The Watergy greenhouse: Improved productivity and water use efficiency using a closed greenhouse

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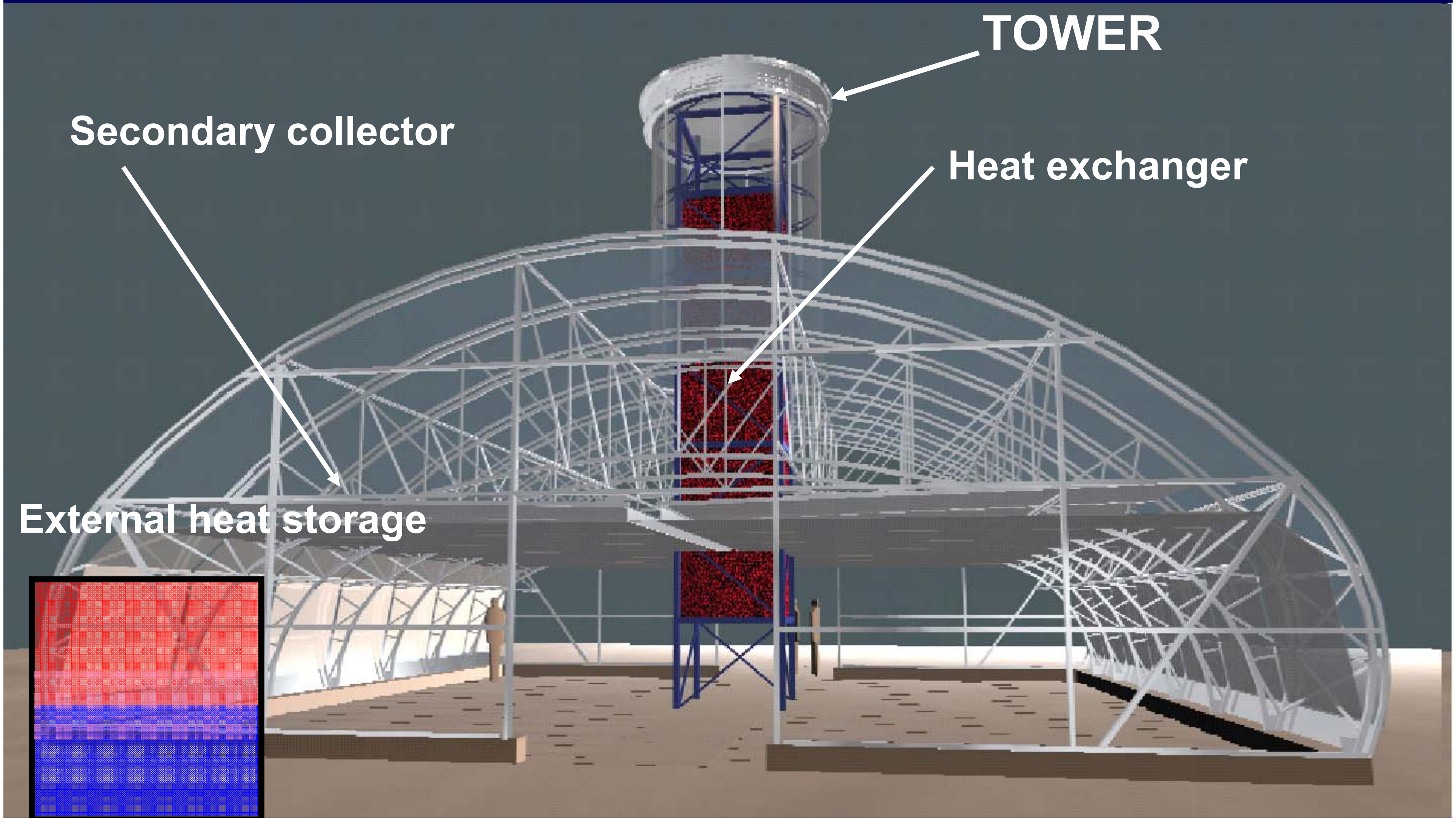
Closed greenhouses for horticultural growing in semi-arid climates

Water saving (recovery of evapotranspiration)

Possibility of bio-production (no pesticides)

Sink of excess emissions of CO_2

Climate control in this case is a very hard task, requiring cooling systems (energy consuming)

