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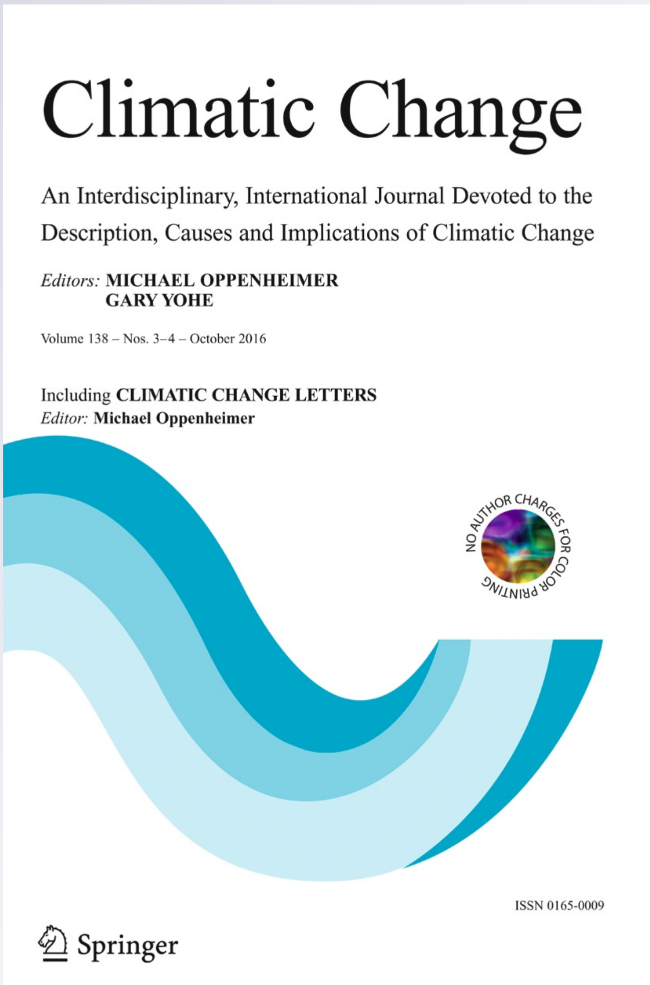

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A summer temperature bias in early alcohol thermometers

Dario Camuffo[1] · **Antonio della Valle**[1]

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Abstract This paper analyses the response of alcohol thermometers in relation to the departure from linearity and the choice of the calibration points. The result is that alcohol thermometers are affected by large departures that reach a maximum (i.e. −6 °C) at 50 °C ambient temperature. This may have caused a severe bias in early records, when alcohol thermometers were popular, especially during the Little Ice Age. Choosing a lower temperature for the upper point, calibration may substantially reduce this bias. Examples are given with thermometers in use in the 17th and 18th centuries. A careful correction of long series is necessary to avoid misleading climate interpretations.

1 Introduction

In the past centuries, temperature readings were essentially made with liquid-in-glass thermometers, except a few records made with air thermometers in the first half of the eighteenth century. Bimetallic sensors or Bourdon tubes were used in thermographs, and became popular from the mid-1800s to 1970s, when they were substituted by more accurate sensors (e.g. platinum resistance, thermocouples, thermistors) and electronic recorders (Middleton 1966; Quinn 1990). In the early period (till mid eighteenth century), various types of thermometric liquids were tested but soon the choice was limited to wine spirit (ethyl alcohol) and quicksilver (mercury), with volumetric expansion coefficient $10.9 \cdot 10^{-4}$ °C^{-1} and $1.8 \cdot 10^{-4}$ °C^{-1}, respectively. Instrument makers preferred either alcohol, e.g. Delisle, or mercury, e.g. Fahrenheit. Alcohol thermometers were especially appreciated for their greater

Dario Camuffo and Antonio della Valle have equally contributed to this paper.

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expansion coefficient and resolution (i.e. 6 times), low weight and especially low cost; mercury for stable colour, not adherence to glass.

The comparability of readings was difficult, even between alcohol thermometers. Derham (1709) commented: "It would have been in vain to have compared his observations with mine, by reason we have not yet a standard for thermometers, as we have for barometers. They being everywhere in all or most respects different; some with large, some with small bottles of spirits; some accordingly with longer, some with shorter; some with wider, some with narrower canes, or shanks; some filled with more highly rectified and consequently more expansive spirits, some with more phlegmatic and duller spirits". The problem became worse when comparing alcohol with mercury thermometers.

It was clear that the alcohol and mercury thermometers gave different readings, but before the researches of Gay-Lussac, Carnot and Regnault, the discovery of the absolute thermometric scale and the constant-volume gas thermometer, it was impossible to know which of the two departed from linearity, and how much. Today it is impossible to test the response of early instruments not only because few of them survived and are jealously kept in museums for their vulnerability, but especially because the long-term ageing may have changed the characteristics of the glass and the liquid, e.g. modifying the polymorphous glass structure; ethanol tending to form linear hydrogen-bonded chains and polymerization.

A unique opportunity of examining the quality of original instruments of the second half of the eighteenth century is given by du Crest (1765) and De Luc (1772). Du Crest raised the problem and made a partially successful experiment. De Luc repeated the experiment and published some tables reporting the results of his tests. This gives the possibility of making further analyses with the above readings and adding new light to early instruments and related records. The bias derived from the non-linearity departure of alcohol thermometers and the advantages derived from the use of alternative calibration points will be the object of this paper. Although the problem of calibration has been stressed in other papers (Middleton 1966; Camuffo 2002) we will see how a convenient choice of the reference points is crucial for accurate readings. This is relevant in the correction and interpretation of climate data, especially in the second part of the Little Ice Age when instrumental observations became available.

