ORNL/TM-2016/580

LIQUIDARMOR^{TM} CM Flashing and Sealant High Impact Technology Demonstration

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December 2016

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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

ORNL/TM-2016/580

Building Technologies Research and Integration Center

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Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831-6283
managed by
UT-BATTELLE, LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

TABLE OF CONTENTS

ACKNOWLEDGMENTS

This report and the work described were sponsored by the Commercial Buildings Integration program within the Building Technologies Office of the US Department of Energy Office of Energy Efficiency and Renewable Energy. The authors wish to acknowledge the contributions of Amy Jiron in guiding this work and the insightful review comments of Som Shrestha of Oak Ridge National Laboratory. This work would not have been possible without the help of David Lesniak, who allowed us to collect data from the Homeland Security Training Center at the College of DuPage; and Jay Johnson, Principal Studio Director from Legat Architects, who provided access to the design details and choose to use a high-performance wall system for energy efficiency.

ABSTRACT

Air leakage is responsible for about 1.1 quads of energy or 6% of the total energy used by commercial buildings in the US. Consequently, infiltration and exfiltration are among the largest envelope-related contributors to the heating, ventilation, and air conditioning loads in commercial buildings. New air sealing technologies have recently emerged that aim to improve the performance of air barrier systems by simplifying their installation procedure. LIQUIDARMOR™ CM Flashing and Sealant is an example of these new advanced material technologies. This technology is a spray-applied sealant and liquid flashing and can span gaps that are up to ¼ in. wide without a supporting material.

ORNL verified the performance of LIQUIDARMOR™ CM with field tests and energy simulations from a building in which LIQUIDARMOR™ CM was one of components of the air barrier system. The Homeland Security Training Center (HTC) at the College of DuPage in Glen Ellyn, IL, served as the demonstration site. **Blower door test results show the average air leakage rate in the demonstration site to be 0.15 cfm/ft^2 at 1.57 psf, or 63% lower than the 0.4 cfm at 1.57 psf specified in the 2015 International Energy Conservation Code (IECC).** According to simulation results, HTC lowered its annual heating and cooling cost by about $3,000 or 9% compared to a similar building that lacked an air barrier system. This demonstration project serves as an example of the level of building envelope airtightness that can be achieved by using air barrier materials that are properly installed, and illustrates the energy and financial savings that such an airtight envelope could attain.

1. INTRODUCTION

The U.S. Department of Energy's (DOE) Windows and Building Envelope Research and Development: Roadmap for Emerging Technologies (DOE 2014) indicates that improving airtightness is among the most cost-effective strategies to decrease heating, ventilation, and air conditioning (HVAC) loads due to the building envelope. This conclusion is based on the fact that air leakage (i.e., infiltration and exfiltration) is responsible for about 1.1 quads of energy or 6% of the total energy used by commercial buildings in the US (DOE 2011). Although air sealing technologies are available for purchase today, installation procedures tend to be complex, time consuming, and rely heavily on quality workmanship. This is especially significant when sealing gaps around penetrations, such as windows, that have curved shapes and/or corners.

New and emerging air sealing technologies improve the performance of air barrier systems by simplifying their installation procedure. LIQUIDARMOR™ CM Flashing and Sealant is an example of this type of new technology; Oak Ridge National Laboratory (ORNL) produced an evaluation report on it (Hun 2016) under the US-China Clean Energy Research Center for Building Energy Efficiency (https://cercbee.lbl.gov/). Additionally, ORNL evaluated the performance of LIQUIDARMOR™ CM through field tests and energy simulations of the Homeland Security Training Center (HTC) at the College of DuPage. This report summarizes the results of this demonstration.

2. LIQUIDARMOR™ CM FLASHING AND SEALANT

The effectiveness of an air barrier system relies on its continuity throughout the entire building envelope. Common areas where continuity is compromised are the wall-to-foundation and wall-to-roof joints, and gaps around items that penetrate the air barrier such as windows, doors, mechanical ducts, electrical outlets, and plumbing pipes. Air barrier systems include products that seal gaps and can also serve as flashing materials at window rough openings. Examples of these products are tapes (Figure 1), coatings with a reinforcing mesh (Figure 2), and liquid flashings (Figure 3). Main differences among these products are material cost, installation time, and installation cost. Furthermore, their performance will vary depending on the product's ease of installation and the amount of training and skill required for successful installations.

