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Improving the climate safety of workers in Almería-type greenhouses in Spain by predicting the periods when they are most likely to suffer thermal stress

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A B S T R A C T

The humidex and wind-chill indices were used to determine the periods in which labourers working in Almería-type greenhouses in southeastern Spain are most likely to suffer conditions able to induce heat and cold stress. Over 500,000 pieces of data for wet and dry bulb temperatures and relative humidity, recorded over a period in excess of five years by a weather station located in an Almería-type greenhouse containing a grass crop, were used in the calculation of these indices. The wind-chill index results showed cold stress never to be a problem, but the humidex index results showed that conditions under which heat stress could develop were common in the warmer months. A clock diagram was produced showing the hours when heat stress is likely to occur in each month of the year. This information could be used to improve the conditions of labourers working in this type of greenhouse; some ways of reducing their exposure to heat stress-inducing conditions are discussed.

1. Introduction

Labourers working in the greenhouses of the Province of Almería in southeastern Spain are commonly exposed to the optimum environmental conditions for growing greenhouse vegetables — conditions that are not necessarily the best under which to work. The greenhouses occupy some 27,000 ha in the Province of Almería (Sanjuán, 2004) providing work to some 45,000 people (Callejón-Ferre et al., 2009). Some 96.5% of Almería's greenhouses are of the low-cost 'Almería' type (Fernández and Pérez, 2004). These are generally in use between the end of July and the following mid-June, allowing two growing cycles each year (Castilla, 2005).

Using the Labour Economic and Sociological Laboratory of France (LEST) method proposed by Guélaud et al. (1975), Callejón-Ferre et al. (2009) found labourers to be at serious health risk in these greenhouses — a consequence of the high temperatures in which they work. These same authors suggested, however, that further study was needed in this area since the LEST method is a generic ergonomic model that may not determine with all the accuracy desirable the risks to which such workers are exposed.

The most commonly used indices in the determination of heat stress include the effective temperature index (ET) (Houghton and Yagoglou, 1923), the corrected effective temperature index (CET) (Bedford, 1940), the heat stress index (HSI) (Belding and Hatch, 1955), the thermal stress index (TSI) (Givoni, 1963, 1970), the humidex index (HI) (Masterton and Richardson, 1979), the wet bulb globe temperature index (WBGT) (Yaglou and Minard, 1957) (using the criteria of the American Conference of Governmental Industrial Hygienists, the Occupational Safety and Health Administration, and standard ISO, 1989), a combination of the mean predicted vote (PMV) (Fanger, 1970) and the percentage of persons in discomfort (PPD) indices (Fanger, 1970) (recommended by ISO, 2005), and the Oxford Index (OI) (Lind and Hellon, 1957). Those most commonly used in the evaluation of cold stress include the wind-chill index (WCI) (Environment Canada, 2001), the clothing insulation requirement (IREQ) (ISO, 2007), and the heat stress index (HSI) (Belding and Hatch, 1955). However, all suffer from limitations (Fundación MAPFRE, 1995). The WBGT index is that most used around the world, but it becomes less reliable when the relative humidity is high and there is little air movement (Budd, 2008). The HI provides reliable results for high temperatures — in fact it is used as a reference index during heat waves (Conti et al., 2007) — but it does not take into account the effect of the wind and radiation.

The aim of the present work was to use HI and WCI to determine when labourers working in Almería-type greenhouses are most likely to be at risk of suffering heat and cold stress. Such information could improve the safety of their working conditions.

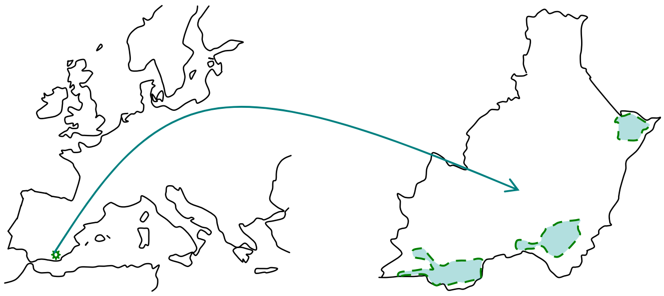

Fig. 1. Location of 80% of greenhouses in the Province of Almería.

