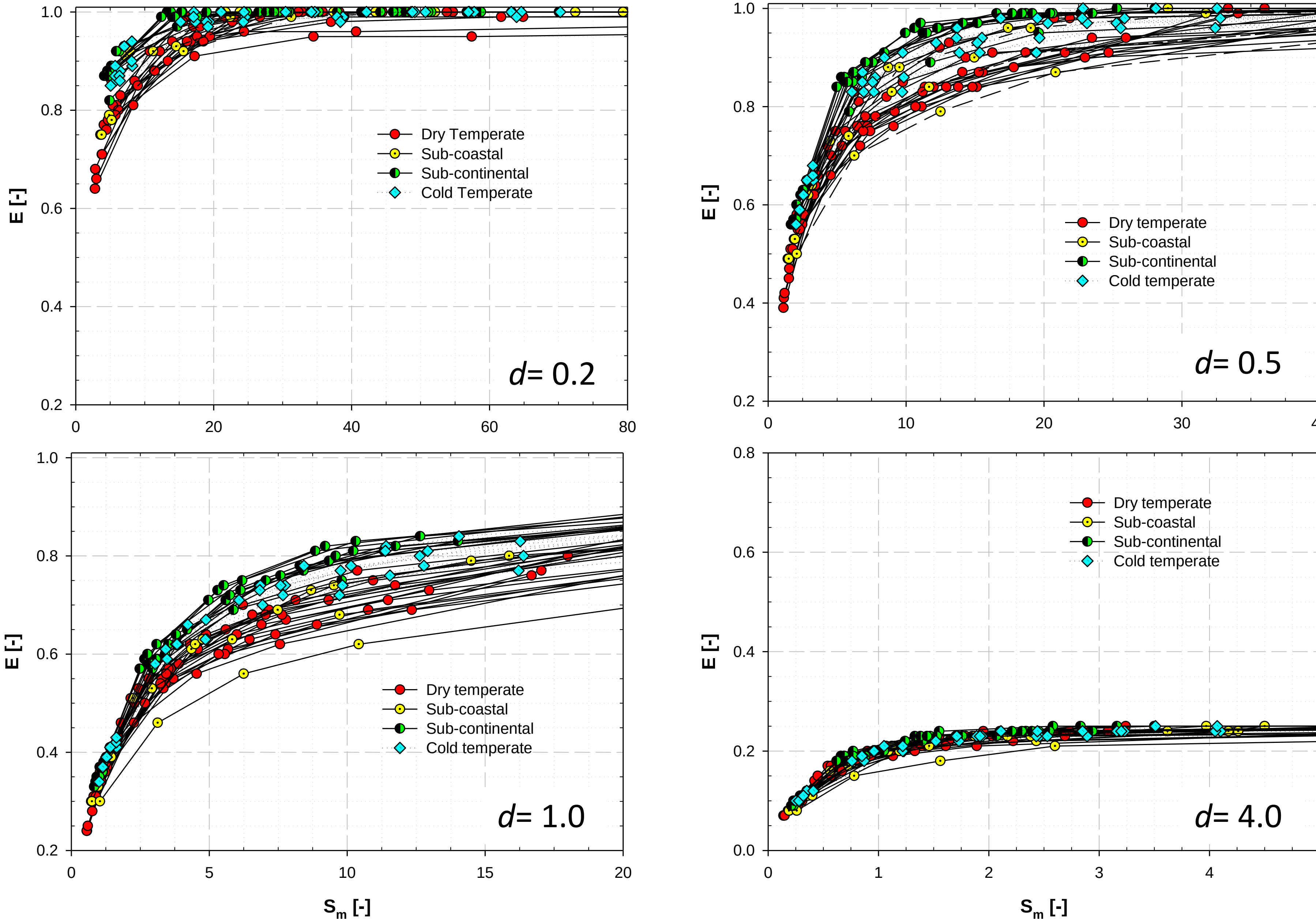
- DRWH system performance under the various precipitaion regime are examined under different dimensionless scenarios of demand fraction *d* and storage fraction s_m

  - $d = 0.2$ → $s_m = 3–240$
  - $d = 0.5$ → $s_m = 1–95$
  - $d = 1.0$ → $s_m = 0.5–48$
  - $d = 4.0$ → $s_m = 0.1–12$