2 The non-linearity of alcohol thermometers

Du Crest (1765) posed the problem and measured the departure between three thermometers, one filled with mercury, one with spirit and one with linseed oil. He plunged them in a pot of water, and made a complete cycle, slowly cooling the pot from 100 °C to 0 °C, and then warming again to 100 °C. The cooling cycle was accurately made. However, during the heating cycle two thermometers were exposed to the heat source and readings became misleading with two thermometers indicating a too high temperature, much above the boiling point of the water in the pot. He expressed temperatures in Celsius, but degrees were expressed in sexagesimal units, i.e. degrees, minutes and seconds (base 60). (See Online Resource).

De Luc (1772) repeated the same experiment but with twelve thermometers, reading all instruments each time they reached an increase of 5 °R. The cycle required 5 h. In addition, he wanted to see how much the presence of water in alcohol might affect readings. To this aim he prepared and tested some thermometers filled with alcohol and water mixed together in different proportions, from pure spirit to pure water, in total twelve thermometers. More precisely: a mercury reference; thermometers with "pure" ethyl alcohol, i.e. "wine spirit" refined in different ways; "water-of-life"; spirit and water mixed together at different dilution with water; finally pure water (see Online Resource). Test readings were reported in tables where temperatures are listed in rows and thermometers in columns. Columns are in decreasing order of proportion of spirit mixed with water, i.e. alcohol by volume (ABV). The Réaumur thermometer is in 4th position with 5:1 alcohol to water ratio, i.e. 83 % ABV, showing a low quality spirit. An undeclared mixture was "old Languedoc wine", where the local traditional recipe added sugar and stimulated fermentation; however, it has been found that the beverage was in the 3:6 ratio i.e. 30 % ABV (Duplais 1855, Vol.2 page 375). Two thermometers have obscure proportions, i.e.: "water-of-life"; "evaporated spirit". In such cases we have considered the intermediate ABV level between the previous and the next column. The relation between thermometers filled with the most refined alcohol (i.e. 95 % ABV) and mercury is a parabola with equation

$$Y_{Hg} = -0.0025\, X_a^2 + 1.2497\, X_a$$

where Y_{Hg} and X_a refer to readings with mercury and alcohol thermometers, respectively. The findings are summarized in Fig. 1 and Fig. 2 and on the Online Resource.

Figure 1 shows how the departure changes with temperature for the various thermometers. The red lines represent the departure of the best alcohol thermometers (including the Réaumur) from the mercury thermometer. The maximum departure for "pure" spirit thermometers is −6 °C and occurs at 50 °C. This result fits with du Crest (1765). From the climate point of view we see that all the real spirit thermometers behave in the same way and that the bias increases with temperature, being maximum in summer.

The same experience was later repeated by Wildt (1825) and others, who reached the same findings (see Online Resource). Ganot (1860) summarized this situation writing "if one considers the two fixed points used for the mercury thermometer, i.e. melting ice and boiling water, and divides this interval in 100 parts, one gets an alcohol thermometer in agreement with the mercury thermometer only at 0° and 100°C. In the interval between them, the alcohol thermometer indicates lower temperatures. It is possible to read 44°C on the alcohol thermometer and 50°C on the mercury thermometer. Hence, alcohol thermometers are usually graduated by placing them in baths at different temperatures together with a standard mercury thermometer, and marking on the alcohol thermometer the temperature indicated by the mercury thermometer. In this manner the alcohol thermometer is comparable with the mercury one; that is to say, it indicates the same temperatures under the same conditions" (section 240, pages 222–223). This is however possible with scales with shorter range.

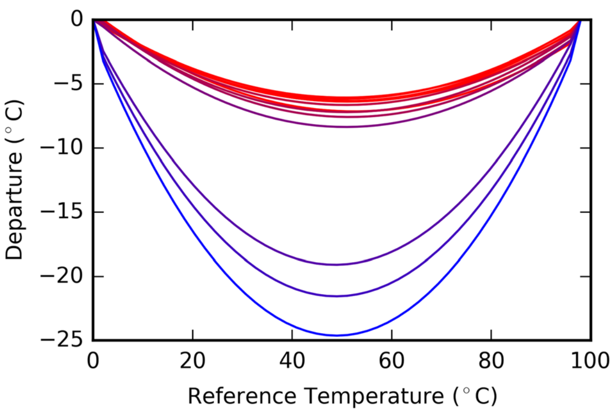

Fig. 1 Difference between readings taken with a spirit-in glass thermometer and a mercury-in-glass thermometer used as a reference, both calibrated at 0 °C and 100 °C calculated after the readings by du Crest and De Luc. *Red lines*: thermometers filled with "pure" wine spirit or with small dilution in water (up to 5/1). *Violet lines*: thermometers filled with various mixtures of spirit and water. *Blue line*: thermometer filled with pure water

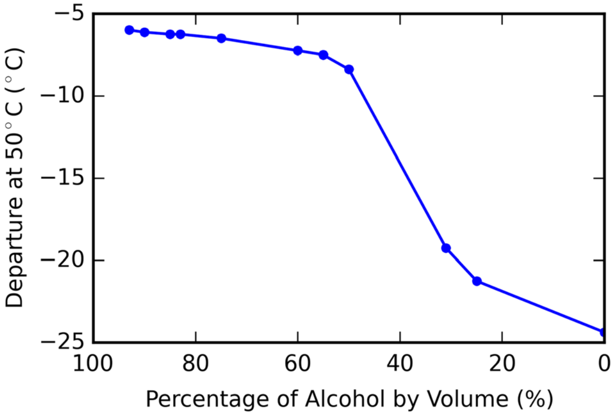

Fig. 2 Maximum departure (i.e. departure at 50 °C) between thermometers filled with a mixture of alcohol and water at different percentages by volume (ABV, %), and thermometers filled with mercury