Figure 1. Tape used to flash window rough openings (left) and to seal joints between boards (right).

Figure 2. Coating and reinforcing mesh flash the rough opening of a window and seal gaps between exterior grade drywall wall sheathing.

Figure 3. Liquid flashing applied with a caulk gun and trowel.

LIQUIDARMOR™ CM Flashing and Sealant can span gaps that are up to a ¼ in. wide without the need for a supporting material (Figure 4) and can be installed with a regular airless paint sprayer making it faster to apply than tape, coatings that require a reinforcing mesh, and liquid flashings that are applied with a caulk gun and trowel.[1] Under the US-China Clean Energy Research Center for Building Energy Efficiency, ORNL assessed the performance of LIQUIDARMOR™ CM through laboratory evaluations per test standards from the American Society for Testing and Materials (ASTM) International[2,3,4,5,6] and the American Architectural Manufacturers Association (AAMA).[7] LIQUIDARMOR™ CM was installed in these evaluations over fiberglass mat gypsum sheathing and foil-faced polyiso foam boards, and gaps that were up to ¼ in. wide did not have a supporting material. These air barrier assemblies passed the aforementioned tests; that is, air leakage rates were less than 0.04 cfm/ft^2 at 1.57 psf per the 2015 International Energy Conservation Code (IECC) requirement for air barrier assemblies and water penetration was not observed throughout the tests (Hun 2016).

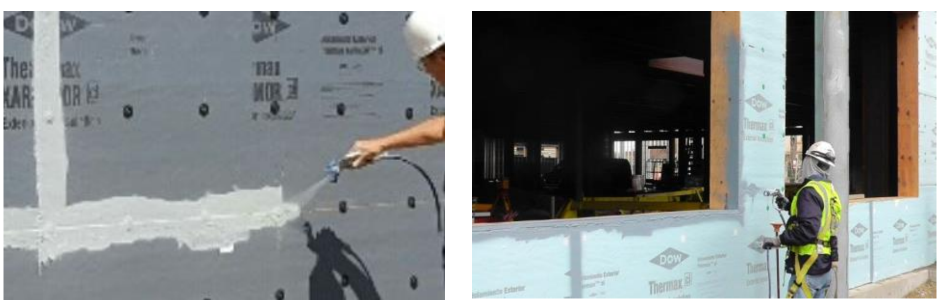

Figure 4. LIQUIDARMOR™ CM sprayed over board joints and a window rough opening.

[1] https://www.youtube.com/watch?v=aVf9_Pg5gkY

[2] ASTM E283-04. Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen.

[3] ASTM E2357-11. Standard Test Method for Determining Air Leakage of Air Barrier Assemblies.

[4] ASTM E1424-91. Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure and Temperature Differences Across the Specimen.

[5] ASTM E331-00. Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference.

[6] ASTM E2268-04. Standard Test Method for Water Penetration of Exterior Windows, Skylights, and Doors by Rapid Pulsed Air Pressure Difference.

[7] AAMA 501.5-07. Test Method for Thermal Cycling of Exterior Walls.

3. HOMELAND SECURITY TRAINING CENTER AT THE COLLEGE OF DUPAGE

The Homeland Security Training Center (HTC) at the College of DuPage served as a demonstration site for third party verification of LIQUIDARMOR™ CM Flashing and Sealant performance. HTC is located in Glen Ellyn, IL, was built to comply with the 2009 IECC, and was completed in the fall of 2015. This building has an area of 34,600 ft^2 on its first floor and 6,000 ft^2 at its basement/mechanical room. The front third of the building is primarily composed of classrooms and the back of the building is used as an enclosed and air conditioned shooting range. In the front third of the building, the air barrier system is composed of continuous exterior insulation that is sealed at its joints and gaps with closed-cell spray foam from the inside of the building and LIQUIDARMOR™ CM from the exterior side (Figure 5). As illustrated in Figure 6, the air barrier system in the back of the building is made of insulated precast concrete panels in which joints were treated with backer rods and sealants that are typically used with precast concrete.