Water demand scenarios → Assuming harvested rainwater to be used only for domestic toilet flushing use, values of *d* lower or at least equal to unity are usually expected in practical application

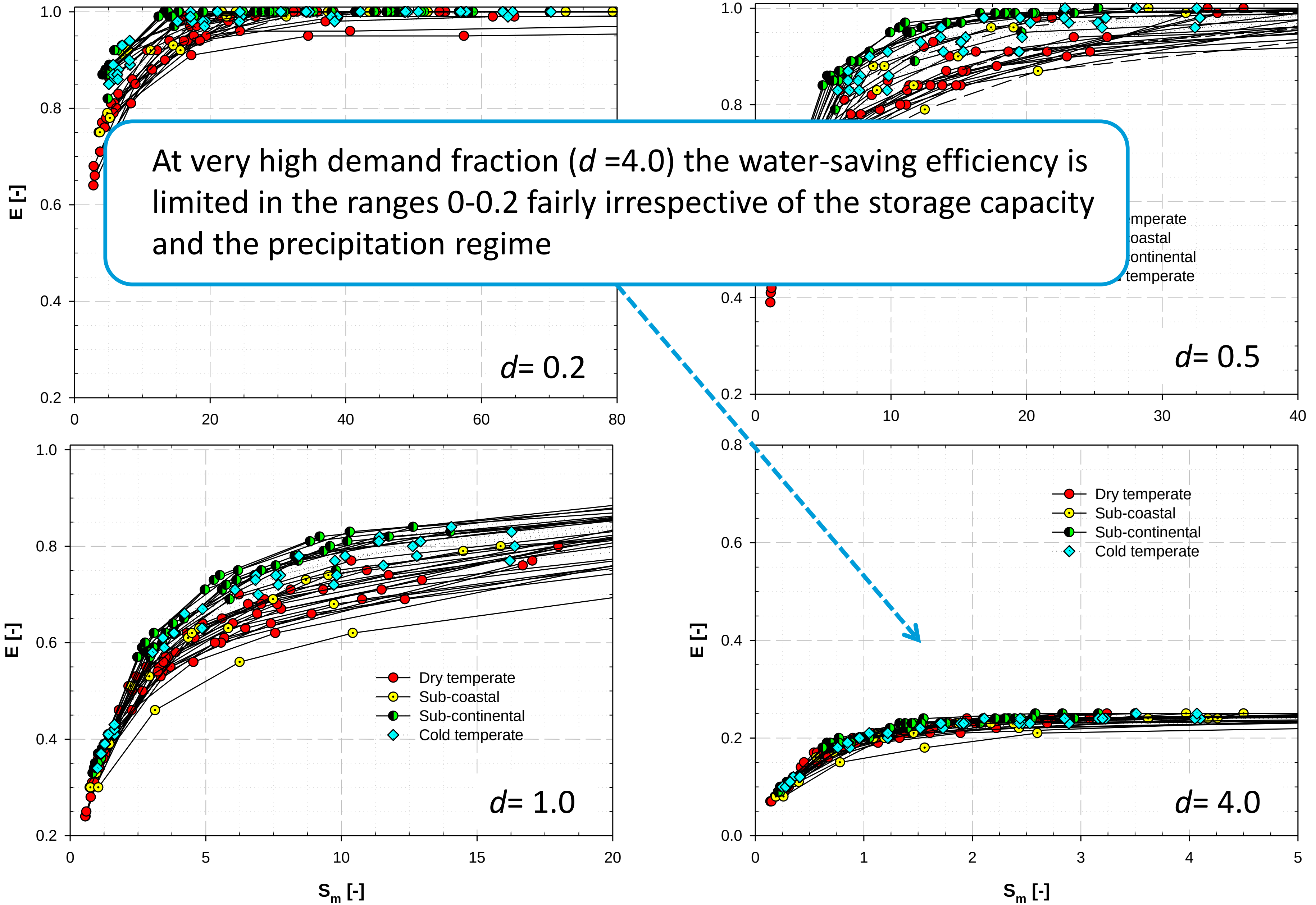
Storage scenarios → the analysis is carried out with respect to five storage fraction value for each demand scenarios. To perform comparable operational conditions, five reference values of S/Q equal to 0.01, 0.03, 0.06, 0.1 and 0.3 are used.