Figure 2 shows how the maximum departure, i.e. at 50 °C, changes when the thermometric liquid is a mixture of alcohol and water in various proportions, expressed as how much alcohol is contained in a given volume, i.e. ABV. Starting from pure alcohol (100 % > ABV > 95 %), the effect of dilution with water slowly increases up to ABV = 50 %; then a sharp transition occurs and the maximum (i.e. −25 °C) is reached with pure water (ABV = 0 %). It is evident that increasing the proportion of water the bias increases, but the degree of purity of distilled wine spirit is not so relevant so that all the real thermometers behave in the same way. The poor purity of alcohol in the Réaumur thermometer, i.e. ABV = 83 %, was not critical, and we expect that real thermometers in use in the eighteenth century and later might have been around this level. This test shows that the alcohol purity in real thermometers (i.e. ABV > 80 %) was not a crucial factor.

Returning to the general problem and the eighteenth century, it was evident that alcohol and mercury gave slightly different readings, but it was unclear which of the two was correct. Only after the absolute thermodynamic scale was discovered and accurate gas thermometers were used (Chappuis 1888; Guillaume 1889), it was recognized that mercury has a very small departure from linearity, i.e. ±0.11 °C in the range − 20° to 100 °C, and ethyl alcohol a much bigger one, i.e. from +0.9 °C to −6.0 °C (Rostagni 1957; Rivosecchi 1975). The non-linearity error typical of spirit-in-glass and mercury-in-glass thermometers calibrated at melting ice and boiling water temperature is shown in Fig. 3. From the practical point of view, records taken with mercury

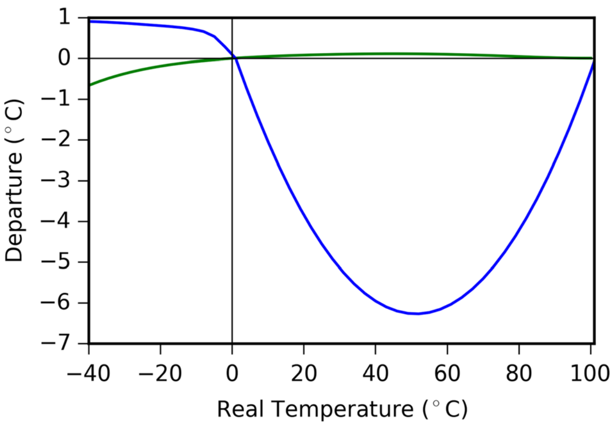

Fig. 3 Departure of spirit-in glass thermometers (*blue*) and mercury-in-glass thermometers (*green*) from the real temperature

thermometers are affected by a small non-linear distortion that might be considered negligible in comparison with other uncertainty sources (e.g. exposure, shield, sampling time). On the other hand, alcohol thermometers are affected by a relevant non-linearity. The non-linearity curve has a turning point at 0 °C and low temperatures are overestimated. Severe winters (e.g. temperatures around or below −10 °C) may appear 0.5° to 1 °C milder. Above 0 °C, the error is negative and its absolute value increases with temperature. In summer, it may reach 4° to 5 °C underestimation. An example is given in Online Resource Fig. 7 where a record of indoor temperature measured with an alcohol thermometer is reported, showing the original and the corrected readings.

So far we have considered the liquid as the major source of departures. Chappuis (1888) and Guillaume (1889) report the estimated error for various types of glass (e.g. Jena, English glass, hard-glass, soft-glass) and the correction formulae. The departures are very small, i.e. generally smaller than 0.1 °C. However, the experience with common thermometers reported by Ganot (1860) was more negative. He wrote: "Regnault has found that some mercury thermometers, which agree at 0° and at 100°C, differ in the interval between these points, and that the departures frequently amount to several degrees. Regnault thinks that this is due to the unequal expansion of different kinds of glass" (section 238, page 222). Unfortunately, this departure is difficult to know and correct, especially because in general the temperature records do not include such specific information. The glass-related departure remains a source of uncertainty, almost negligible compared with the others.

3 The choice of the calibration points

Things may change when the calibration is made with different reference points. In this paper we will consider two examples: the Little Florentine Thermometer (LFT) and the particular choice of the Fahrenheit scale.

The Accademia del Cimento (flourished 1657–1667) and the Medici Network (flourished 1654–1670), both founded by the Grand Duke of Tuscany (Targioni Tozzetti 1780; Carrington Bolton 1900; Camuffo and Bertolin 2012) used spirit-in-glass thermometers, known as LFT. The comparability of readings taken with the LFT was based on the same response of all instruments, identical between them, being an accurate replica of the same prototype. As the LFT was the first thermometer able to take quantitative measurements, the discovery that fixed points do exist, and are usable for calibration occurred years later. However, a rough control of the scale was made plunging the thermometer in the cold water of the Arno River and exposing it to the summer sunshine in Florence and was limited to the usual range in temperate latitudes (Magalotti 1666). If we suppose that the reference made in cold water was around 6 °C and the upper point at 30° or 40 °C summer hot, the scale was divided in equal parts and is represented by the magenta and red straight lines in Fig. 4. The upper calibration point was in proximity of the maximum departure and the chord interpolation reduced very much (about one order of magnitude) the departure. This is given by the distance of the blue line from the above straight lines, and is represented by the red and magenta curved lines. In practice, the non-linearity error of the LFT was limited to ±0.5 °C.