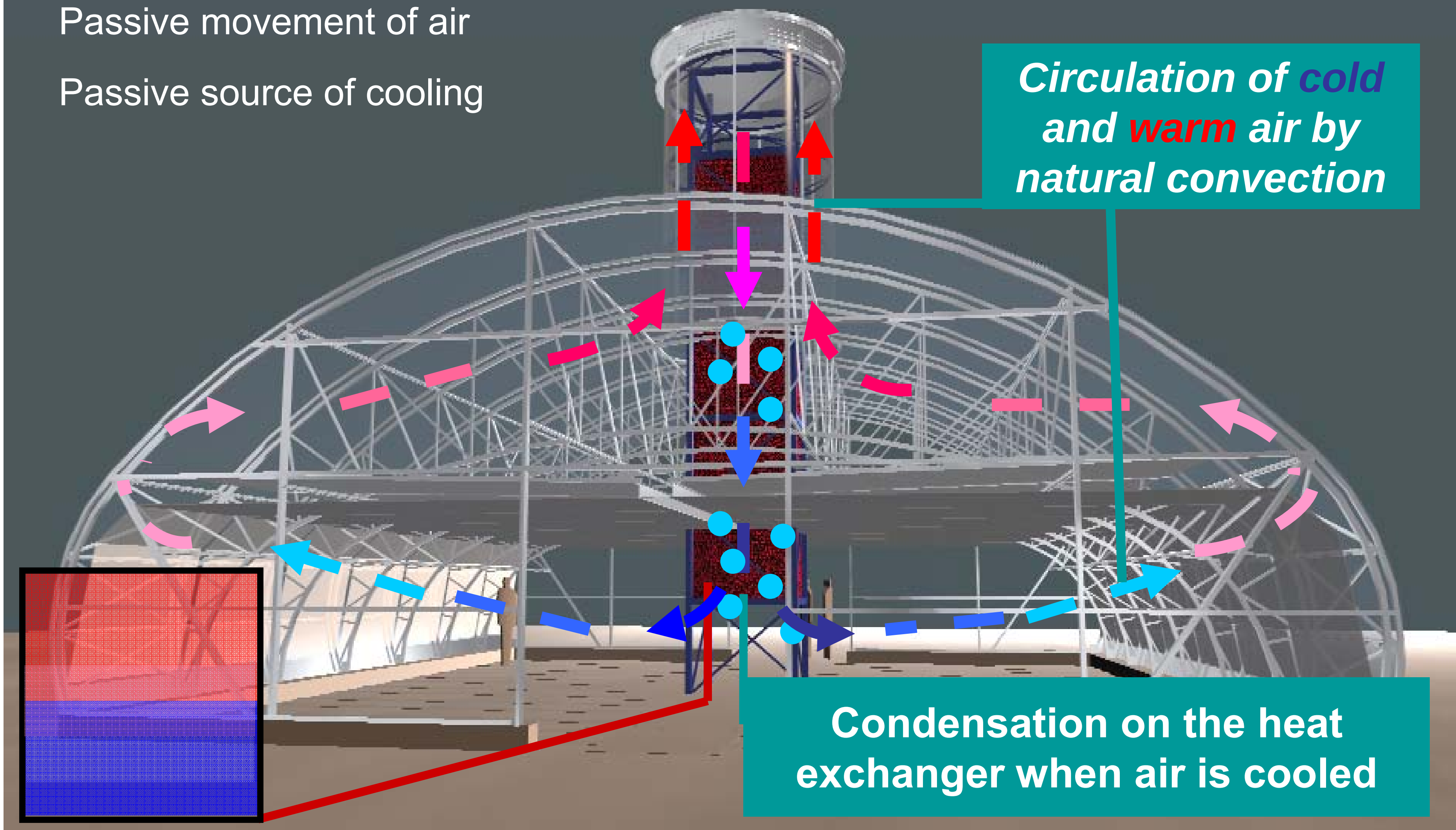


TOWER
Secondary collector
Heat exchanger
External heat storage

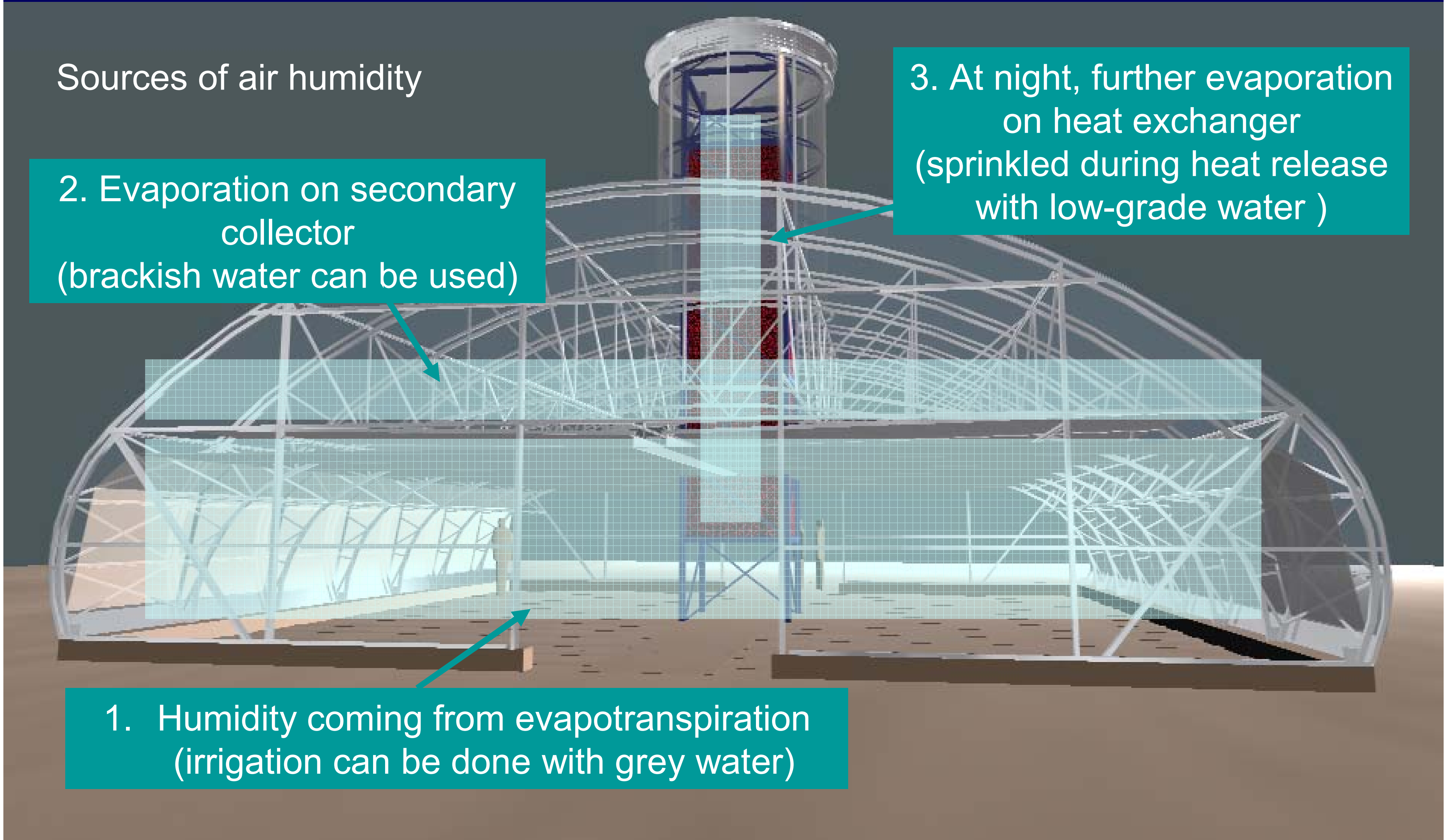
Watergy Prototype of a closed greenhouse