2. Material and methods

2.1. Study location

This study was performed in the Province of Almería in the southeast of Spain (Fig. 1), between 1 October 2003 and 2 January 2009. All data were collected in a typical, east-west orientated Almería-type greenhouse with an inverted V-shaped roof (Fig. 2). The dimensions of this greenhouse were: length 20.5 m, width 24.0 m, height at roof ridge 3.5 m. The cover was made of 200 μm-thick thermoinsulating polyethylene. Following the normal prac-tice of the region, the cover was painted with whitewash when protection from excessive solar radiation was required. This became necessary on 05/03/2003 and 02/06/2004; this whitewash came off with the first Autumn rains.

2.2. Calculation of the humidex and wind-chill indices

The ideal situation would be to calculate WBGT, but due to the limitations of this type of greenhouses, which were described by Budd (2008), only the temperature and humidity were measured. Therefore the globe temperature was not considered. Also it was not considered that the greenhouses in Almería are usually covered by plastic, which causes a solar radiation diffuse, atten-uated or modified because of its additives (Nijskens et al., 1985). Therefore the application of the ISO 7243 (WBGT) might not be adequate as indoor as external of the greenhouses. Thus, HI is an empirical method, easy to use, and more or less adapted to the conditions of the study area (no wind, high temperatures and high humidity). Similarly, because of the location of the study area has light winters and the problems caused by the cold usually occur with the absence of radiation and almost no wind, WCI is valid.

The HI and WCI indices were calculated in order to determine the hours during which the greenhouse environmental conditions could have caused workers to suffer heat or cold stress on each day of the experimental period.

The HI expresses people's perception of temperature, bearing in mind that a high humidity level around the body can obstruct the process of sweat evaporation (Masterton and Richardson, 1979). This index is therefore ideal for use in high tempera-ture situations in which sweating is continuous. It determined using the following equation (Masterton and Richardson, 1979) Eq. (A1).

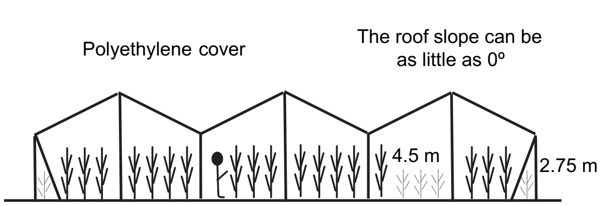

Fig. 2. Cross section of a typical Almería-type greenhouse.

Table 1
HI values and their association with heat stress (Masterton and Richardson, 1979), and WCI values and their association with cold stress (Environment Canada, 2001).

Humidex Index		Wind-Chill Index	
Value	Effects	Value	Effects
$HI \leq 29$	Comfortable	$WCI > 10$	Comfortable
$30 \leq HI \leq 39$	Some discomfort	$10 \geq WCI > -1$	Some discomfort
$40 \leq HI \leq 44$	Great discomfort	$-1 \geq WCI > -10$	Great discomfort
$45 \leq HI \leq 54$	Dangerous	$-10 \geq WCI > -18$	Sensation of great cold
$HI \geq 55$	Heat stroke imminent	$-18 \geq WCI > -29$	Risk of freezing if exposed for a long time
–	–	$-29 \geq WCI > -50$	Freezing occurs if exposed for a long time
–	–	$WCI \leq -50$	Rapid freezing occurs if exposed for >30 s

Table 1 shows the ranges of HI values associated with different levels of discomfort.

The WCI describes the 'cold' felt by people under different combinations of temperature and wind conditions (Environment Canada, 2001). This index is calculated as follows Eq. (A2).

Naturally, in a greenhouse, the wind speed is virtually 0 km h^{-1} Table 1 shows the ranges of WCI values associated with different levels of discomfort.

2.3. Collection of the required data for determining the HI and WCI

Climatological data for use with these equations were obtained at the "Las Palmerillas" research station (36°48″N, 2°43″W; alt. 151 m; property of the Fundación Cajamar) using a weather station located in an Almería-type greenhouse placed over a growing grass crop (Fig. 3). The conditions in this greenhouse were assumed to be very similar to those found in any Almería-type greenhouse in the Province of Almería. Indeed, the weather station used to collect the data — the only one of its type in Almería — is the reference station that provides the information required for calculating irrigation needs in all of the Province's Almería-type greenhouses (Fundación Cajamar, 2008). Wet and dry bulb temperatures and relative

