Plastering in the UK and Europe was based upon three main ingredients: earth (clay-bearing sub-soil, improved with sands as necessary, often with organic additions, such as ox hair or hay); sand or limestone aggregates and quicklime.

Until at least 1800 in the UK, and until later elsewhere and, most certainly in North America, plastering systems included both earth-lime mortars and lime mortars, applied in a unified craft practice. Until 1800, at least, in England, the majority of stone buildings of all status were built with earth or earth-lime bedding mortars, pointed to the exterior with lime rich, hot mixed mortar and plastered within with an earth-lime basecoat over which was laid a haired, lime rich finish coat of between 4 and 8 mm. Similar prevailed for buildings of timber-frame construction. Similar systems predominate in Spain, Italy, France and Ireland in our observation and were doubtless as common elsewhere. Ukrainian migrants carried the routine use of similar mortars into northern Alberta during the later 19thC, used in conjunction with timber-framed and log construction farmsteads.

The quicklime addition to a clay-bearing subsoil might be as little as 5%, delivering twice this proportion upon slaking with the earth mortar. It was sometimes higher than this. The lime finish might be pure lime plus hair, or include very fine aggregate, such as chalk or other limestone dust.

Lime-sand plasters had been common enough before 1800, but the enclosure of common lands in Britain, and their general consolidation in the hands of the ruling class, meant that earth for building was no longer so readily available to the common man, or even to the bourgeoisie, at the same time as lime sand stucco'd interiors had increased in status and desirability throughout the 18^{th} century, increasingly displacing previously panelled or wainscotted interiors.

The use of quicklime continued, however.

The routine use of previously slaked putty lime as a binder, as opposed to being used on its own for fine finish coats, was a mainly 20^{th} C development and was predicated upon the assumption that small volumes of Portland cement (for building) or of gypsum (for plastering) would be added before use – speeding the set and compensating for the loss of 'tenacity' and binding qualities offered by quicklime run to putty which had always been assumed historically. Gypsum had been a common addition to pure lime putty finish coats in the past, but had not generally been added to the previous sand-lime coats, though Gilmore allows it in 1860s USA when fast setting was essential (see below). Millar talks about running previously dry-slaked lime to a paste for plastering binders in 1897 (see below), whilst observing that traditional hot mixing persisted in Scotland, as well, in my observation, in northern England.

The conditional 20thC practice of slaking quicklime to a liquid putty led into the key assumptions (and confusions) of the lime revival, that putty lime was a traditional binder and was slaked by drowning in an excess of water and laid down for a period of months before mixing with aggregates for use. Generally, during the 18th and 19th centuries, when putty was not used immediately and whilst still hot, it was laid down for no more than two weeks.

Until the 20thC, the primary use for lime putty was in situations where residual lumps of unslaked lime would be a nuisance and where significant tenacity was not required – for fine plaster finish coats and for the very fine jointing of gauged brickwork and finely jointed stone ashlar. This putty was made by slaking lump lime with a minimum of water (to guarantee that the slake reached the minimum necessary temperature of between 100 and 120 degrees centigrade) and then laying the emergent 'dough-like' material down for all late slaking to occur (as was done by the Romans for fine stucco finishes), or by thinning the dough-like material with more water after the slake was complete to facilitate its being run through a sieve to remove the unwanted lumps.

The mortar for all previous coats, as for building mortars, was hot mixed from quicklime – the quicklime slaking along with the sand. This was typically achieved by forming a 'basin' of the necessary sand, placing the lump lime in the middle of this and adding just sufficient water to the quicklime to achieve the slake (or just enough and a little more to produce a thick paste); banking the sand over the slaking lime until the slake was generally complete (a matter of minutes for the purer limes) and then mixing the lime and the sand together whilst both remained very hot. This was termed the 'ordinary' or 'common' method of mixing (and slaking) by Spanish, French, British and North American authors historically, indicating its frequency. The operation might be carried out on a flat surface, within a shallow mortar pit in the ground or in mortar boxes.

When just enough water was added, a dry-mix of sand and hydrated lime would emerge. This could be stored for a period, even indefinitely if contained within barrels in a damp cellar, but more commonly it was thrown through a screen to remove larger lumps of aggregate and unslaked lime and mixed to a mortar for use. When the mortar was to be mixed for immediate use, a little more water might be added, but in either case, more water would be added to produce a workable mortar for immediate or prompt use.

Immediate use was not recommended for plastering, however, due to the risk of late slaking of quicklime under- or over-burned in the kiln. The late slaking of these lumps would disrupt and break a finished plaster surface, leaving it riddled with 'bullet holes'.

The response to this hazard was not, however, to make putty lime, laying this down to 'mature' – it was to hot mix the mortar as above and to lay down this mortar, or coarse stuff, for a period of time to be sure that all slaking had occurred.