Passive movement of air

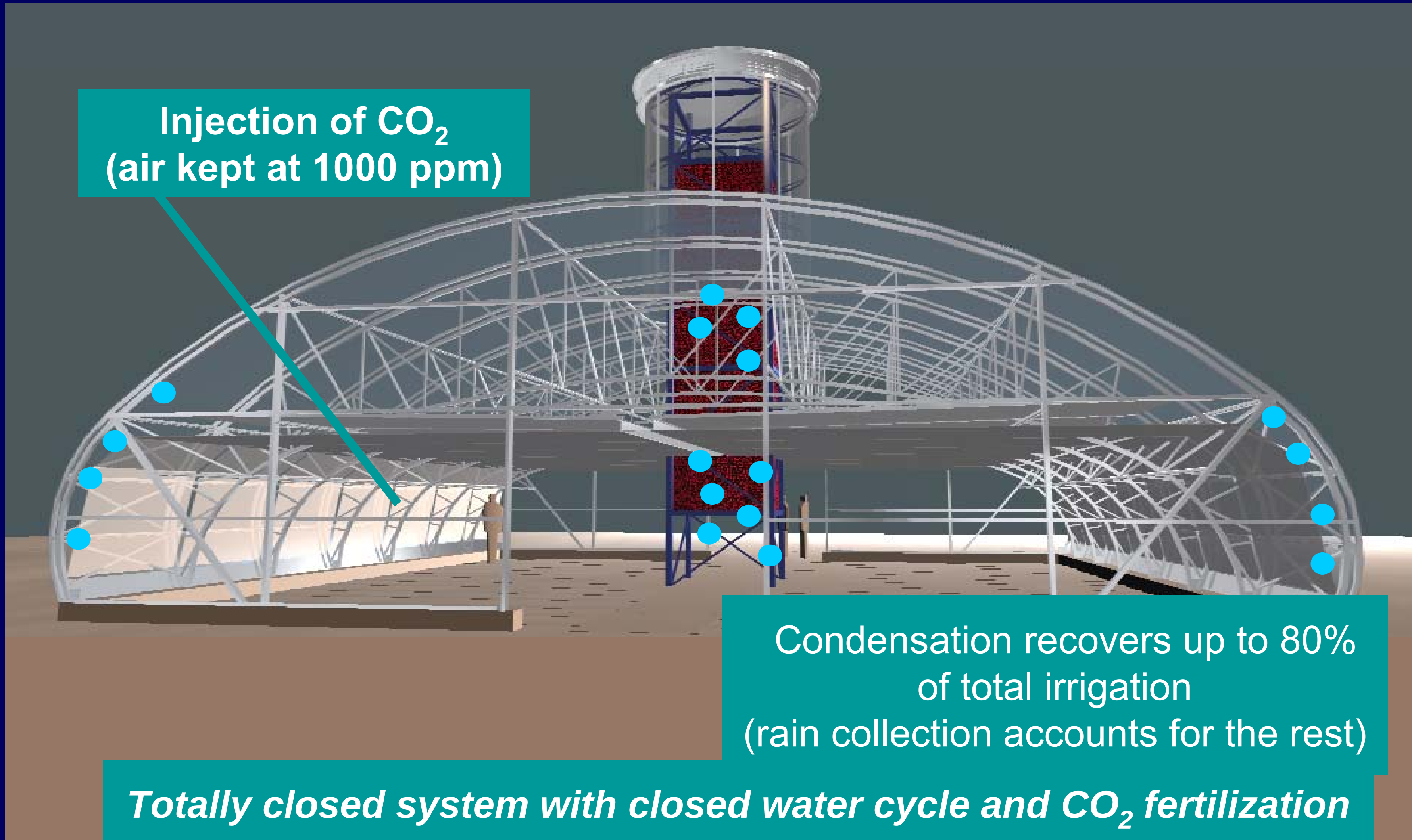
Passive source of cooling



Watergy Prototype of a closed greenhouse



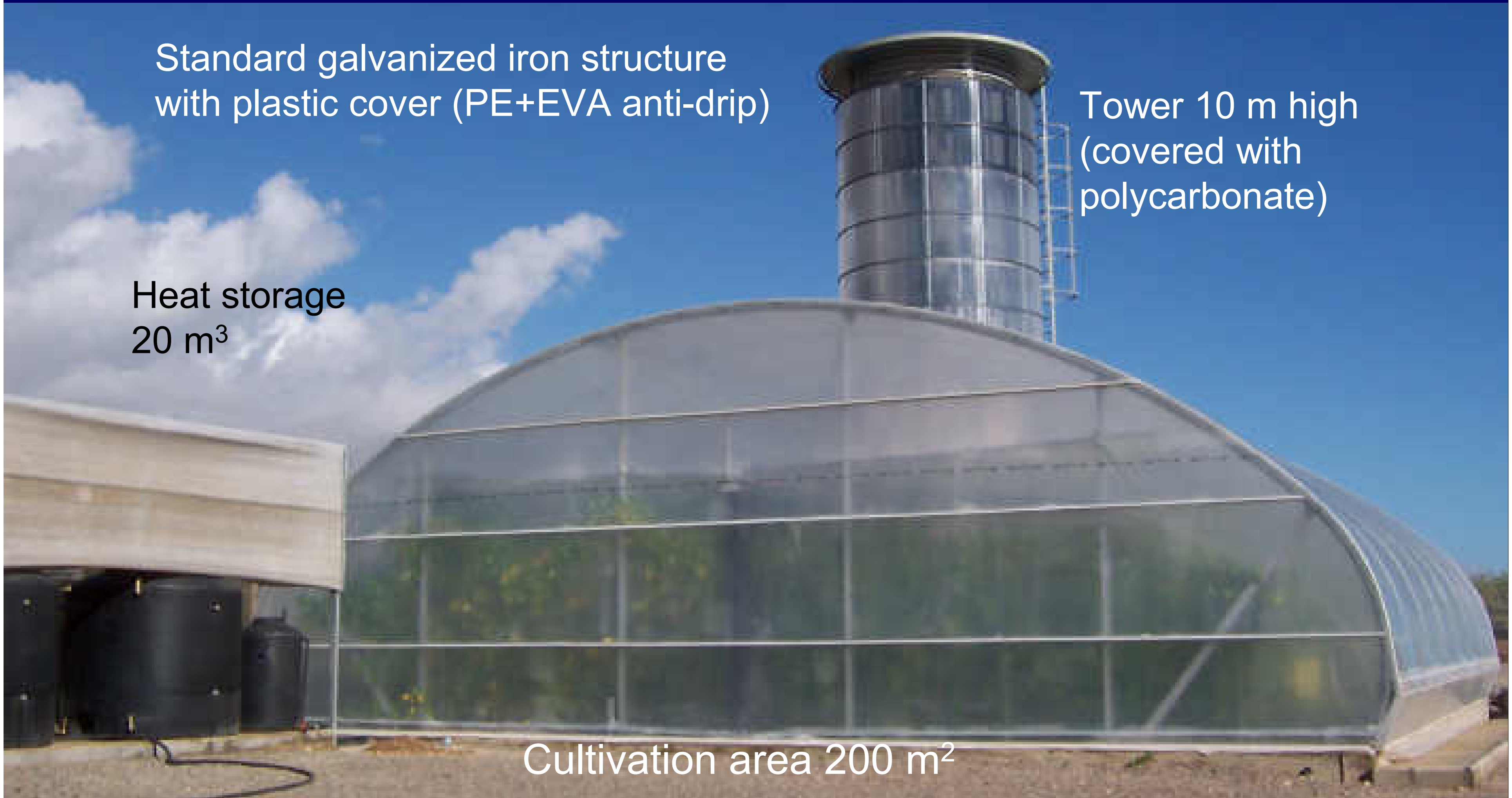
Watergy Prototype of a closed greenhouse



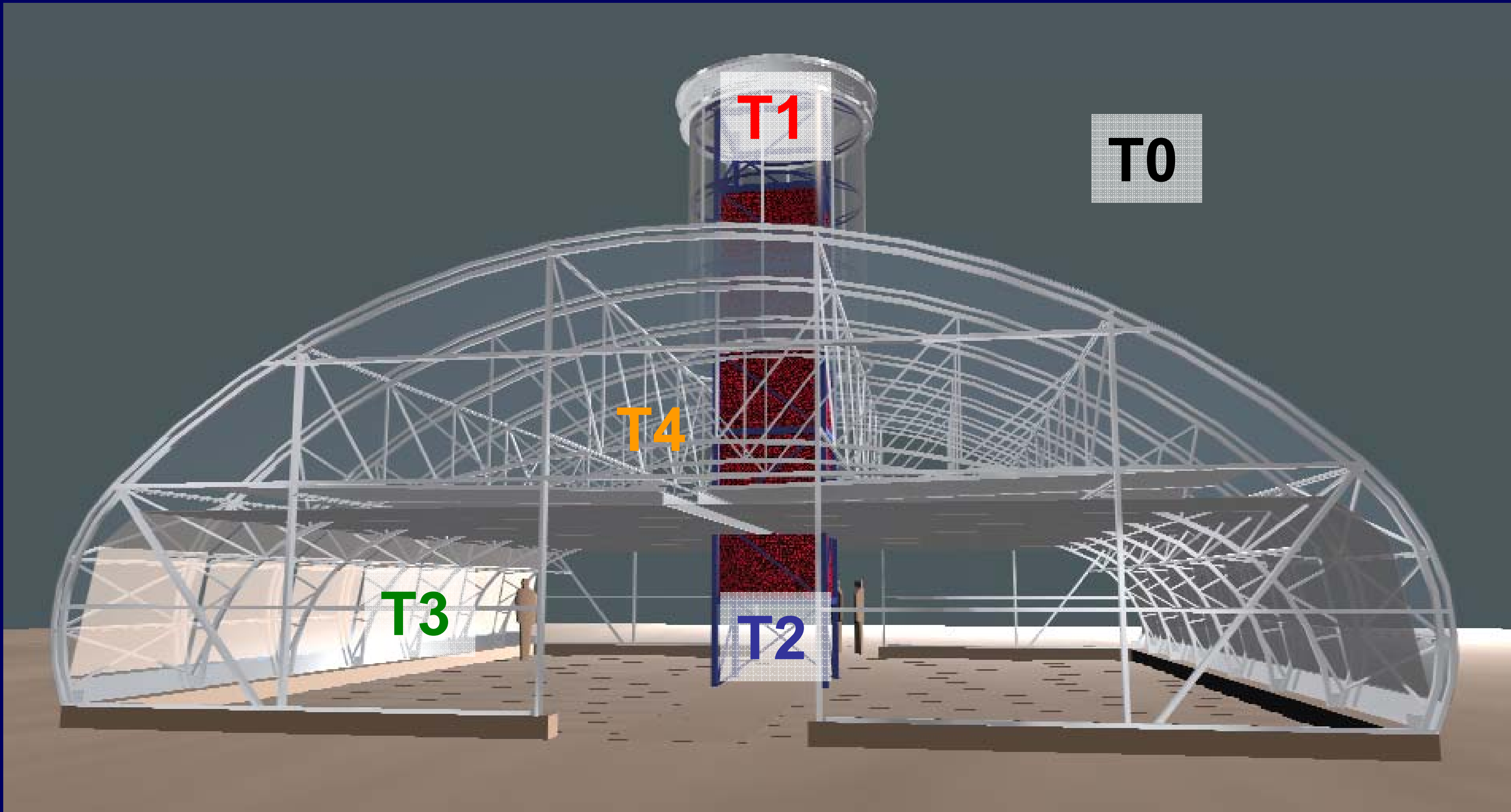
Totally closed system with closed water cycle and CO_2 fertilization