We have found a unique combination of a LFT that operated in parallel with a Réaumur mercury thermometer located in the same room, from 1742 to 1754 in Bologna, Italy. The relationship between the two thermometers is independent from the units used in readings, that have been left in the original form, i.e. Galileo (°G) for the LFT and °R for the Réaumur thermometer. If both instruments are filled with the same liquid, or none of them is affected by non-linear distortion, plotting the readings of the LFT versus the Réaumur thermometer, a

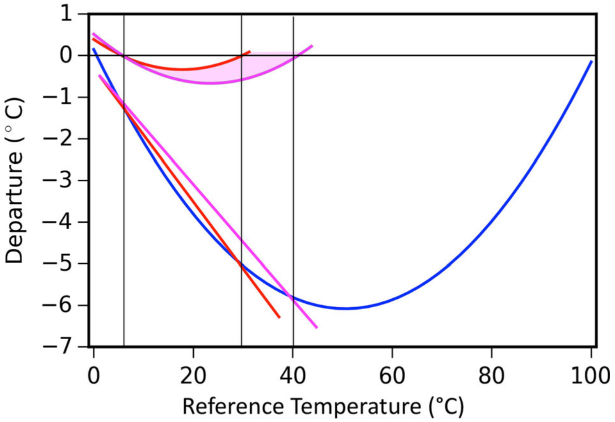

Fig. 4 Difference between readings taken with a spirit-in glass thermometer and a mercury-in-glass thermometer used as a reference, both calibrated at 0 °C and 100 °C (*blue line*) calculated after the readings by du Crest and De Luc. *Red* and *magenta straight lines*: chords when calibration is made at 6 °C and 30 °C (*red*) or 40 °C (*magenta*) as in the case of the Little Florentine Thermometer (LFT). *Red* and *magenta curved lines*: difference between readings taken with a LFT calibrated at 6 °C and 30 °C (red) or 40 °C (*magenta*) and a mercury-in-glass thermometer used as a reference. The expected departure of the LFT was in the *pink* area between the *red* and the *magenta borders*

straight line is expected. As opposed, if the non-linear distortion of the spirit of the LFT is dominant, the plot should follow a parabola. The best-fit of the readings (Fig. 5) has been calculated with a linear and a second-order interpolation, i.e.:

$$\mathrm{LFT}(^\circ\mathrm{G}) = 0.962\ \mathrm{RT}(^\circ\mathrm{R}) + 9.669, \text{ with } \mathrm{R}^2 = 0.994$$

$$\mathrm{LFT}(^\circ\mathrm{G}) = 0.007\ \mathrm{RT}^2(^\circ\mathrm{R}) + 0.815\ \mathrm{RT}(^\circ\mathrm{R}) + 10.174, \text{ with } \mathrm{R}^2 = 0.996.$$

In this temperature range, the curvature coefficient in the parabola is very small and the two above equations give similar results, the determination coefficient R^2 being almost the same (i.e. 0.2 % difference). This test demonstrates that the LFT is characterized by a small departure from linearity, i.e. within ±0.5 °C as already discussed, for the fortunate choice of the calibration points, both in the same branch of the parabola, i.e. below the vertex at 50 °C.

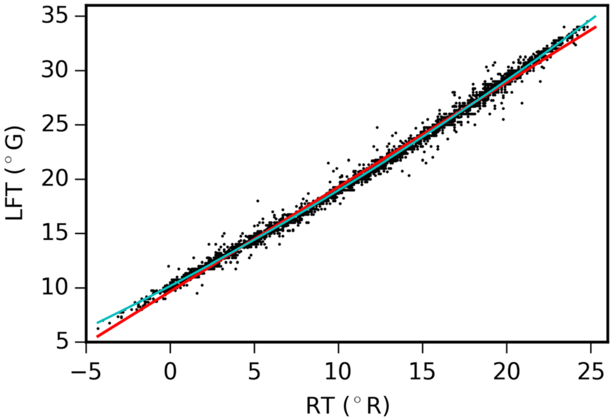

Fig. 5 Readings of the Little Florentine Thermometer (LFT) versus the readings of a Réaumur mercury thermometer (RMT) taken at the same sampling time, over a common period from 1742 to 1754 and in the same room. *Red line*: linear best-fit interpolation. *Cyan line*: second-order interpolation. Readings have been left in the original units, i.e. °G (i.e. Galileo degrees) for LFT and °R (i.e. Réaumur degrees) for RMT

Fahrenheit (1724) built thermometers using quicksilver and for calibration he suggested a mixture of water, ice, ammoniac salts and marine salt for the lower point and blood temperature of a healthy man for the upper level. These calibration points covered the climate range in Northern Europe; the lower point was not clearly defined and produced uncertainties up to 5 °C (Toaldo 1775; Camuffo 2002), but the upper point was appropriate. The uncertainty of using in summer a mercury thermometer calibrated with the blood temperature was certainly smaller than using an alcohol thermometer calibrated at boiling water temperature. This may even apply to alcohol thermometers with Fahrenheit scale but calibrated at boiling water.

4 Conclusions

Spirit-in-glass thermometers and the departure from linearity of ethyl alcohol in thermometers calibrated at melting ice and boiling water temperatures have produced readings affected by bias, most pronounced in summer and least in winter. Winters with very low temperature appear milder (e.g. +1 °C). The freezing level is a turning point and readings are unaffected. The bias becomes negative and increases with temperature: in Southern or Continental Europe the summer temperature was strongly underestimated. For instance, from 1971 to 2000, in Rome, Italy, the average temperature ranged between 7.4 °C in January and 24.5 °C in August (Italian Air Force 2009). If readings were taken with a spirit-in glass thermometer, the above values would appear 1.8 °C and 4.7 °C lower, respectively.