It was generally understood that the hot mix method delivered a mortar of greater tenacity, bond strength and workability than did the mixing in of cold lime putty that may have been 'drowned' during production.

It was also a reliable and economic method of adding sufficient lime for maximum workability and performance whilst producing a mortar for immediate use.

The vast majority of historic lime mortars have at least 1 part of lime to 2 parts of aggregate and more usually 2 parts of lime to 3 parts of aggregate. That this high lime content was *critical* to their performance was ignored during the lime revival, which prescribed mortars of 1 part of slaked lime to 3 parts of aggregate – a binder-aggregate proportion with zero historic precedent before the advent of cement-lime mortars (1:2:9; 1:3:12) early in the 20thC .

Whilst 2:3 mortars might be mixed from putty slaked in the traditional way, they could not be produced with over-wet modern putty limes slaked by drowning, lest these had been laid down for decades.

Hot mixing methods, however, allow the water content to be readily controlled by the mortar mixer.

A succession of French, British, Spanish and North American engineers in the later 18th and earlier 19th Centuries rigorously tested their materials and methods. All concluded that the maximum amount of sand or other aggregate that could be added to 1 part of quicklime, without compromising the workability and necessary performance of the mortar, was three parts, in the case of pure and feebly hydraulic limes. Prior to this time, lime mortars were frequently richer than 2:3. They were never leaner than this, however, though, if the quicklime was in the form of powder, and would therefore leave no unslaked lumps to perform as aggregate in the mix, 1:4 would be (and remains) an appropriate maximum of sand to one part of quicklime.

Pure/fat or feebly hydraulic quicklimes will typically double in volume upon slaking, so that a 1:3 quicklime: sand mix will deliver a 2:3 lime: aggregate mortar.

Hydraulic limes, also hot mixed (or, for the more hydraulic and least reactive, sand-slaked) and used almost exclusively for underwater or routinely wetted works, expand less on slaking, so that the prescribed maximum proportions were 1 or 2 parts of sand to 1 part of quicklime, depending upon its hydraulicity.

This, too, was substantially missed by the lime revival, as well as the fact that more than feebly hydraulic limes were rarely used for building in the air historically, lest the only limestone locally available was itself hydraulic, at least until the late 19thC, when they were quickly displaced by cement-lime mortars for general building.

Hydraulic lime mortars, even at 1:3, tend to be too hard and brittle for use in conjunction with traditional historic fabric and are generally too low in *effective* porosity to be compatible with either earth-lime or sand lime mortars prepared using pure or feebly hydraulic quicklimes. A pure or feebly hydraulic lime mortar with a high free lime content, typically hot mixed delivers a very high level of effective porosity, actively keeping traditional fabric dry – protecting timbers from decay and masonry from frost damage, as well as preferentially, and sacrificially, 'harvesting' damaging salts, whilst maximising the thermal performance of the structure (Wiggins HES Technical Paper 28 2017).

Hot mixing was the most efficient method of producing mortars of necessarily high free lime content, though masons and plasterers were thinking much more of what 'felt right' – what method and lime: aggregate proportion gave them a material of eminent workability, 'tenacity' and bond, which made their work not only durable but which allowed them to achieve what they wished to with the material, economically and efficiently. This material was deformable during its sometimes lengthy period of setting up – able to respond to the settlement and flex of a traditional building without cracking or separation. Earth-lime mortars offered similar properties, as well as excellent workability and bond strength.

For plastering, a hot mixed lime mortar delivers a material with excellent adhesion and excellent cohesion – it sticks to almost any substrate and within the mortar, the lime, aggregate *and water* are intimately combined and locked together. Used hot, the mortar will readily stiffen, but without drying out too rapidly – hot mixes are reluctant to let all their water go too quickly, enjoying excellent water retentivity. Quicklime is also the cheapest form of lime, reducing the cost of a project. There is very little waste of material – left-over mortar may be re-tempered indefinitely, so long as it is protected from drying out.

There was a long tradition of pulverising lump lime to a coarse powder before slaking. This became the norm when mixing in mortar mills. It had been common enough before, especially as it would accelerate the otherwise slow slaking of hydraulic limes. There was a general understanding from at least the 17thC that mixing powdered quicklime intimately with the sand or other aggregate before slaking delivered a mortar of even greater adhesion and tenacity than that achieved by the 'ordinary' method.

In modern usage, using commercially available powdered quicklime eliminates the need to lay down the coarse stuff to allow for late slaking – hot mixed plastering mortar may be used with confidence whilst still hot or immediately after cooling. In our own practice, we tend to hot mix the plasters with powdered quicklime for use the following day. Used hot, the plaster is 'tackier' than when cooled. After cooling, it has greater 'elasticity' but without loss of adhesiveness.

Most of the benefits associated with hot mixing endure after cooling, though a hot mixed mortar used when still hot will offer maximum porosity and harling (thrown exterior rendering) in Scotland was routinely done with the mortars still hot. There is much textural and anecdotal evidence from around the world that plastering was as routine with hot mortars as it was with cold, certainly for the first and second coats of three-coat plaster schemes. The possible ill-effects of late slaking could be dealt with prior to the application of the putty lime finish coats.