DRWH SYSTEM PERFOMANCE (II)

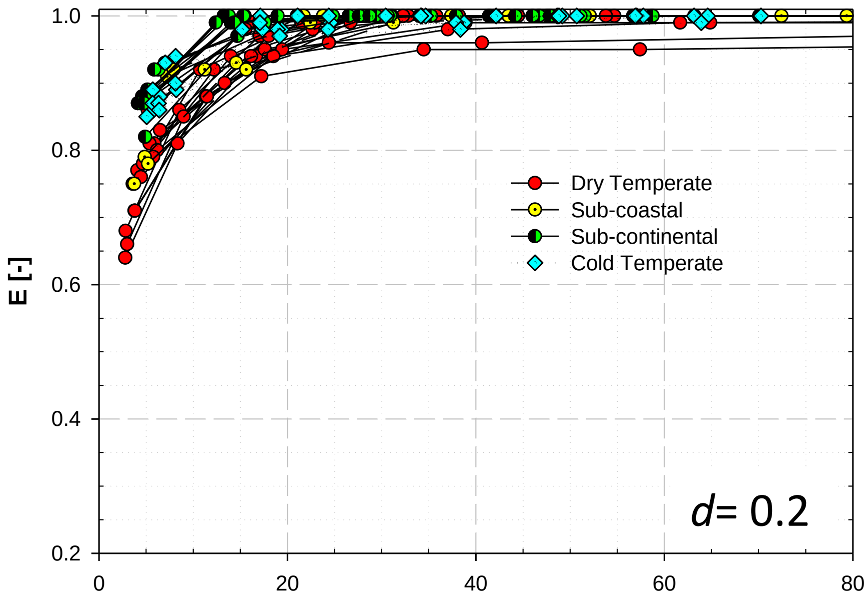


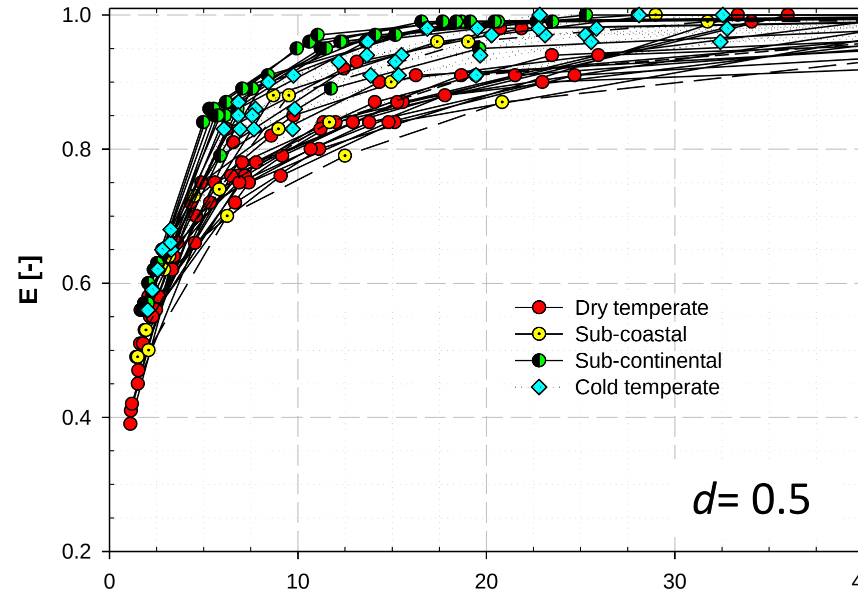
DRWH SYSTEM PERFOMANCE (II)