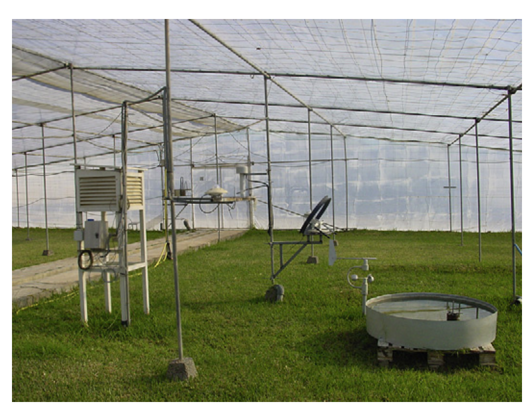

Fig. 3. The weather station used to collect data in this work. Note its siting over a crop of grass.

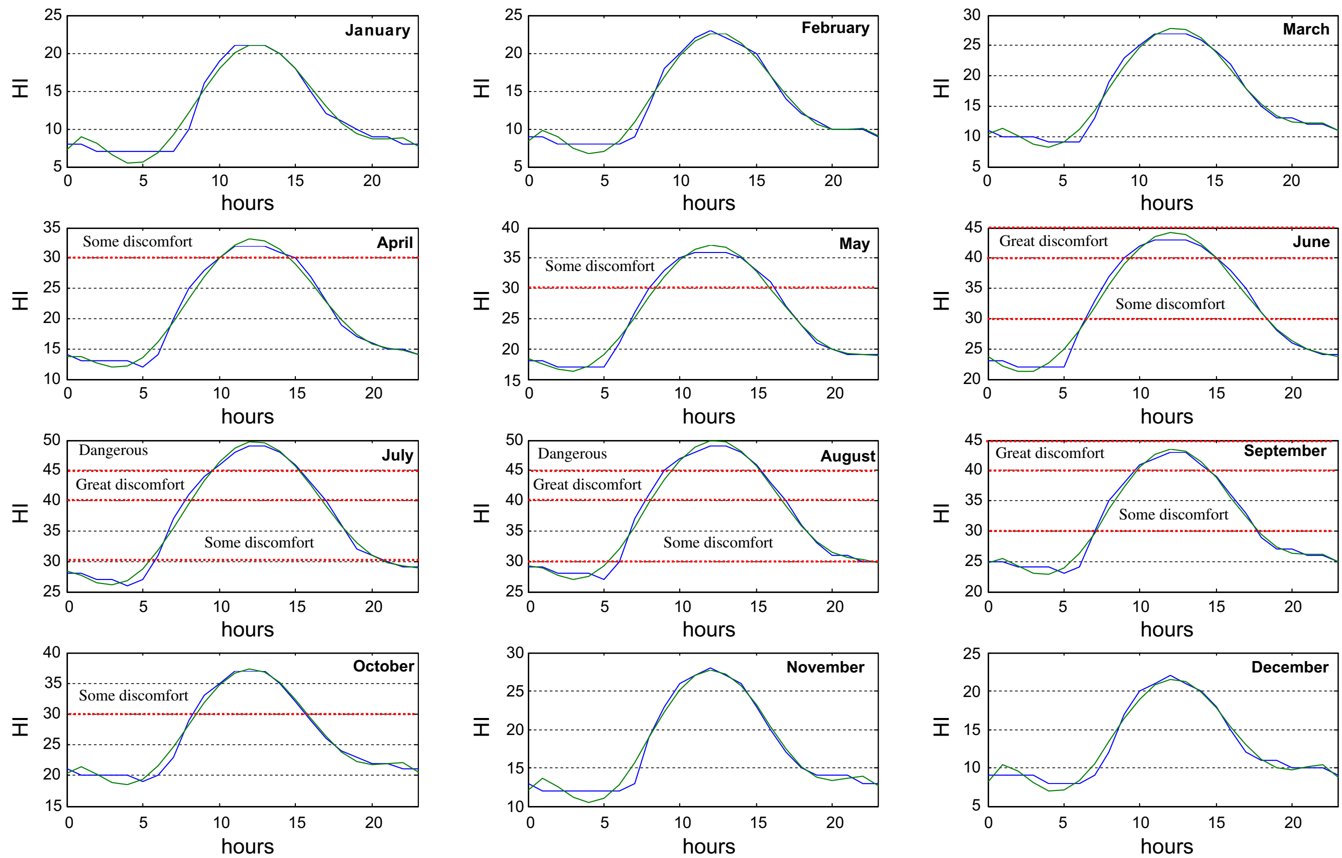

Fig. 4. Mean monthly HI for each hour of the day. Lines in red are thresholds shown in Table 1 (for interpretation of the reference to colour in this figure legend, the reader is referred to the web version of the article).