From the climate point of view, one should consider that the alcohol thermometer was very popular from the 18th to the first half of 20^{h} century, and often the thermometer type was not specified. Several long series include readings affected by this bias. In the case they have not been adequately corrected, the climate in the Little Ice Age may appear colder than reality.

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Online Resource

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Wine, Water-of-Life, Wine Spirit

Wine is an alcoholic beverage made from juice of fermented grapes. After fermentation, wine may reach an alcoholic level generally in the range 9-19% ABV (percentage of alcohol by volume) depending on the initial content of sugars in grapes, which increases with sunshine.

Ethyl alcohol (ethylene) is derived from vegetables that contain sugar or glucose; it is the product of the decomposition of the saccharine that takes place during the vinous or alcoholic fermentation. It is obtained from the distillation of grape, wine, molasses, beet, potatoes, grain, rice, sorghum, fruits etc. The distillation produces ethyl alcohol mixed with water so that repeated distillations may be due to increase the proportion of alcohol (Chomel and Marret 1732; Savary des Bruslons 1762; Duplais, 1855). The product of the first distillation is used as spirituous liquor and its name reflects the country and the vegetable from which it was originated, e.g. brandy, grappa, whiskey, bourbon, vodka, rum, sake.

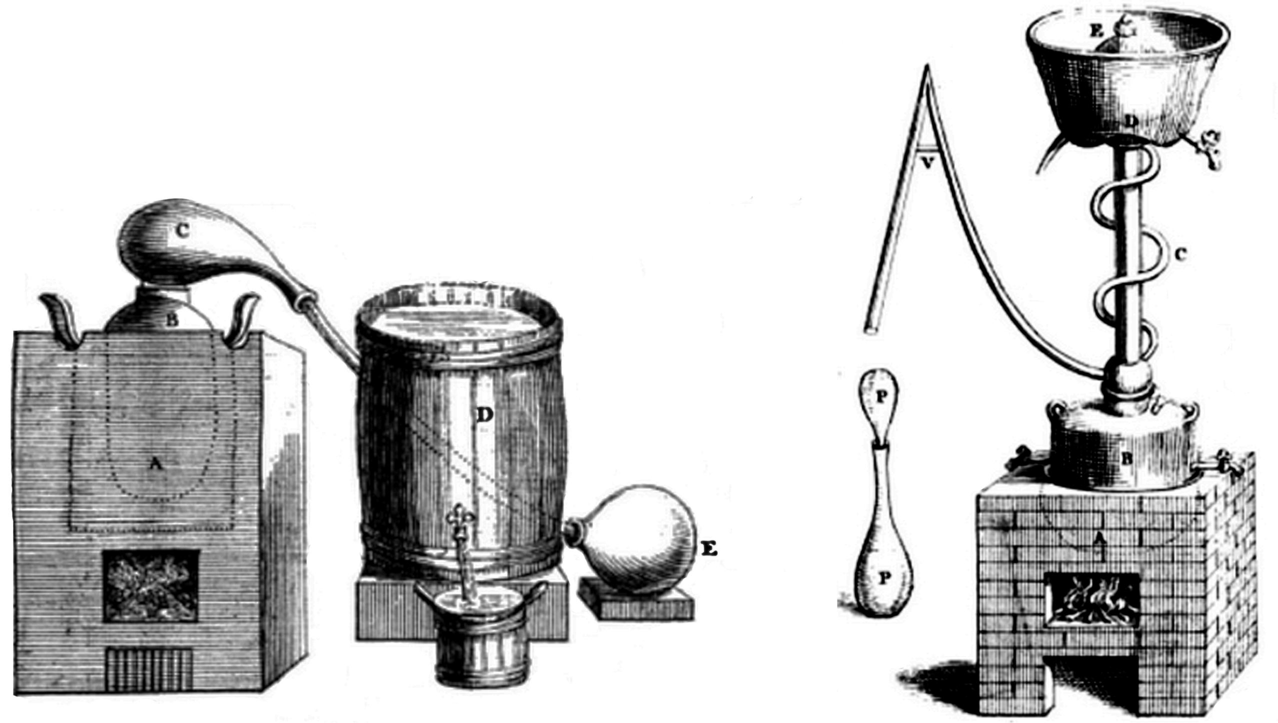

Fig.1 Apparatus for the distillation of the water-of-life (left) and the spirit of wine (right) (Chomel and Marret 1732)

The product of the first distillation was named *Water-of-Life*; in France "*Eau-de-Vie*", obtained by distillation of wine; in Italy "*Acquavite*" by distillation of dregs of pressed grapes; in Ireland "*Wiskey*" by distillation of fermented grains etc. Distillation was slowly made at bain-marie, or on hot ashes, or gentle fire. The vapour of ethylene was cooled in a condenser and collected in a vessel (Fig.1 left). The distilled liquid reached 60-70% ABV. It was used to fill thermometers at this degree or further refined. As a spirituous liquor it was put in oak barrels for aging and partial evaporation until it reached 40-45% ABV, under the commercial name of "*brandy*" or "*cognac*" in France, "*grappa*" in Italy, etc

In order to concentrate the alcohol, the water-of-life was refined with two or more distillations, until it reached 80 – 95 % ABV. The water-of-life was placed in a closed pot over a furnace, the vapour passed through a serpentine and arrived on a pot kept on the top of a column to be cooled with a refrigerant and condensed (Fig.1 right). The product of the second distillation was called "*wine spirit*" ("*esprit de vin*" in France - Chomel and Marret 1732; Savary des Bruslons 1762), or "*burning water*" ("*acquarzente*" in Italy - Accademia della Crusca 1612). In the case of further distillations, the specification "purified" or "rectified" was added.