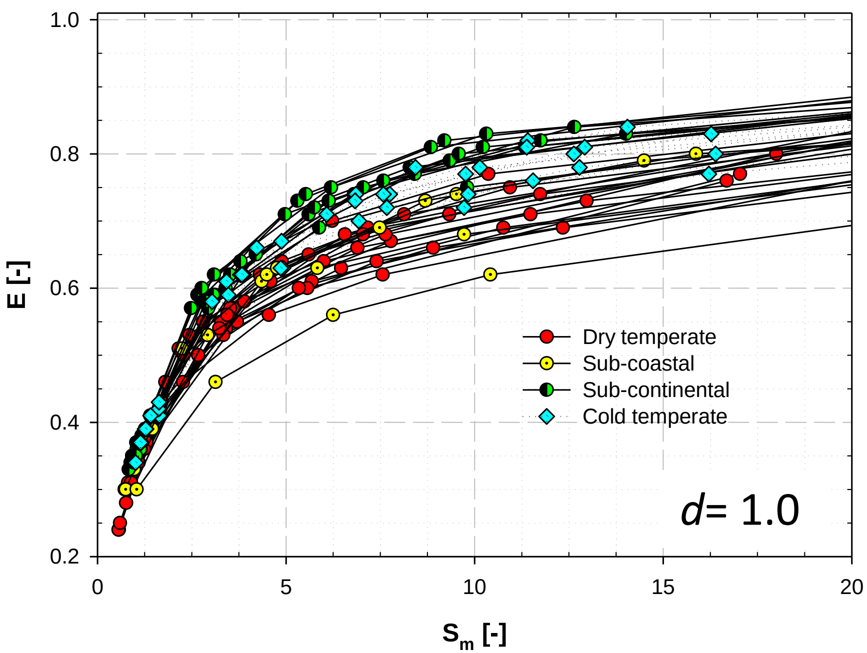
At very high demand fraction (*d* =4.0) the water-saving efficiency is limited in the ranges 0-0.2 fairly irrespective of the storage capacity and the precipitation regime



DRWH SYSTEM PERFOMANCE (II)







For *d* =0.2, 0.5 and 1:

- ✓ the water-saving efficiency is affected by the tank size and the precipitation regime;
- ✓ two different classes of system behavior respectively typical of the dry-temperate/sub-coastal (red and yellow dots) and sub-continental/cold (green and blue dots) climates.

S_m [-]

DRWH tank sizing (I)

- A regression analysis is carried out to relate water-saving efficiency E, and the modified storage fraction, s_m

$$E = 1 - \frac{1}{(1 + a \cdot s_m)^b}$$

where *a* and *b* are the **dimensionless regression coefficients**. Curve suitable to describe the efficiency being limited between [0,1].

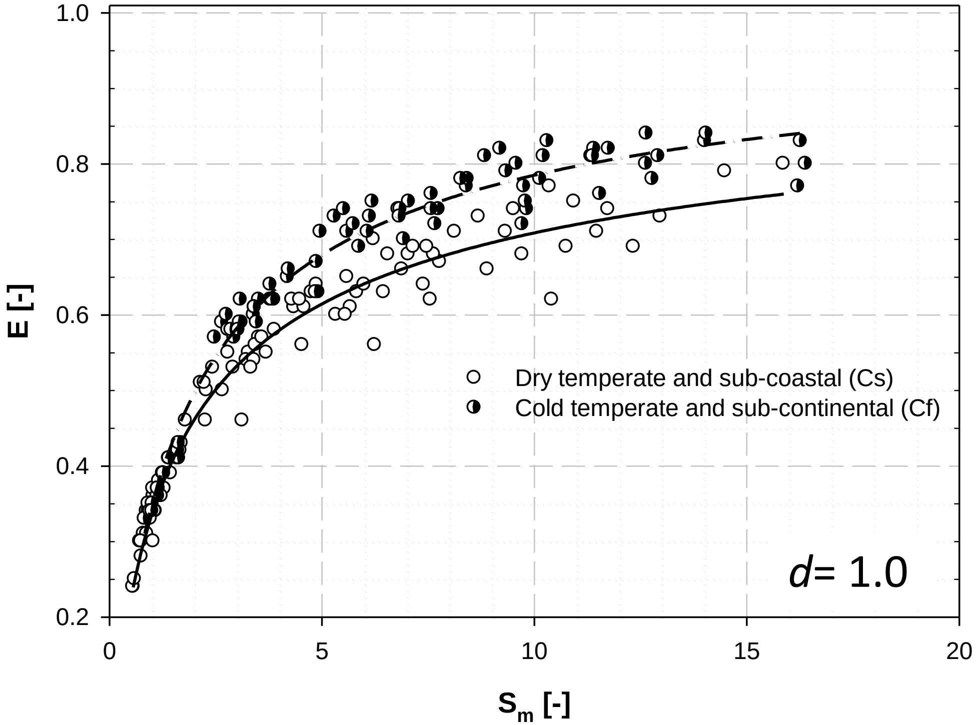
- The analysis is carried out by considering **two classes of data** respectively describing the performance observed in the dry temperate/sub-coastal climate and the ones observed for the sub-continental/cold temperate