humidity were measured using an aspiro-psychrometer ventilated at a rate of 4.5 m s^{-1}. This instrument was 1.5 m above the crop and was fitted with Pt-100 sensors. Data were collected every 5 min from 0:00:00 h on 01/10/2003 until 0:00:00 h on 02/01/2009; a total of 528,915 data readings were therefore taken. The monthly mean HI and WCI for each hour of the day were then calculated. Data were processed as needed by Microsoft Office Access, Microsoft Office Excel and Matlab.

3. Results

The monthly mean HIs for each hour of the day showed workers were never at risk of suffering heat stress in November, December, January, February or March (Fig. 4). April was associated with some discomfort due to heat around midday, the HI reaching over 30 between 10.00 h and 15.00 h, with a maximum of 32 between 12.00 and 13.00 h (Fig. 4).

The monthly mean HIs for each hour of the day for May were associated with much more heat stress. The HIs between 08.00 h and 16.00 h were all indicative of some level of heat stress, with a maximum of 36 reached between 12.00 h and 13.00 h. For June, HIs indicative of mild heat stress were reached between 07.00 h and 08.00 h, and of great discomfort between 08.00 h and 15.00 h; the maximum HI was 43, again between 12.00 h and 13.00 h. The results for July reflected some discomfort between 06.00 h and 07.00 h, and again between 18.00 h and 21.00 h; the hours between 07.00 h and 9.00 h and between 15.00 h and 18.00 h were associated with great discomfort. The HIs for between 09.00 h and 15.00 h showed this period to be dangerous to workers, especially from 12.00 h to 13.00 h when the maximum HIs were reached (Fig. 4).

The monthly mean HIs for each hour of the day for August were similar to those of July, although HIs associated with some discomfort were noted from 06.00 to 07.00 h, and between 18.00 h and 23.00 h. The maximum HI (49) was again reached between 12.00 h and 13.00 h, although all those between 09.00 h and 15.00 h were associated with danger to workers. The results for September resembled those for June, although the period associated with great discomfort was 2 h shorter (starting at 10.00 h and ending at 15.00 h). Finally, the mean results for October were similar to those of May, although the period associated with great discomfort was again 2 h shorter (staring at 09.00 h and ending at 16.00 h) (Fig. 4).

Polynomial regressions (3rd grade to 6th grade) were obtained (Table 2) with their corresponding r^2 values for each of the graphs showing the mean monthly HIs for each hour of the day (Fig. 4). The 6th grade polynomial provided the best results, with r^2 values always >0.98305.

Fig. 5 provides a clock-type illustration of the monthly mean HIs for each hour of the day.

Wind speeds of over 5 km h^{-1} inside the greenhouse were not contemplated; it is highly unlikely that any such breeze should develop in an Almería-type greenhouse. Thus, the WCI never fell below 10 (no stress) during normal working hours, even in winter; workers in Almería-type greenhouses therefore never experience cold stress in this part of Spain (Table 3). Accordingly, no regressions were plotted.

Table 2
Polynomial regressions (3rd grade to 6th grade), where y = HI and x = hours.