Thermometers were filled with more or less refined alcohol, i.e. water-of-life or wine spirit, i.e. one or more distillations (Magalotti 1667; Réaumur 1730; De Luc 1772; Cotte 1774; Targioni Tozzetti 1780). The percentage of alcohol was determined after the liquid density, determined with an aerometer (Fig.2). Another method consisted in layering the distilled liquid over other liquids of known density at selected temperatures (Adams 1794; Duportal 1811; Lavigne 1829).

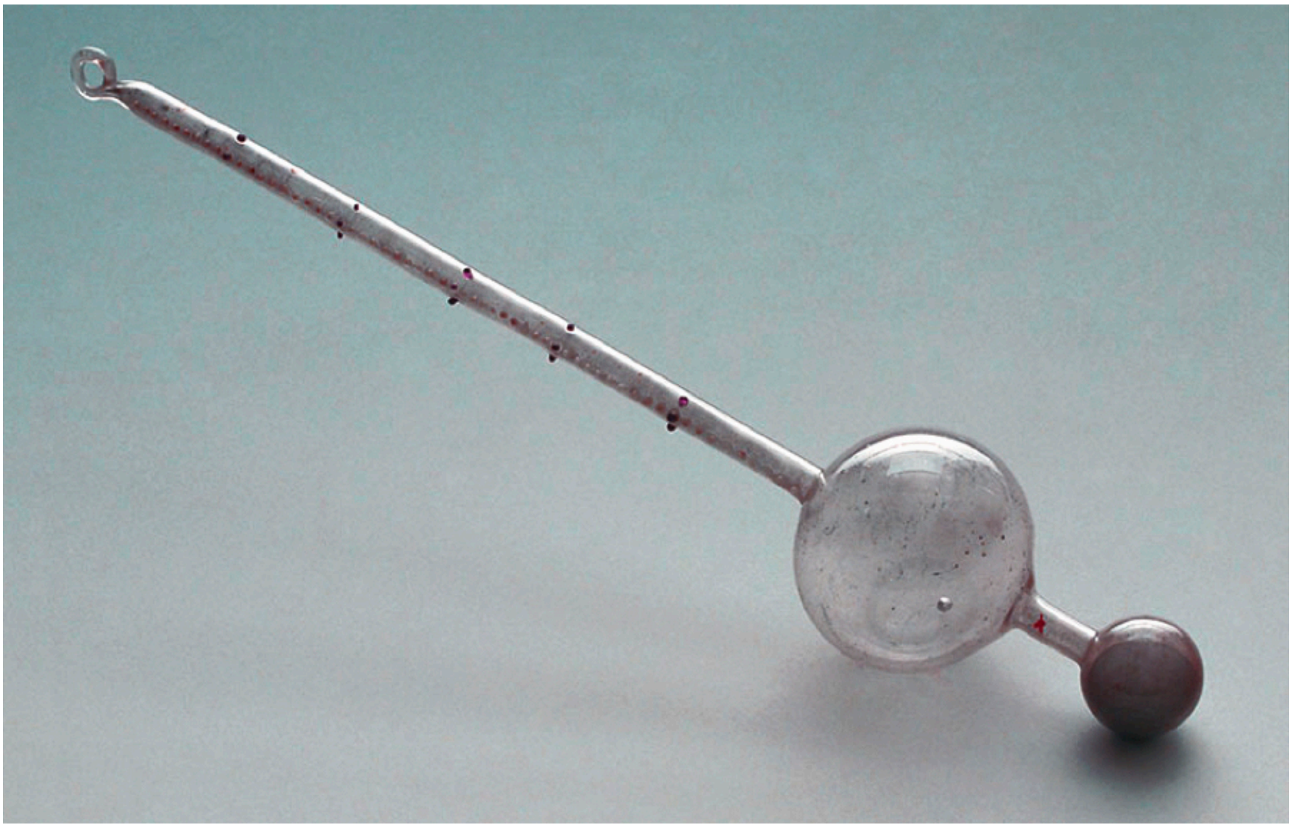

Fig.2 Stick-floating aerometer to measure the density of liquids by counting the beads on the part of the stick emerging from the liquid. Instrument built in Florence in the mid of the 17th century, invented by the *Accademia del Cimento* (flourished 1657-1667). Overall length: 180 mm. (By courtesy of Museo Galileo - Institute and Museum of History of Science, Florence)

The Tables published by du Crest (1765) with the first experience is reported in Fig.3; by De Luc (1772) with the comparison of 12 thermometers in Fig.4; by Wildt (1825) in Fig.5.

ein UniversalThermometer zu verfert. 75

	Weingeist.	Mercur.			Leinöl		
	Grade	Grade	Min.	Sec.	Grade	Min.	Sec.
Sied. Waß.	100	100			100		
Grade der Wärme	90	92	24		92		
	80	84	16		83	33	20
	70	75	36		74	40	
	60	66	24		65	20	
	50	56	40		55	33	20
	40	46	24		45	20	
	30	35	36		34	40	
	20	24	16		23	33	20
	10	12	24		12		
Mittelmäßig	0	0			0		
Grade der Kälte	10	12	56		12	26	40
	20	26	24		25	20	
	30	40	24		38	40	
	40	54	56		52	26	40
	50	70			66	40	
	60	85	36		81	20	
	70	101	44		96	26	40
	80	118	24		112		
	90	135	36		128		
	100	153	20		144	26	40