Figure 5. Front of the Homeland Security Training Center. The picture on the left shows exterior insulation that was sealed at its joints with LIQUIDARMOR™ CM Flashing and Sealant. The picture on the right shows the finished building cladded with metal curtainwall panels.

Figure 6. Back of the Homeland Security Training Center. Exterior walls are made of insulated precast concrete panels.

Legat Architects designed the Homeland Security Training Center. Jay Johnson, Principal at Legat Architects and Project Manager for this building stated after the completion of this project that “The product replaces a self-sticking tape system. I believe it removes human error because it is a liquid spray that self-seals all joints and penetrations.”

4. BLOWER DOOR TEST

ORNL hired TMI® as a contractor to measure the air leakage rate of the HTC. On April 30, 2016, TMI® conducted a blower door test per ASTM E779-10.[8] The basement was isolated or guarded because of its negligible contribution to air leakage given that this space is below grade. Twelve fans were used as shown in Figures 7 and 8; nine pressurized/depressurized the first floor and three guarded the basement. Louvers that provide fresh air (Figure 8) were closed with mechanical dampers. Equipment setup, air leakage measurements, and equipment dismantling were completed in 10 hours.

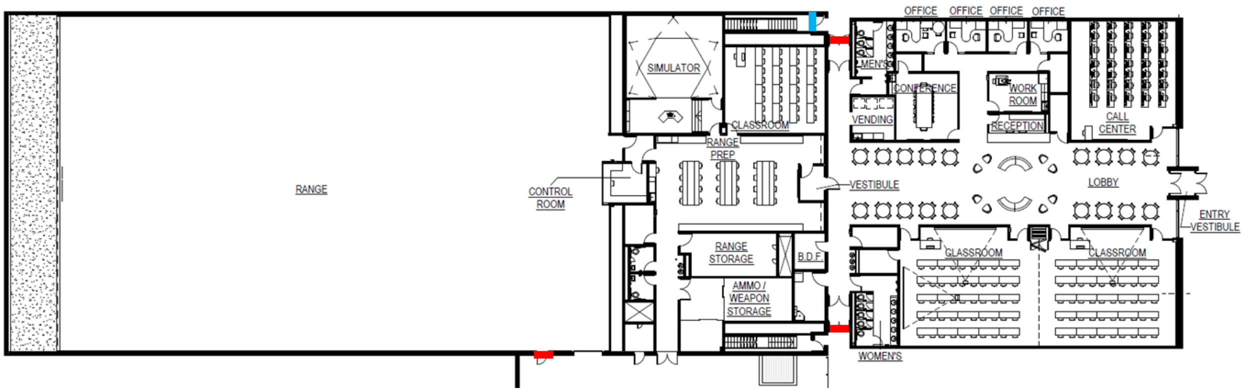

Figure 7. Location of blower door fans. The red lines indicate a group of three fans that were used to pressurize/depressurize the first floor. The blue line shows the location of three fans that guarded or isolated the basement.[9]

Figure 8. Blower door setup on west side of building. Left picture shows the louvers that provide fresh air and that were closed with mechanical dampers during the blower door test.

The measured leakage rates are summarized in Table 1. Leakage rates when the building was depressurized and pressurized to ±1.57 psf were 11,145 and 16,697 cfm, respectively. Pressurization values are typically larger because dampers and doors tend to slightly open when the building is under positive pressure. In the case of the HTC, the difference of 50% was likely caused by the 20 ft wide by 10 ft tall louvers that are located on the east and west (Figure 8) sides of the building. Large louvers are needed at the HTC to provide sufficient fresh air when the shooting range is in use. Louvers are typically sealed with an adhesive membrane during blower door tests because mechanically closed dampers may still leak, but it was not feasible for TMI® to use an adhesive membrane on the very large and high

[8] Standard Test Method for Determining Air Leakage Rate by Fan Pressurization.
[9] http://www.cod.edu/about/facilities/pdf/htc_drawings.pdf

louvers. Therefore, the measured air leakage rates are likely higher than the actual leakage rates because the HTC louvers were closed with dampers during the blower door test.