	a	b	c	d	e	f	g	r^2	b	c	d	e	f
Jan	−2.72E-05	0.0019625	−0.051873	0.60083	−2.8049	4.0102	7.269	0.98305	8.26E-05	−0.0030809	0.0138	0.42075	−2.5887
Feb	−2.57E-05	0.0018471	−0.048552	0.55533	−2.5171	3.4113	8.4245	0.99121	7.37E-05	−0.0025246	0.0015703	0.52578	−2.8137
Mar	−2.77E-05	0.00197	−0.050961	0.5641	−2.3591	2.6199	10.496	0.99201	6.17E-05	−0.0014313	−0.031796	0.91533	−4.0788
Apr	−2.24E-05	0.0015972	−0.040854	0.43375	−1.5838	1.2054	13.793	0.99283	5.23E-05	−0.00075539	−0.048691	1.0672	−4.2179
May	−1.69E-05	0.0011955	−0.029646	0.28922	−0.76187	−0.28835	18.391	0.99506	2.69E-05	0.00068509	−0.075699	1.2434	−4.3906
Jun	−1.38E-05	0.00096434	−0.023074	0.20016	−0.19574	−1.4446	23.683	0.99343	9.65E-06	0.0017049	−0.097962	1.4425	−4.7959
Jul	−1.79E-05	0.0012843	−0.032441	0.32477	−0.91086	−0.17522	28.406	0.99564	4.79E-05	−0.00035121	−0.061313	1.2107	−4.5153
Aug	−2.13E-05	0.0015243	−0.038788	0.40302	−1.3502	0.62244	29.261	0.99346	5.17E-05	−0.00056753	−0.056822	1.1766	−4.5468
Sep	−2.85E-05	0.0020156	−0.051596	0.56102	−2.2635	2.3892	24.833	0.99415	4.98E-05	−0.0005749	−0.052834	1.1096	−4.5113
Oct	−3.05E-05	0.0021426	−0.05463	0.59747	−2.4981	2.9245	20.402	0.99197	3.68E-05	2.69E-05	−0.060129	1.1154	−4.4678
Nov	−3.01E-05	0.0021302	−0.054925	0.61381	−2.7015	3.5644	12.157	0.98825	5.09E-05	−0.00095585	−0.035507	0.8665	−3.7348
Dec	−3.00E-05	0.0021333	−0.055767	0.64245	−3.0346	4.6095	8.2302	0.9869	6.32E-05	−0.0020379	−0.0039821	0.51747	−2.6572
	$y = ax^6 + bx^5 + cx^4 + dx^3 + ex^2 + fx + g$								$y = cx^4 + dx^3 + ex^2 + fx + g$				

4. Discussion

Navarro et al. (2006) and Callejón-Ferre et al. (2009) have investigated heat stress in workers in Almería-type greenhouses. The results of this latter work showed the LEST method (Guélaud et al., 1975) to overestimate the risk of heat stress to workers in Almería-type greenhouses. Those of the present work, however, show the HI to well identify on a monthly basis the hours of the day associated with heat stress (Figs. 4 and 5). Further, the results of this study confirm that the definition of 'greenhouse' (of reference