Watergy Prototype of a closed greenhouse

Estación Experimental Fundación Cajamar El Ejido (Almería)



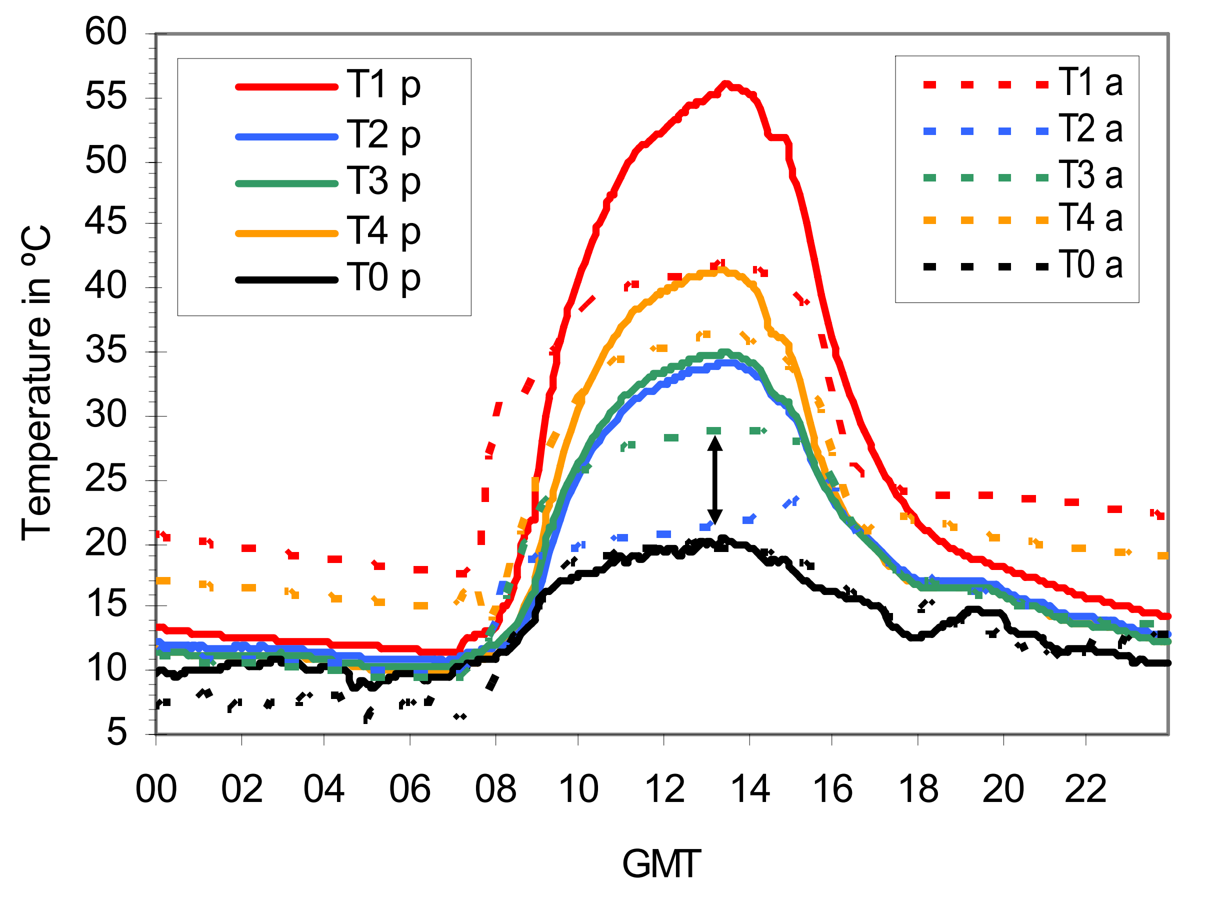
Performance of the system



Performance of the system

p: non-operating → no cooling (vertical gradient of T)

a: operating → cooling (cold air circulates from bottom of tower)



Temperatures:

T1: top of the tower

T2: bottom of the tower

T3: greenhouse

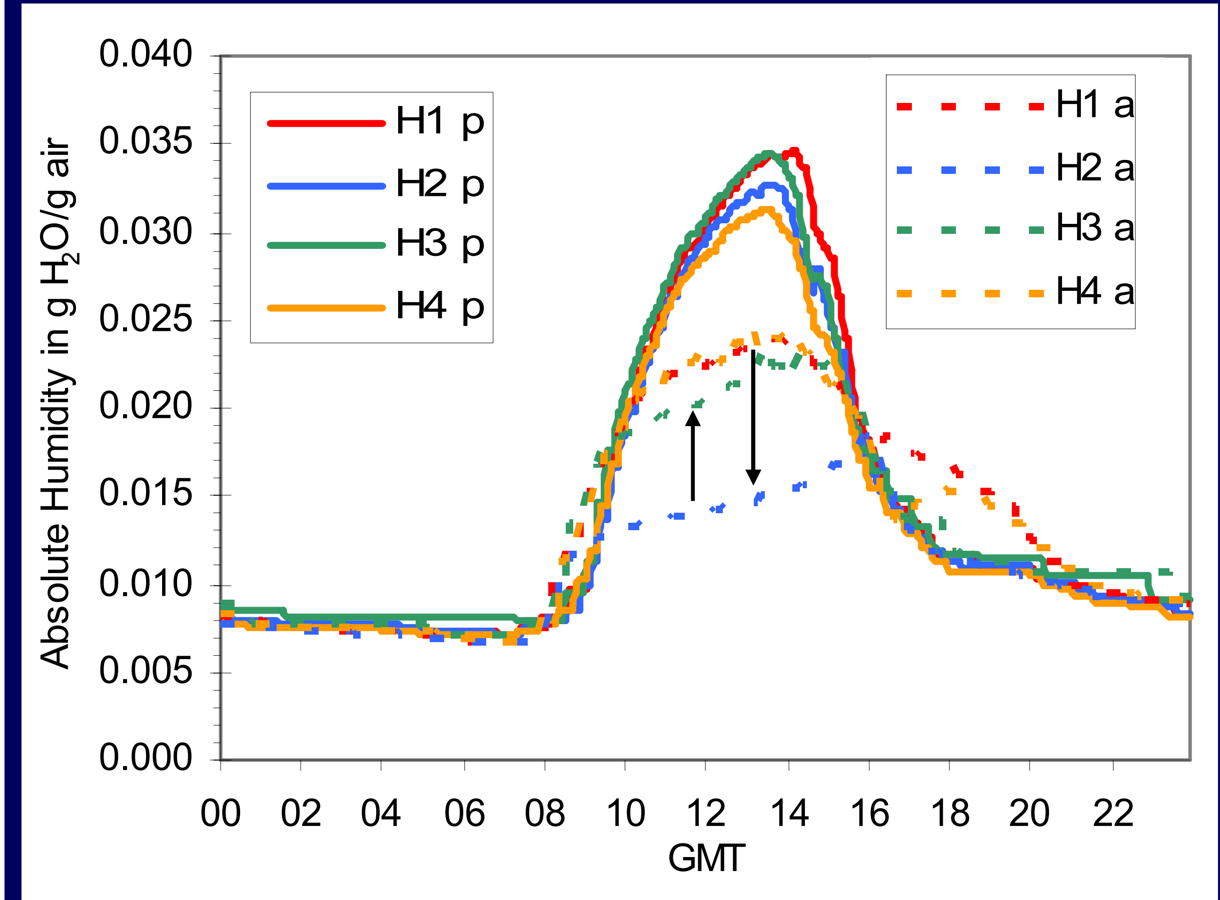
T4: secondary collector

T0: outside

Performance of the system

p: non-operating → no cooling (no drying)

a: operating → cooling (air humidity decreases inside the tower)