Results indicate that the HTC has an average air leakage of 0.15 cfm/ft^2 at 1.57 psf, which is 63% lower than the 0.4 cfm at 1.57 psf specified in the 2015 IECC. Table 2 compares the air leakage measurements from the HTC to that of commercial and institutional buildings from a database compiled by the National Institute of Standards and Technology (Emmerich and Persily 2014). **The data indicate that the airtightness level of the HTC is 45% lower than the average value of 0.28 cfm/ft^2 at 1.57 psf from 79 commercial buildings with air barriers, and 83% less than the average value of 0.86 cfm/ft^2 at 1.57 psf from 290 buildings without air barriers.**

Table 1. Blower door test results from the Homeland Security Training Center at the College of DuPage.

Measurements	Depressurization	Pressurization	Average
Leakage rates at 1.57 psf			
Airflow (cfm)	11,145 (±0.9%)	16,697 (±1.3%)	13,921 (±0.8%)
Air changes per hour (1/h)	0.81	1.21	1.01
Air leakage (cfm/ft^2)[a]	0.12	0.18	0.15
Airflow equation			
Flow coefficient (C, cfm/psf^n)	8,749 (±14.6%)	13,243 (±23.4%)	10,996 (±15.6%)
Exponent (n, dimensionless)	0.536 (±0.035)	0.513 (±0.056)	0.525 (±0.033)
Correlation coefficient	0.999	0.998	

a. Normalization is based on the area of the exterior walls, roof and floor; their sum equals 92,868 ft^2.

Table 2. Comparison of air leakage rates from the Homeland Security Training Center at the College of DuPage and from a database compiled by the National Institute of Standards and Technology (NIST).

NIST database	Sample size	Air leakage (cfm/ft^2) at 1.57 psf[a]	Air Leakage of HTC = 0.15 cfm/ft^2 at 1.57 psf
Buildings w/ air barrier	79	0.28	45% lower
Buildings w/o air barrier[b]	290	0.86	83% lower
All buildings	387	0.72	79% lower

a. Emmerich and Persily (2014). Normalization of the leakage rates is based on the area of the exterior walls, roof and floor.

b. These are buildings that were not specified as having an air barrier, but some could have had one in place.

5. ENERGY SIMULATIONS

A simulation model was created to estimate the energy savings due to the airtightness achieved at the HTC. The DOE's whole building energy simulation software EnergyPlus™ ver 8.3 (DOE 2016a) was used in this task. The building geometry was obtained from the architectural drawings that included the dimensions, floor plans, and construction material layouts. The HVAC system in the HTC consists of water cooled chilled water for cooling and boilers for heating. Internal loads, lighting, HVAC set point temperatures and efficiency, and their respective schedules were primarily based on information from the architectural drawings; assumptions that are commonly made for typical office buildings based on DOE prototype buildings (DOE 2016b) were used as inputs for missing information. The generated model was not calibrated because building energy consumption data were not available.

The effect of air leakage on energy use was evaluated by conducting a parametric analysis. The following airflow equation was used as the basis of this assessment:

$$Q = C \times \Delta P^n$$

where Q is the airflow rate in cfm, C is the flow coefficient in cfm/psf^n, ΔP is the pressure differential in psf, and n is a dimensionless exponent. Per Table 1, the performed blower door tests indicate that the values for the average flow coefficient and exponent are 10,996 cfm/psf^n and 0.525, respectively. Different air leakage rates and energy use were calculated by varying the flow coefficient, given that it is proportional to the size of the holes through which leakage occurs, and by keeping the exponent constant. Additionally, Typical Meteorological Year (TMY) weather data for DuPage, IL, were used to generate the outdoor conditions in the simulations.

As previously mentioned, the HTC has an average air leakage of 0.15 cfm/ft^2 at 1.57 psf, which is the blower door measurement normalized with respect to the area of the above grade walls, roof, and slab on grade per the IECC. In contrast, simulation models use air leakage rates that are normalized using only the area of the above grade walls and roof because air typically does not leak through the slab on grade. Consequently, the leakage rates used in the simulations were 0.27 cfm/ft^2 at 1.57 psf for the HTC[10] and 1.29 cfm/ft^2 at 1.57 psf for buildings without air barriers.[11]

Figure 9 illustrates the simulation results for the annual cooling energy consumption as a function of air leakage rate and suggests that the airtightness level of the HTC can lead to an energy usage of about 188 MWh per year. Furthermore, Figure 9 suggests that the higher leakage rate from buildings without an air barrier could increase the cooling energy use of the HTC to191 MWh; this change is minor because of the relatively mild summers at DuPage, IL, in which the average high temperature in July is 81°F. Conversely, Figure 10 shows that the annual heating energy increased by 26% because consumption grew from 950 MBTu to 1,200 MBtu given that the winter season is more severe than the summer.