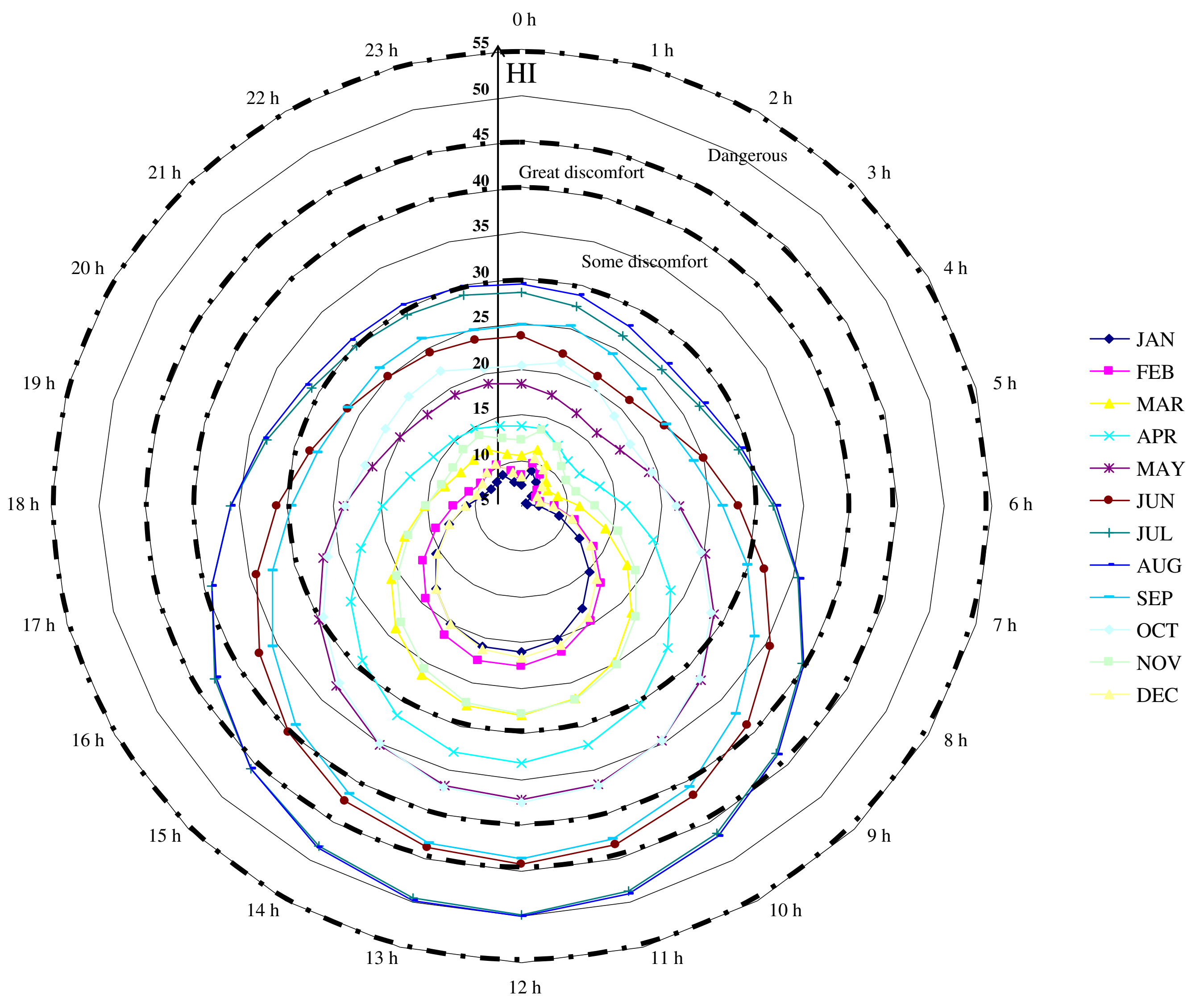

Fig. 5. Clock diagram showing the mean monthly HI for each hour of the day.

Table 2 (continued).

g	r^2	c	d	e	f	g	r^2	d	e	f	g	r^2
9.412	0.9437	0.0016689	−0.082388	1.2266	−5.0295	10.736	0.93277	−0.0056199	0.10681	0.42103	5.6689	0.79337
10.446	0.95797	0.0017151	−0.084288	1.2451	−4.9924	11.628	0.94974	−0.0053934	0.094274	0.60911	6.4205	0.81113
12.672	0.9674	0.0021192	−0.1037	1.5177	−5.9033	13.661	0.96374	−0.0062151	0.095744	1.0181	7.2271	0.83027
15.554	0.98	0.0022512	−0.10958	1.5773	−5.7629	16.392	0.97792	−0.0060227	0.066767	1.5895	9.5575	0.86014
19.723	0.98744	0.0022311	−0.10701	1.5057	−5.185	20.154	0.98687	−0.0043762	0.0085864	2.1018	13.38	0.86729
24.771	0.98929	0.0022596	−0.1092	1.5366	−5.081	24.925	0.98923	−0.0052525	0.020355	2.299	18.065	0.89052
29.816	0.98905	0.0024019	−0.11707	1.6778	−5.9301	30.583	0.98766	−0.0065786	0.066077	1.9146	23.291	0.88129
30.939	0.98342	0.0024064	−0.11705	1.6812	−6.075	31.768	0.98167	−0.006354	0.066483	1.7842	24.462	0.86617
27.074	0.97142	0.0022888	−0.11083	1.5955	−5.9828	27.872	0.96935	−0.0055437	0.059729	1.4923	20.923	0.83409
22.802	0.95944	0.0021431	−0.10298	1.4745	−5.5552	23.392	0.95802	−0.004403	0.036443	1.4441	16.885	0.8081
14.528	0.94935	0.0019702	−0.094762	1.3629	−5.2384	15.343	0.94601	−0.0041348	0.040971	1.1961	9.3618	0.78897
10.59	0.93052	0.0015954	−0.07756	1.1339	−4.5243	11.603	0.9229	−0.0041722	0.063413	0.68624	6.759	0.77014
		$y = dx^3 + ex^2 + fx + g$						$y = dx^3 + ex^2 + fx + g$				

according to standard UNE-EN-13031-1 (2002) does not strictly apply to Almería-type greenhouses since labourers are not able to work comfortably (Fig. 5). The same was reported in the previous study undertaken by our group using the LEST method (Callejón-Ferre et al., 2009).