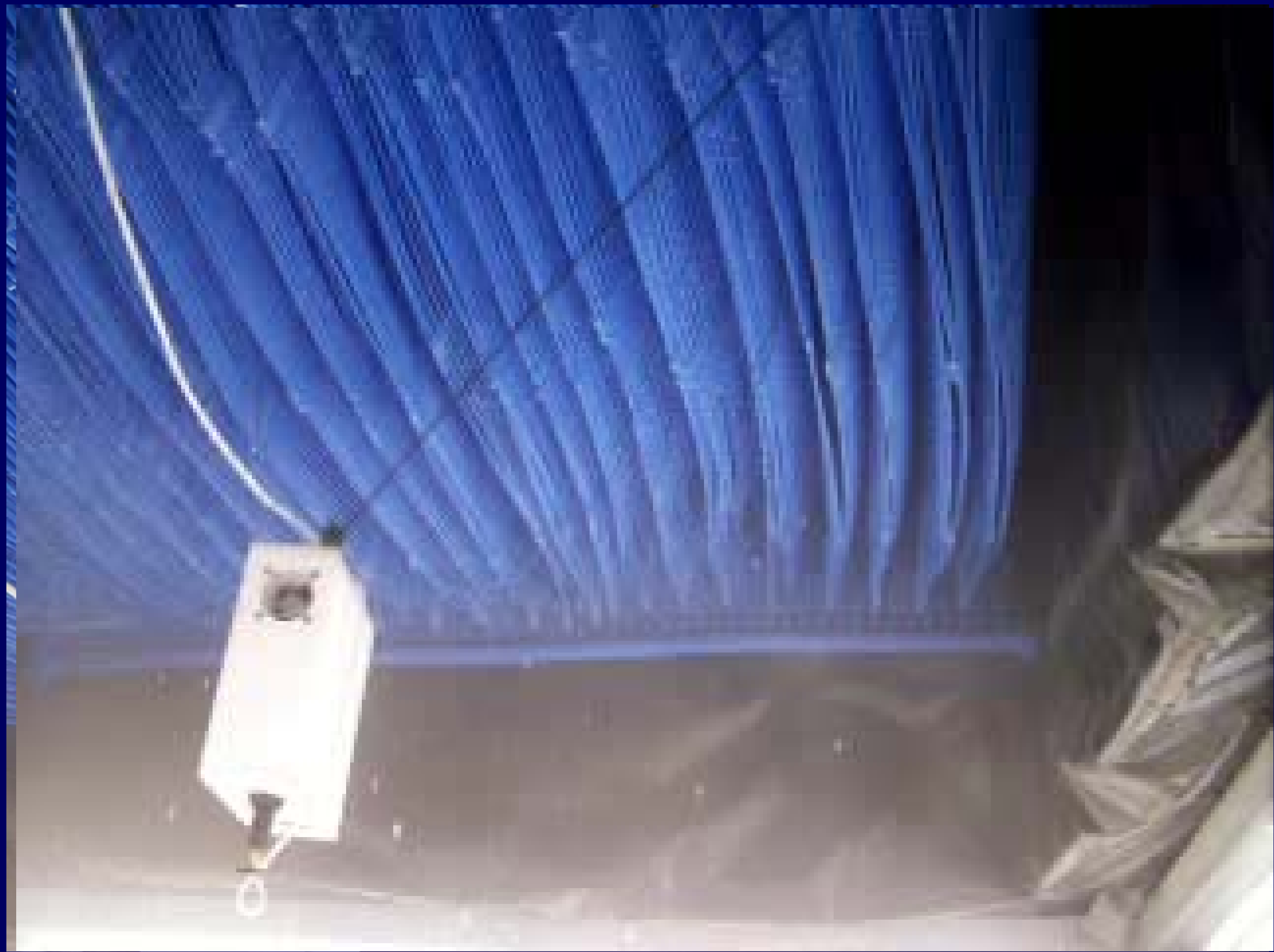
Humidity content of the air :

H1: top of the tower

H2: bottom of the tower

H3: greenhouse

H4: secondary collector

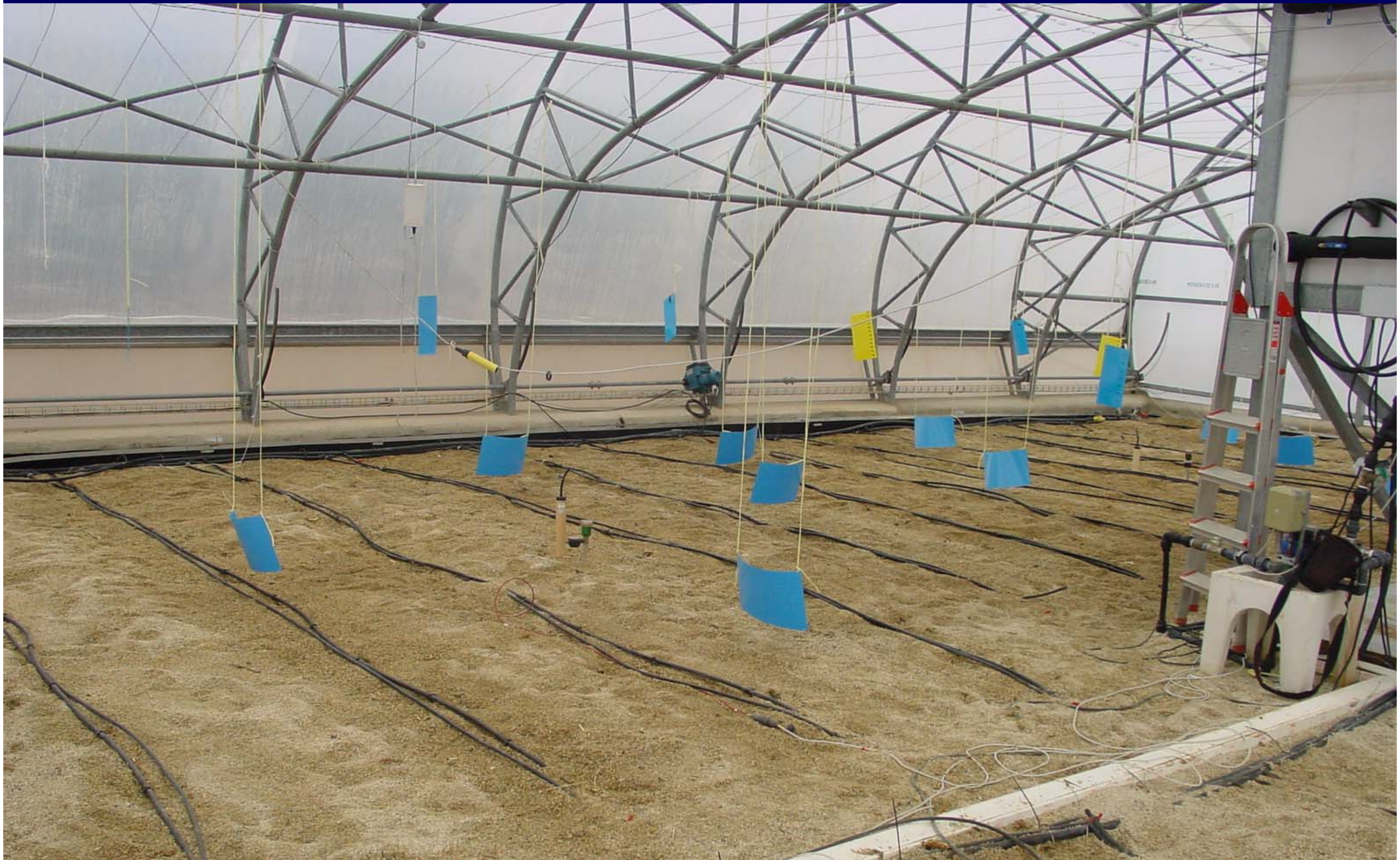


video

watergy

estación experimental

FUNDACIÓN cajamar



watergy

estación experimental FUNDACIÓN cajamar

Agronomical evaluation of the Watergy prototype and main results (2004-2007)