Fig. 3 Table published by du Crest (1765, page 75) in which three thermometric liquids are compared: spirit-of-wine (*Weingeist*), mercury (*Mercur.*) and linseed oil (*Leinöl*), all immersed in the same pot of water, for a cooling and heating cycle. Rows are ordered following the cooling cycle, and then the heating one. The first column, indicates the "degrees of heat" (*Grade der Wärme*) from 100° (Boiling point of water - *Wasser Siedepunkt*) to 0°C (Middlepoint – *Mittelmässig*) and the "degrees of cold" (*Grade der Kälte*) from 0° to 100° measured with the spirit thermometer kept as a reference. All readings are in °C, but the temperature in the second and third column is surprisingly expressed in degrees and sexagesimal parts, i.e. Degrees Minutes and Seconds (*Grade Min. Sec.*). The cooling cycle is in agreement with the results by De Luc (1772). The heating cycle has something wrong, probably because the mercury and linseed oil were affected by the heat source, indicating a too high temperature, much above the boiling point of the water in the pot.

326 II. PART. CONST. ET USAGE DU BAROM.

TABLE des degrés correſpondans, de dix Thermomètres faits de liqueurs différemment ſpiritueuſes & des Thermomètres d'eau & de mercure.

Mercure.	Eſp.d.v. diſtillé au bain de ſable après avoir brulé la poudre.	Eſp.d.v. qui brul.la poud.	Eſp. de v. reſt. de la diſtill. au bain de ſable.	Eſp. de v. de M. *de Réaumur*, 5. p. d'eſ.d.v. & 1 partie d'eau.	3 Part. d'eſp.de v.& 1p. d'eau.	Eau-d. vie.	Eſp.d. v.aff par l'évapor. tion.	1 part. d'eſ.de v. & 1 partie d'eau.	Vin vieux de Languedoc.	1 part. d'eſprit-d. v. & 3 p. d'eau.	Eau.
80	80,0	80,0	80,0	80,0	80,0	80,0	80,0	80,0	80,0	80,0	80,0
75	73,8	73,8	74,0	73,9	73,7	73,4	73,4	73,2	72,4	71,6	71,0
70	67,6	67,8	67,9	67,8	67,5	67,4	66,9	66,7	64,3	62,9	62,0
65	61,5	61,9	62,1	61,8	61,5	61,4	61,0	60,6	56,6	55,2	53,5
60	55,5	56,2	56,4	56,2	55,8	55,6	55,0	54,8	49,5	47,7	45,8
55	50,3	50,7	50,8	50,5	50,2	49,8	49,3	49,1	42,5	40,6	38,5
50	45,1	45,3	45,5	45,0	44,9	44,4	44,0	43,6	36,2	34,4	32,0
45	40,0	40,2	40,2	39,8	39,7	39,2	38,9	38,4	30,1	28,4	26,1
40	35,0	35,1	35,2	35,0	34,8	34,2	34,0	33,3	24,6	23,0	20,5
35	30,1	30,3	30,0	30,1	29,8	29,4	29,2	28,4	19,9	18,0	15,9
30	25,5	25,6	25,2	25,5	25,2	24,7	24,6	23,9	15,3	13,5	11,2
25	20,9	21,0	20,6	20,8	20,7	20,3	20,2	19,4	11,2	9,4	7,3
20	16,5	16,5	16,3	16,3	16,2	15,9	16,0	15,3	7,7	6,1	4,1
15	12,0	12,2	11,9	11,9	11,8	11,8	11,6	11,1	4,9	3,4	1,6
10	7,9	7,9	7,9	7,9	7,7	7,7	7,6	7,1	2,3	1,4	0,2
5	3,9	3,9	3,9	3,9	3,8	3,8	3,8	3,4	0,9	0,1	— 0,4
0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Fig.4. Table by De Luc (1772, Chapter II, page 326) with the comparison of twelve thermometers. The first column is with the mercury thermometer, used as a reference. The next three columns are with thermometers filled with "pure" *spirit-of-wine* (*esprit-de-vin*) distilled in different ways, immersed in baths of sand (*bain de sable*) (90-95% ABV). "*Spirit*" was the closest approximation to ethyl alcohol. The fourth column is the "Réaumur spirit" i.e. a mixture in the ratio 5:1 of spirit and water (*eau*) (i.e. 83% ABV). The next columns are mixtures spirit and water, with spirit in ratios decreasing towards the right hand side, i.e. mixture in the ratio 3:1 (i.e. 75% ABV); water-of-life (*eau-de-vie*) (i.e. 60-70% ABV); spirit of wine after some evaporation e.g. brandy; mixture in the ratio 1:1 (i.e. 50% ABV); old wine of the Languedoc (Southern France), an old recipe with the addition of sugar and stimulated fermentation, with ratio 3:6, i.e. 30% ABV (Duplais, Vol.2, page 375); mixture in the ratio 1:3 (i.e. 25% ABV). The last column is for pure water (*eau*), i.e. 0:1, 0%ABV.