The routine use of hot mixed lime mortars of high free lime content should not be seen solely as a 'conservation' issue, though they offer a truly 'like-for-like' and compatible option for the repair and conservation of old buildings of traditional construction. It is as relevant to eco-build projects, and especially those involving the use of earth mortars and solid wall earth construction. High free lime mortars will keep these buildings dry and prevent the potential accumulation of moisture within their fabric associated with the use of cementitious (or strongly hydraulic lime) mortars. A building the fabric of which is healthy will be healthy for those who live or work within it.

The strength and durability of hot mixed high calcium limes may be enhanced by the addition of small volumes of pozzolanic material. Pozzolans are fired clays. Hydraulic limes are produced from clay-bearing limestones, the clays fired in the kiln along with the free lime, the two combining to provide an hydraulic set. In craft practice historically, a small volume of pozzolan was often added to final pointing mortars or to exterior renders to enhance their durability and to hasten their initial set, or was added where elevated moisture levels would inconveniently slow the initial set of a non-hydraulic mortar. The addition of up to 10% of a pozzolan *as a proportion of the lime content* will not disrupt the effective porosity of a mortar high in free lime (Wiggins 2017). Traditional pozzolans were brick dust (from bricks fired at around 900 degrees C); trass (volcanic ash from central Europe); true pozzolan (volcanic ash from the Naples region of Italy); ashes and clinker from blacksmiths' forges and wood ash. Wood ash was probably the most common pozzolan in vernacular usage, along with pulverised brick, where bricks were being made. Pulverised fly ash and calcined china clay, both used in the concrete industry are useful modern pozzolans.

For underwater work, the volume of pozzolan was higher – John Smeaton, the English engineer, concluded that 2 parts of sharp sand to one part pozzolan to one part high calcium quicklime, hot mixed, was the minimum of pozzolan necessary for the mortar to set reliably underwater. Earlier mixes for such uses were 1 part quicklime to 3 parts, or fewer, pulverised pozzolan (aggregate and dust), and no sand.

Hot mixed mortars are easy to produce and are more tolerant of inexperience than other forms of lime mortar. Contrary to common assumption, the use of quicklime is no more hazardous than the use of other routinely used alkaline binders, such as Portland cement, hydraulic or hydrated lime. Properly slaked, the temperature of a hot mixed mortar will not exceed 120 degrees Centigrade during slaking and will fall to between 50 -60 degrees C once sufficient water to produce a workable mortar is added. This process takes a matter of minutes. The same or significantly higher temperatures are encountered in the average domestic kitchen every day. Quicklime is used in a wide range of applications across the world – soil improvement; soil stabilisation; water purification, as well as in the manufacture of lightweight concrete blocks and as a flux in steel production.

Eye protection is essential when working with any calcareous binder; gloves are always advisable, as is robust clothing and common sense. When the mixing method may involve dust (which it need not), appropriate dust masks should be worn. Quicklime should be stored in a dry place.

Quicklime is available in most parts of the world, and can be made on a small scale wherever there is a supply of suitable limestone or sea-shell. It is sustainable. A high calcium lime mortar will absorb almost as much carbon dioxide during its set as was produced during the burning of the lime it contains. Only free lime will re-absorb carbon dioxide, so that most hydraulic limes will absorb a relatively small amount of the carbon dioxide produced in their manufacture and Portland cement next to none. The production of Portland cement is a major contributor to global warming.

There has been a revival in the use of hot mixed lime mortars in the UK and Ireland over the last 3 years, with many craftspeople – masons, bricklayers and plasterers - embracing their routine use once more. What began as a grassroots 'rebellion' against the routine specification of what were perceived as over-hard and generally inauthentic hydraulic lime mortars, has been significantly enhanced by on-going research projects and papers commissioned by the Historic England Architectural Conservation Research Team and its equivalent at Historic Environment Scotland, as well as by the enthusiasm of a growing number of professionals, and especially structural engineers. Alarm at the indiscriminate use of modern hydraulic lime mortars has only grown as a result. Initial anxieties that hot mixed air lime mortars might prove as overly sacrificial as drowned putty lime mortars of similar chemistry (the premature failure of which had led to the uncritical embrace of hydraulic lime mortars in the UK during the 1990s) have been proven by experience and observation (as well as historic precedent and material science) to have been unfounded, and the vast majority of craftspeople, once introduced to hot mixed mortars, would not wish to use anything else, reiterating the preferences of their forebears - since so long as it was that the mason, bricklayer or plasterer designed the mortars they used (generally until the end of the 19thC), they chose to use hot mixed fat or feebly hydraulic lime mortars, or, indeed, a combined system of these mortars and earth-lime mortars.