2004	ENE	CONSTRUCTION
	FEB	
	MAR	
	ABR	
	MAY	
	JUN	
	JUL	
	AGO	
	SEP	French beans ("*Donna*")
→	OCT	
	NOV	
	DIC	
2005		
2006		
2007		

Phase 1: autumn 2004

greenhouse finished except for automation and monitoring

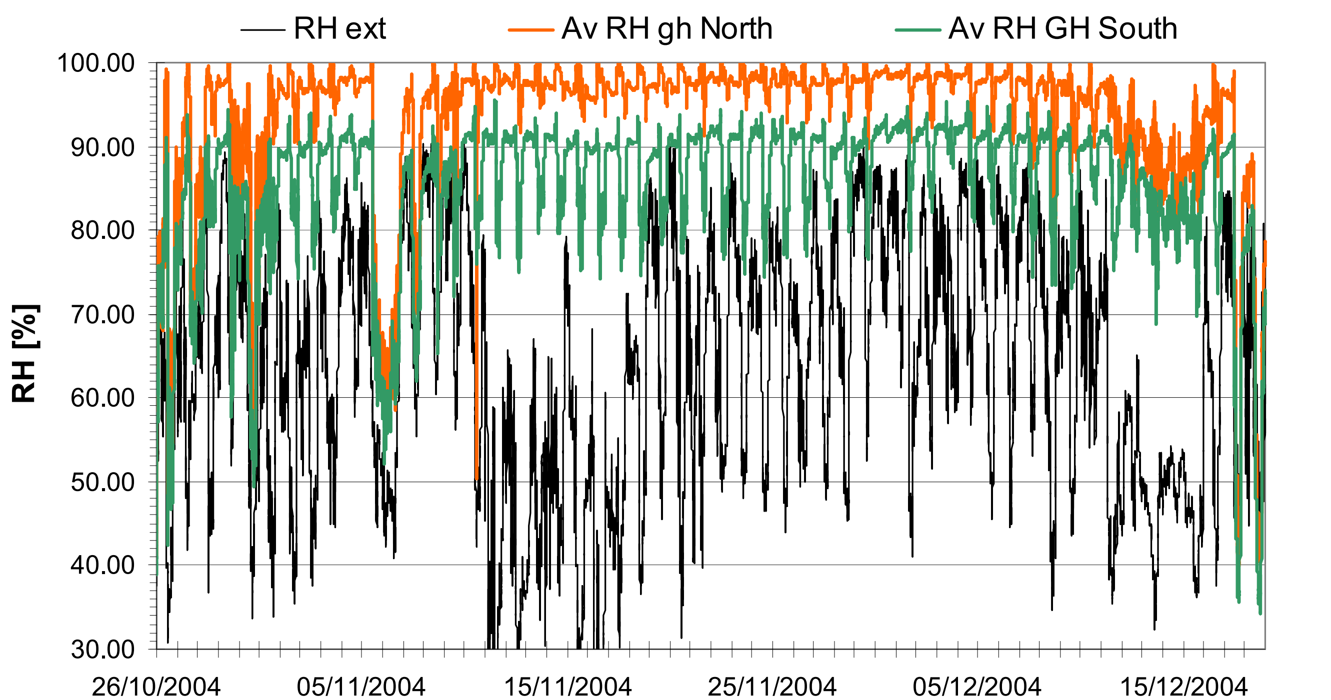
preliminary cultivation of beans (cv “*Donna*”)

from 10 Sep 04 to 7 Dec 04

very high density (2 plants/m^2)

→ excess shadow in the north

→ excess humidity



Phase 1: autumn 2004

greenhouse finished except for automation and monitoring

preliminary cultivation of beans (cv "*Donna*")

from 10 Sep 04 to 7 Dec 04

very high density (2 plants/m^2) → excess shadow in the north

→ excess humidity

Yield:

north: 1.5 kg/m^2

south: 3 kg/m^2 → larger than standards of the area for that cultivar and season

2004	ENE	CONSTRUCTION
	FEB	
	MAR	
	ABR	
	MAY	
	JUN	
	JUL	
	AGO	
	SEP	French beans ("*Donna*") — density too high — North: 1.5 kg/m² — South: 3 kg/m²
	OCT	
	NOV	
	DIC	
2005	ENE	ADJUSTMENTS TO MONITORING (CONDENSATION)
	FEB	
	MAR	French ("*Festival*") and Bush ("*Parker*") Beans
	ABR	
	MAY	
	JUN	
2006		
2007		

4-4-05

6-5-05

2004	ENE	CONSTRUCTION		
	FEB			
	MAR			
	ABR			
	MAY			
	JUN			
	JUL			
	AGO			
	SEP	French beans ("*Donna*")	density too high	North: 1.5 kg/m² South: 3 kg/m²
	OCT			
	NOV			
	DIC			
2005	ENE	ADJUSTMENTS TO MONITORING (CONDENSATION)		
	FEB			
	MAR	French ("*Festival*") and Bush ("*Parker*") Beans	ADJUSTMENTS TO COOLING	flowers fade (reduced cooling performance)
	ABR			
	MAY			
	JUN			
	JUL	Okra (Plant Tests)	ADJUSTMENTS TO COOLING	
	AGO →			
	SEP			
2006				
2007				

25-7-05

8-7-05

17-8-05

2004	ENE–AGO	**CONSTRUCTION**		
2004	SEP–DIC	French beans ("*Donna*")	density too high	North: 1.5 kg/m² South: 3 kg/m²
2005	ENE–FEB	ADJUSTMENTS TO MONITORING (CONDENSATION)		
2005	MAR–JUN	French ("*Festival*") and Bush ("*Parker*") Beans	ADJUSTMENTS TO COOLING	flowers fade (reduced cooling performance)
2005	JUL–SEP	Okra (Plant Tests)	ADJUSTMENTS TO COOLING	
2005–2006	OCT–ENE	Bush Beans ("*Parker*")	reduced transmission of plastic (50%)	Yield: 2 kg/m² PW: 100 kg/m³
2006	FEB	CHANGE OF PLASTIC		
2006	MAR–JUN	Bush Beans ("*Strike*")	Okra (variety trial)	
2007				

27-04-06

17-05-06

Phase 3: spring-summer 2006

Beans and Okra (variety trial)

from 24 Feb 06 to 1 Jun 06

Beans ("*Strike*")

Yield: 1.2 kg/m^2 → similar to optimal of the area for that cultivar and season

Productivity of water: 51 kg/m^3 → 4-5 times larger than open greenhouse standards (Orgaz et al., 2005)