Wildt

300 Vergleich d. Thermometer. 301

das Qecks. Therm.	das Weing. Therm.	Nach Beobachtung
80°	80,00	von de Luc
75	73,90	73,80
70	67,95	67,80
65	62,14	61,90
60	56,48	56,20
55	50,97	50,70
50	45,60	45,30
45	40,38	40,20
40	35,31	35,10
35	30,38	30,30
30	25,60	25,60
25	20,97	21,00
20	16,48	16,50
15	12,14	12,20
10	7,95	7,90*)
5	3,90	3,90
0	0,00	von Luz.
5	3,75	3,90
10	7,36	7,60
15	10,82	11,20
20	14,13	14,50
25	17,30	
30	20,32	
35	23,19	
40	25,92	
45	28,50	

*) du Crest 7,94.

Fig.5 Table published by Wildt (1825, pages 300-301) where the first column reports the reference readings of a quicksilver (*Queks*.) thermometer, the second of a spirit-of-wine (*Weing*.) thermometer, and the third the values observed (*beobachtung*) by De Luc (1772), except a reading from du Crest (1765)

The relationship between the most refined (i.e. 95%ABV) alcohol thermometer and the mercury thermometer in the De Luc (1772) Table is a parabola, with equation

$Y_{Hg} = -0.0025\ X_a^2+1.2497\ X_a$

where Y_{Hg} and X_a refer to readings with the mercury and the alcohol thermometer.

The plot is shown in Figure 6.

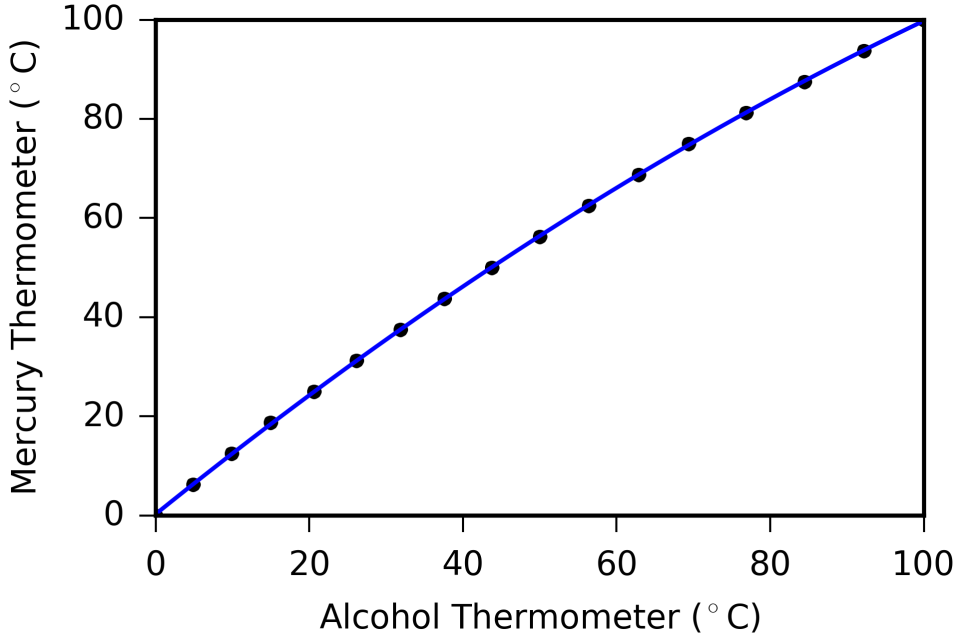

Fig.6 Relationship between readings taken with the most refined alcohol thermometer and the mercury thermometer in the De Luc (1772) Table

An example of the bias is given in Fig.7 where a record of indoor temperature observed in 1782 in Bologna, Italy, with an alcohol thermometer, is reported, with the observed and the corrected readings. In summer, the indoor temperature has been evaluated to be some 4°-5°C higher than outdoors.

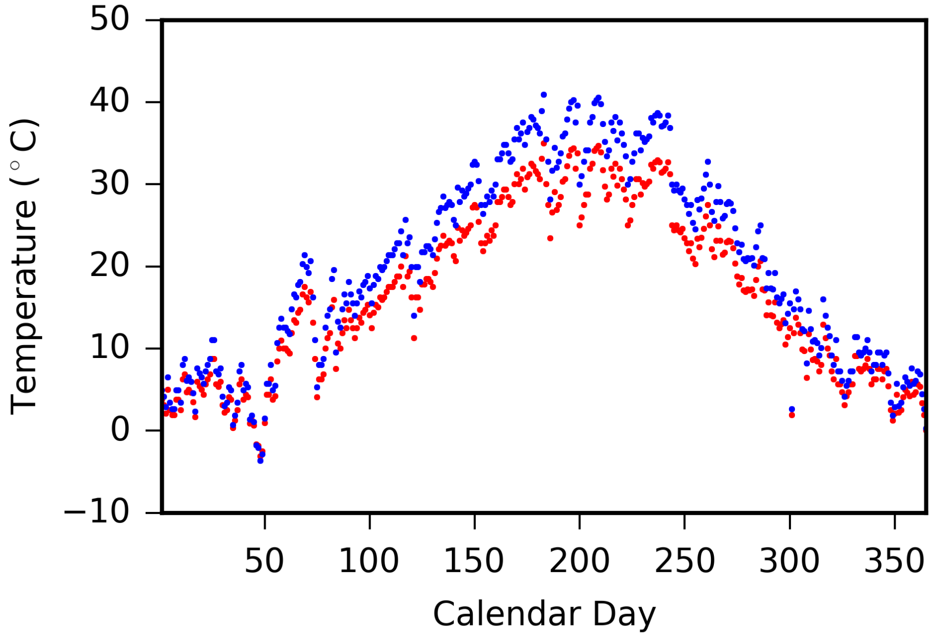

Fig.7 Record of indoor temperature observed with an alcohol thermometer in 1782 in Bologna, Italy. Red: observed readings; blue: corrected readings

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