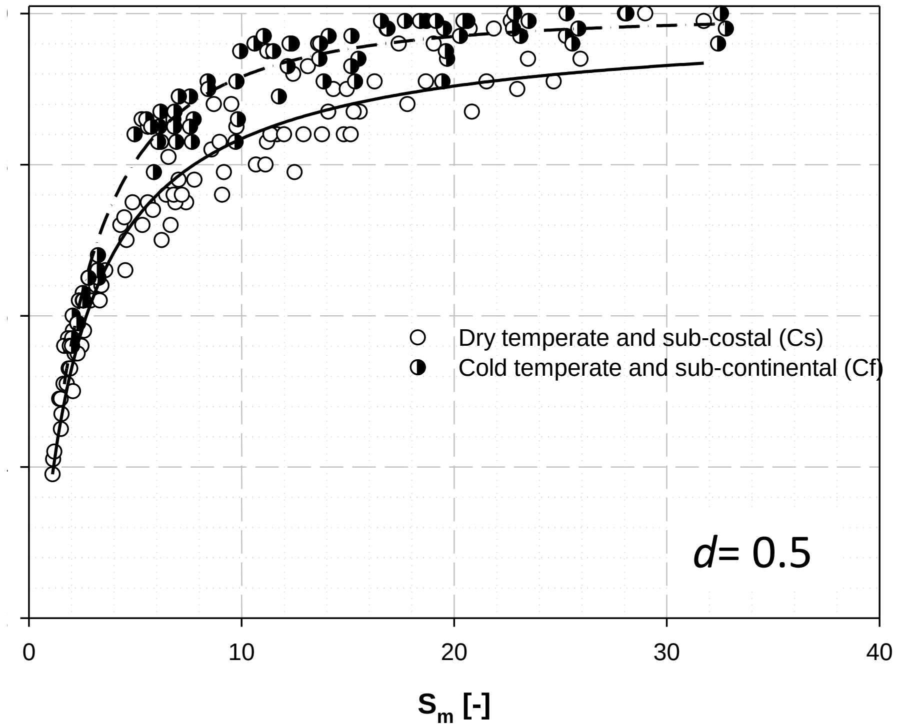
DRWH tank sizing (II)

d	Climate Koppen zone	Regression curve parameters		Regression curve Statistics	
		a	*b*	R^2	Normality test
0.2	Cs	0.3138	1.6729	0.94	Passed
0.2	Cf	0.2495	2.4929	0.91	Failed
0.5	Cs	0.6903	0.8700	0.95	Passed
0.5	Cf	0.2845	1.8421	0.97	Failed
1.0	Cs	1.5310	0.4419	0.96	Failed
1.0	Cf	0.8973	0.6687	0.98	Passed
4.0	Cs	11.4082	0.0813	0.95	Passed
4.0	Cf	13.4294	0.0785	0.94	Failed

At high demand fraction it is possible to describe the system behaviour by using a single regression relationship thus confirming that in such condition the precipitation regimes do not affect the performance.

DRWH tank sizing (III)





CONCLUSIONS

- Dimensionless parameters *d* and s_m, are suitable to describe the performance of a DRWH system under different hydrological and operational conditions;

- As the impact of precipitation regime is concerned, two class of system behavior are identified in the Italian territory, respectively corresponding to the the dry temperate/sub-coastal (Cs) and the cold temperate/ sub-continental (Cf) climates according to the Köppen-Geiger classification

- Regression curves describing the relationship between the water-saving efficiency and the modified storage fraction allow to size the DRWH tank based on the required system performance.

...Rainwater harvesting...

Thank you for your attention !