2004	ENE–AGO	CONSTRUCTION		
2004	SEP–DIC	French beans ("*Donna*")	density too high	North: 1.5 kg/m² South: 3 kg/m²
2005	ENE–FEB	ADJUSTMENTS TO MONITORING (CONDENSATION)		
2005	MAR–JUN	French ("*Festival*") and Bush ("*Parker*") Beans	ADJUSTMENTS TO COOLING	flowers fade (reduced cooling performance)
2005	JUL–SEP	Okra (Plant Tests)	ADJUSTMENTS TO COOLING	
2005	OCT–DIC	Bush Beans ("*Parker*")	reduced transmission of plastic (50%)	Yield: 2 kg/m² PW: 100 kg/m³
2006	ENE–FEB	CHANGE OF PLASTIC		
2006	MAR–JUN	Bush Beans ("*Strike*")	Okra (variety trial)	Yield: 1.2 kg/m² PW: 51 kg/m³
2006	JUL–DIC		Okra (variety trial)	
2007	ENE	CHANGE OF PLASTIC		
2007	FEB–MAY	Bush Beans ("*Strike*")		

Phase 4: spring 2007

cultivation of beans (cv “*Strike*”)

from 25 Jan 07 to 30 Apr 07

simultaneous cultivation in an open greenhouse

	WATERGY		OPEN GREENHOUSE
Yield:	1.9 kg/m²	40% more	1.4 kg/m²
Productivity of water:	106 kg/m³		13 kg/m³

8 times better use of water

Summary of beans production inside the Watergy closed greenhouse

Table 1. Production of beans (*Phaseolus Vulgaris*) inside the prototype in each cycle. Total fruit yield is indicated, together with the value of the productivity of water (PW), expressed as kg of fruits per m^3 of water consumed.

Crop cycle (from seeding to cutting)	Cultivar	Production	PW
10 Sep 04 – 7 Dec 04	*"Donna"*	north:1.5 kg/m^2 south: 3 kg/m^2	(not accounted)
30 Sep 05 – 23 Jan 06	*"Parker"*	2 kg/m^2	100 kg/m^3
24 Feb 06 – 1 Jun 06	*"Strike"*	1.2 kg/m^2	51 kg/m^3 *(40 - 54 kg/m^3)* (*)
25 Jan 07 – 30 April 07	*"Strike"*	1.9 kg/m^2	106 kg/m^3
open greenhouse 25 Jan 07 - 30 April 07	*"Strike"*	1.4 kg/m^2	13 kg/m^3

→ 50% light transmission

→ yield period shortened

CONCLUSIONS

Horticultural growing inside the closed Watergy greenhouse is possible all year long

No use of additional energy but solar energy

Much larger water use efficiency (almost a factor 10)

FUTURE WORK

Better anti-drip cover material is needed

Improvements in the heat destruction (passive)

Average temperature inside the Watergy closed greenhouse

CO_2 ~ 1000 p.p.m.

[ºC] 2006

	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
0:00	11	14	19	22	24	28	28	26	22	18	16
1:00	11	14	18	21	23	29	29	26	22	18	16
2:00	10	13	18	21	23	28	29	26	21	17	15
3:00	10	13	18	21	23	28	28	26	21	17	15
4:00	10	13	18	20	22	28	28	25	21	17	15
5:00	9	13	18	21	22	28	28	25	21	17	15
6:00	9	13	18	22	25	28	27	24	21	17	15
7:00	11	17	22	25	29	32	31	27	24	17	15
8:00	16	23	27	29	32	35	35	31	28	20	17
9:00	22	28	31	31	33	37	37	34	31	24	22
10:00	26	31	31	31	34	39	38	35	32	26	24
11:00	28	32	32	32	35	40	39	36	32	27	25
12:00	30	33	32	32	36	40	39	36	32	27	25
13:00	31	33	31	32	36	40	39	36	32	27	24
14:00	31	33	31	32	36	40	39	35	32	26	24
15:00	29	33	30	32	36	40	39	34	31	26	24
16:00	26	31	29	32	35	39	38	34	29	24	22
17:00	22	27	27	30	36	38	36	31	26	22	19
18:00	17	21	25	27	32	36	34	29	25	20	18
19:00	14	18	22	25	29	33	31	27	24	20	17
20:00	13	17	21	24	28	31	30	27	23	19	17
21:00	12	16	20	23	27	30	29	26	23	19	17
22:00	11	15	20	22	26	29	28	26	22	18	17
23:00	11	15	19	22	25	29	28	25	22	18	16

[ºC] 2007

	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP
0:00	16	17	18	19	21	24	25	24
1:00	16	17	17	19	21	24	25	24
2:00	16	16	17	18	21	23	25	23
3:00	15	16	17	18	20	23	24	23
4:00	15	15	17	18	20	22	24	23
5:00	15	15	16	18	20	23	24	23
6:00	14	15	17	21	24	26	25	23
7:00	15	19	21	27	29	30	30	27
8:00	19	25	25	30	32	34	33	31
9:00	25	30	28	31	33	35	35	33
10:00	28	30	29	33	35	37	37	34
11:00	28	30	30	34	37	38	38	35
12:00	28	30	30	35	37	39	38	35
13:00	29	30	30	35	38	40	39	36
14:00	29	29	31	35	38	40	39	35
15:00	29	29	31	34	37	40	39	34
16:00	28	27	30	33	36	39	38	33
17:00	24	25	27	32	35	38	37	31
18:00	20	22	23	28	33	36	33	28
19:00	19	20	21	25	28	31	30	27
20:00	18	19	20	22	26	28	28	26
21:00	18	18	19	21	24	27	27	25
22:00	17	18	19	20	23	26	26	25
23:00	17	17	18	20	22	25	26	24

Average solar radiation inside the Watergy closed greenhouse

CO_2 ~ 1000 p.p.m.

[W/m²] 2006

	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
0:00											
1:00											
2:00											
3:00											
4:00											
5:00											
6:00			64	84	76	64	64				
7:00	78	145	147	134	118	109	141	141	154	53	
8:00	206	268	244	219	173	168	265	221	249	160	135
9:00	348	389	336	290	223	232	362	305	351	234	206
10:00	450	508	418	334	258	269	429	378	427	297	292
11:00	594	574	439	370	281	300	466	419	472	348	322
12:00	595	603	422	385	286	315	486	440	472	349	334
13:00	582	582	389	357	287	307	486	409	431	317	282
14:00	533	500	316	304	265	271	426	327	305	236	210
15:00	350	356	230	232	226	214	296	227	186	153	131
16:00	226	188	131	164	162	146	180	148	82	52	
17:00	67	78	75	95	127	108	101				
18:00					51						
19:00											
20:00											
21:00											
22:00											
23:00											

[W/m²] 2007

	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP
0:00								
1:00								
2:00								
3:00								
4:00								
5:00								
6:00			74	103	116	65		
7:00	61	161	177	172	192	118	115	113
8:00	181	302	299	258	283	200	169	159
9:00	319	457	404	343	360	268	238	223
10:00	450	547	468	405	427	323	294	279
11:00	527	607	533	447	466	363	319	307
12:00	556	595	489	446	479	379	319	303
13:00	524	529	515	427	452	358	299	284
14:00	425	428	488	384	397	319	271	216
15:00	295	274	406	312	322	260	210	157
16:00	157	159	259	226	225	172	118	85
17:00		67	130	125	126	86	67	
18:00					63			
19:00								
20:00								
21:00								
22:00								
23:00								

