Zero Energy System for Precast Concrete

Dr. Bruce J. Christensen
Degussa Construction Chemicals Asia Pacific

Abstract: The concept of a Zero Energy System (ZES) was first introduced to the precast industry in Italy in September 2001. As the name implies, the premise of the system is to eliminate the need to input mechanical or thermal energy into the process of consolidating and curing precast concrete elements. This is achieved by the use of innovative chemical admixtures and a proper mixture design. The ZES has a number of distinct advantages over the conventional precast manufacturing process, which include economic, quality and safety considerations.

Background: The profitable production of good quality precast concrete elements involves overcoming many challenges. Some of these challenges include increasing fuel and material prices, a shrinking pool of skilled labor and a need to improve working conditions. In an attempt to help address these challenges, as well as provide additional benefits, a new approach known as the “Zero Energy System” has been developed [1-3]. The key components of this new system are chemical admixtures that make possible a new level of concrete performance. Many articles have already been published on this topic, so only a brief overview and number of references are given here.

Contents:

Components of ZES:

1. High Early Strength High Range Water Reducer (HES-HRWR)
   A key component to the ZES is a HES HRWR. This admixture is based on a next-generation polycarboxylate ether (PCE), which provides excellent dispersion via a steric mechanism and improved hydration kinetics [4, 5]. This generation of PCE is believed to cover less of the surface of the cement grain, thereby actually providing accelerated hydration as compared to a non-admixture treated reference. As shown in Figure 1, the early age compressive strength development is significantly improved from earlier generation PCE’s. Even further improvements to the early strength development and workability retention properties of the HES HRWR have recently been made [6].

2. Self-Consolidating Concrete (SCC) Mixture Design with a Viscosity Modifying Admixture (VMA)
   Another important component of the ZES is the use of a SCC mixture design. These mixtures are highly fluid and typically have slump flow values of greater than 550 mm.
Therefore, these mixtures must be designed to exhibit adequate dynamic and static stability. This includes suspension of the coarse aggregate and control of bleeding. The HES HRWR will typically impart improved stability over earlier generation PCE’s, but is not always adequate for some applications. Early generation concrete mixtures relied upon a higher fines content to achieve the required stability. This approach often invoked concerns on the long-term creep and shrinkage characteristics of such concretes. It also made it impossible for precast manufacturers who were interested in high coarse aggregate contents for architectural finishes to use SCC [7]. An improved approach is to use a more conventional mixture design and to incorporate a VMA [5, 8]. Use of the appropriate type and amount of VMA for the application will adjust the rheology of the concrete to provide the desired stability. An example of the effect of adding a VMA to a concrete with poor stability is shown in Figure 2 (left side treated with VMA, right side without).

Benefits of ZES:

1. Reduce placing time
   Conventional concrete is typically less than 200 mm slump, so placement requires mechanical input from human labor and/or vibrators. SCC is very fluid and can be poured directly into forms without additional effort (see Figure 3). Discharge time from the mixer or the truck now becomes the rate-limiting step in the placing process.

2. Reduce cycle time
   One key performance attribute that most precast manufacturers are interested in from an admixture is rapid early strength development. This is important to reduce the time from casting to stripping of the molds, thereby freeing up the molds for future use. Therefore, if better utilization of production capacity is more important that reducing energy costs, the benefits of the HES HRWR can be realized in this manner. These benefits have also been exploited in some unique ready mixed concrete applications, as well [9].

3. Eliminate or reduce vibration
   The use of vibrators to consolidate conventional concrete around heavy reinforcement or into intricate shapes can have detrimental effects on workers, in the form of high noise levels and “white knuckle” disease. It also has detrimental effects on the equipment, in the form of costly repairs to vibrators and more rapid replacement of forms. Removal of vibration has the benefit of significantly improving the working environment, as well as an economic payback in the form of equipment and energy savings.
4. **Eliminate or reduce heating cost**
   The ZES attempts to reduce all the various forms of energy used to produce the desired element. A major contributor to this overall energy use is the thermal energy, typically in the form of steam or electrical heaters. This thermal energy is used to accelerate the hydration process, which ultimately increases the rate of strength development. With the ZES, the desired effect is achieved in the form of chemical activation and the thermal energy liberated from hydration. Regular production cycles of 14 to 18 hours can be achieved without the use of steam and the use of the HES HRWR at ambient temperatures [4]. Removal of heating costs, therefore, is a true economic benefit, especially in light of rising energy costs.

5. **Reduce cement cost**
   If reducing the consumption of thermal energy is less important to a producer, another option to realize savings is by a reduction of or change in type of cement. Typically, an ASTM C150 Type III cement, which is more expensive than a Type I, is used in many precast operations to speed up the early strength development. With the ZES, a couple options are now available. One is a change from a Type III to a Type I [3, 10]. Not only does this have positive economic benefits, but the handling characteristics of plastic concrete made with Type I cement are generally much better than those of concrete made with Type III. Another option is replacement of an increasing portion of cement with supplementary materials like flyash. The reduction in the amount of cement used to make concrete has both positive environmental and economic benefits.

6. **Reduce labor requirements**
   The placement, consolidation and finishing of conventional concrete requires trained and skilled labor. With the use of SCC as part of the ZES, the concrete easily flows into the formwork and is generally self-leveling. As a result, only minimal labor is required to get the concrete into its intended location. When compared to conventional concrete, a reduction in labor costs is generally possible.

7. **Improve concrete quality and intricacy of shapes**
   The use of the ZES can improve both the engineering properties and aesthetic properties of the finished element. It has been reported steam curing can compromise the later age compressive strength development [11]. The use of a HES HRWR provides equal or improved early and late age compressive strength when compared with heat curing [12]. The engineering properties, such as bond to reinforcement, top-bar effect, creep, and diffusivity are all comparable or better than the properties of similar conventional mixtures [13]. Drying shrinkage is generally better in SCC mixtures, especially when a
VMA is used [14].
The surface appearance of the finished elements is generally improved when compared to
conventional concrete [1, 15]. There is little or no need to surface repairs, grinding or
reworking as a result of the excellent self consolidation of these mixtures. This is true
also for thin, complex elements as shown in Figure 4.

Conclusions: The use of the Zero Energy System (ZES) has a number of economic
benefits for the precast manufacturer. Depending on the specific interests of the producer,
these can include possible reductions in energy and material costs, reductions in equipment
repairs and maintenance, reductions in worker health claims or increased productivity.
Additionally, the use of the ZES results in a finished precast element with improved aesthetics
and engineering properties from that made with conventional concrete.

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Figure 1 Development of compressive strength versus hydration time at 23 C for two concrete mixtures. The mixtures are identical, except one contains a conventional PCE HRWR, while the other contains a HES HRWR. Especially during the period of 6 to 12 hours, there is a significant benefit provided by the HES HRWR.
Figure 2  Concrete with and without a VMA. The right hand portion picture is the mixture before addition, which exhibits severe segregation. The left portion is the same mixture with the addition of a VMA. Adequate stability is then achieved, as evidenced by the curled edge and uniform distribution of aggregates.

Figure 3  SCC being discharged from a drum mixer into a box mold. Note the self-leveling achieved with no vibration.
Figure 4  A thin, intricate precast element that was formed using the ZES.  Note the fine details and good surface appearance.