Since greenhouse growth cycles in Almería run from the end of July until mid-June of the following year (Castilla, 2005), workers performing cultivation functions (sowing, transplanting, pruning, fertirrigation, crop protection activities and harvesting etc.) in Almería-type greenhouses will be exposed often to heat stress-inducing conditions; this is clearly illustrated in Fig. 5. However, the same figure also suggests the periods when workers are least likely to be affected; work timetables could therefore be adjusted accordingly. If there is no alternative but to work during times when heat stress is likely, worker rotation might be practiced to reduce continuous exposure times. Quite apart from the improvement in working conditions this would bring about, if such measures were combined with cultivation practices that are less damaging to the environment, not only might more ecological harvests be obtained, they would be obtained in a manner more respectful towards workers (see Lotter, 2003). This might be seen in a positive light by consumers.

It should be remembered that when no crop is growing in Almería-type greenhouses in this part of Spain, generally in July, there is still work to be done inside them, e.g., replacement of the organic component of the soil, solarization, and the repositioning of the cover etc. Further, the raising of seedlings is in full swing during the summer, although usually this involves the use of multitunnel greenhouses. Certainly, the results show that work conditions in Almería-type greenhouses are dangerous over nearly the entire day at this time of year (Fig. 5), and the same may well apply to other types of greenhouse.

Cold stress was found not to be a problem. The WCI result suggested workers were never at risk of cold stress at any time during normal working hours, even during winter. The climate of Almería is very benign – winters are very mild – and wind speeds are always very low inside the greenhouse studied.

In conclusion, the present modelling method improves the results obtained by the LEST method for determining periods of thermal stress in Almería-type greenhouses. The entire November–March period, plus some hours during the days of April, are the only times when workers are not at some risk of heat stress. Cold stress is not a risk to which workers in such greenhouses are exposed in the Province of Almería.

Table 3
Mean monthly WCI values for each hour of the day (wind speed taken to be 5 km h^{-1}). Although the values in bold are indicative of some discomfort, they occur outside the hours of the normal working day (Table 1).

Hours	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	**8**	**9**	11	13	16	19	23	23	21	17	12	**9**
1	**8**	**9**	**10**	13	16	19	22	23	20	17	12	**9**
2	**8**	**9**	**10**	12	15	19	22	23	20	17	11	**9**
3	**7**	**9**	**10**	12	15	19	22	22	20	17	11	**9**
4	**7**	**9**	**9**	12	15	18	22	22	20	17	11	**9**
5	**7**	**8**	**9**	12	15	19	22	22	20	17	11	**9**
6	**7**	**8**	**9**	13	18	23	25	24	20	17	11	**9**
7	**7**	**9**	12	18	23	27	29	28	24	19	12	**9**
8	**10**	13	18	22	26	30	32	32	28	24	17	12
9	16	17	21	25	29	32	35	35	31	26	21	16
10	18	20	23	27	30	34	36	36	33	28	23	18
11	20	21	25	28	31	35	38	37	34	29	24	20
12	21	22	25	28	31	35	38	38	34	29	24	20
13	20	22	25	28	31	35	38	38	34	29	24	20
14	20	21	24	28	30	34	38	37	33	28	22	19
15	18	19	23	26	29	33	37	36	31	26	20	17
16	15	17	20	24	27	32	35	34	29	24	18	14
17	12	14	17	21	25	30	33	32	27	21	15	12
18	**10**	12	14	18	22	27	30	29	24	20	14	11
19	**10**	11	13	15	19	24	27	26	22	19	13	11
20	**9**	**10**	12	14	18	22	25	25	22	18	13	**10**
21	**9**	**10**	12	14	17	21	24	24	22	18	12	**10**
22	**8**	**10**	11	14	17	20	23	24	21	18	12	**10**
23	**8**	**10**	11	13	16	20	23	23	21	18	12	**9**

Appendix A. Humidex index

$$HI = T + \frac{5}{9} \cdot [e - 10] = T + \frac{5}{9} \cdot \left[\left(6.112 \cdot 10^{\frac{7.5 \cdot T}{237.7 + T}} \cdot \frac{RH}{100} \right) - 10 \right]$$

where "T" is the dry bulb temperature in °C, "e" is the pressure of the water vapour in the air (in hPa), and RH is the relative humidity.

Appendix B. Wind-chill index

$$WCI = 13.12 + 0.6215 \cdot T - \left(11.37 \cdot V^{0.16}\right) + \left(0.3965 \cdot T \cdot V^{0.16}\right)$$

where "T" is the dry bulb temperature (in °C), and "V" is the wind speed (in km h^{-1}).

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