Average relative humidity [%] inside the Watergy closed greenhouse

2006

	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
0:00	83	85	85	92	86	88	89	90	85	84	84
1:00	84	85	86	92	89	89	91	92	85	84	83
2:00	84	86	86	92	89	89	92	92	85	84	83
3:00	84	86	86	92	89	89	92	92	85	84	83
4:00	84	86	86	92	89	89	92	92	85	84	83
5:00	84	86	86	92	90	90	93	93	85	84	84
6:00	84	86	90	93	92	91	92	91	86	84	83
7:00	84	83	91	94	93	93	90	92	90	87	84
8:00	78	76	88	93	92	93	88	92	91	91	90
9:00	68	70	84	90	91	92	87	90	89	91	90
10:00	60	64	85	89	89	91	83	87	88	88	86
11:00	56	65	85	89	88	88	81	85	87	88	84
12:00	54	65	85	89	86	87	79	83	87	86	82
13:00	51	65	85	88	86	87	79	83	87	86	82
14:00	50	64	85	89	86	88	80	84	87	86	84
15:00	54	64	86	90	87	88	83	87	89	88	85
16:00	60	67	84	90	88	88	83	86	87	87	81
17:00	66	71	84	87	82	86	82	86	86	88	85
18:00	76	79	84	87	81	83	79	82	84	85	84
19:00	81	83	84	89	81	83	80	84	85	84	83
20:00	82	84	86	90	83	84	82	85	85	84	84
21:00	83	84	86	91	84	85	82	85	85	84	84
22:00	83	85	86	91	84	86	83	85	85	84	84
23:00	83	85	86	91	84	86	83	85	85	84	84

2007

	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP
0:00	81	84	87	92	92	92	93	92
1:00	81	84	87	92	93	93	93	92
2:00	81	84	87	92	93	93	93	92
3:00	81	84	87	92	93	93	93	92
4:00	81	85	87	92	93	93	93	92
5:00	82	85	86	93	94	94	93	92
6:00	82	85	87	94	96	95	94	94
7:00	82	86	87	94	95	93	93	96
8:00	78	82	84	90	92	90	91	95
9:00	71	76	83	88	90	88	89	93
10:00	67	76	80	86	88	86	87	91
11:00	67	76	78	85	86	84	85	90
12:00	66	75	78	84	84	82	85	89
13:00	64	75	78	84	85	82	85	89
14:00	65	75	78	85	84	82	85	90
15:00	67	78	79	86	85	83	86	90
16:00	69	80	81	87	87	85	87	91
17:00	77	82	83	86	88	85	87	90
18:00	79	85	86	87	88	86	88	91
19:00	80	84	86	89	89	89	90	91
20:00	80	84	86	90	91	91	92	91
21:00	80	84	86	91	92	92	92	91
22:00	80	84	86	91	92	92	92	91
23:00	81	84	86	91	92	92	92	91

FUTURE WORK

Better anti-drip cover material is needed

Improvements in the heat destruction (passive)

After > 30 years growing in open greenhouses, plant scientists have selected the right cultivars and practices

High T

High RH

High CO_2

→ The turn of plant scientists to get into the closed greenhouses

watergy

estación experimental — FUNDACIÓN cajamar

2004	ENE – AGO	**CONSTRUCTION**		
2004	SEP – DIC	French Beans ("Donna")	density too high	North: 1.5 kg/m^2 South: 3 kg/m^2
2005	ENE – FEB	ADJUSTMENTS TO MONITORING (CONDENSATION)		
2005	MAR – JUN	French ("Festival") and Bush ("Parker") Beans	ADJUSTMENTS TO COOLING	flowers fade (reduced cooling performance)
2005	JUL – SEP	Okra (Plant Tests)	ADJUSTMENTS TO COOLING	
2005–2006	OCT – ENE	Bush Beans ("Parker")	reduced transmission of plastic (50%)	Yield: 2 kg/m^2 PW: 100 kg/m^3
2006	FEB	CHANGE OF PLASTIC		
2006	MAR – JUN	Bush Beans ("Strike")	Okra (variety trial)	Yield: 1.2 kg/m^2 PW: 51 kg/m^3
2006	JUL – DIC		Okra (variety trial)	
2007	ENE	CHANGE OF PLASTIC		
2007	FEB – MAY	Bush Beans ("Strike")		Yield: 1.9 kg/m^2 PW: 106 kg/m^3
2007	JUN – DIC	Biomass for high quality fiber Kenaf (*Hibiscus Cannabinus*)		

4 days since sawing

3 weeks

4 weeks

5 weeks

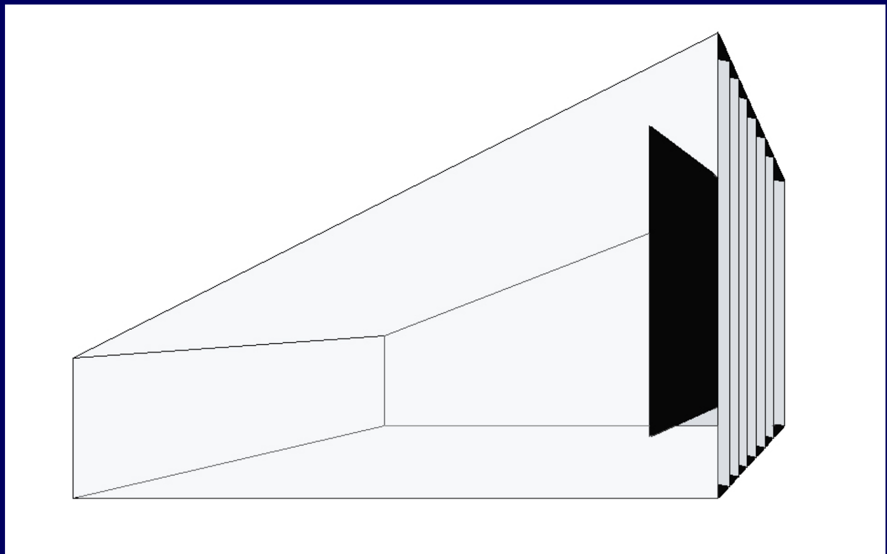
3 months after sowing (time to harvest)

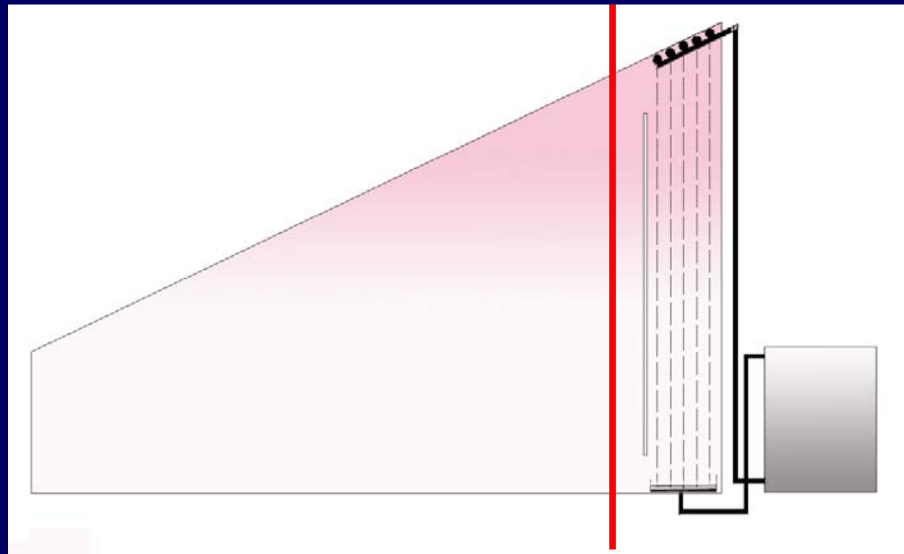
4 crop cycles have been performed during 13 months

With interplanting, potential yield for kenaf can be >140 T/Ha

PW > 30 kg/m^3 (>10 times larger comparing with open air growing)

Direction of future development





Construction from circular to linear symmetry to extend surface

Dissociate the structure from the cooling system
(forced movement of air to an external heat exchanger)

Push the possibilities of passive heat destruction to its limit