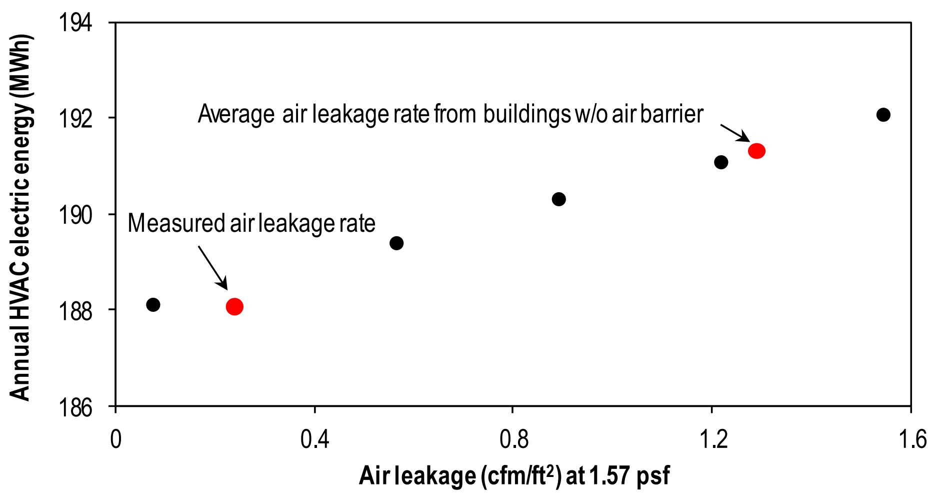

Figure 9. Simulation results of the annual HVAC electric energy consumed by the Homeland Security Training Center as a function of air leakage rate through the above grade walls and roof.

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[10] The combined area of the walls and roof at the Homeland Security Training Center is 50,268 ft^2.

[11] Data in Table 2 from Emmerich and Persily (2014) were recalculated to exclude from the normalization the area of the slab on grade. Therefore, the air leakage rate of buildings without an air barrier increased from 0.86 to 1.29 cfm/ft^2 at 1.57 psf.

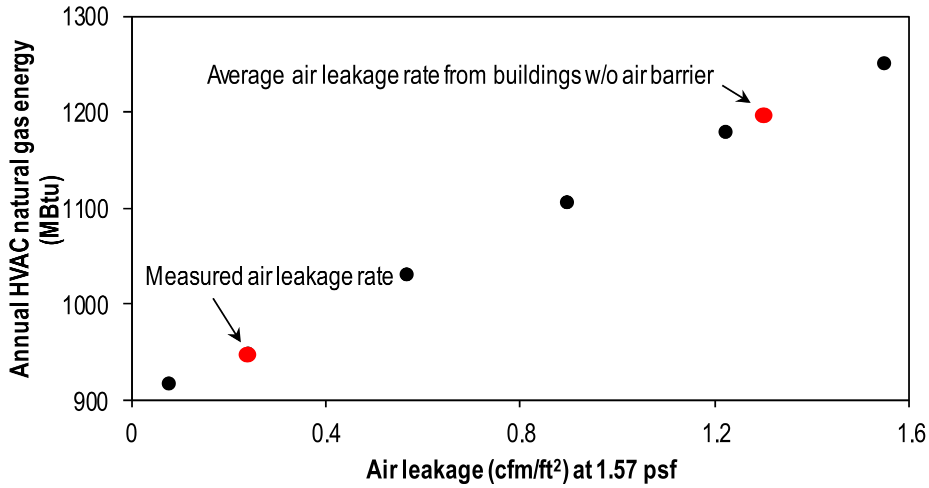

Figure 10. Simulation results of the annual HVAC natural gas energy consumed by the Homeland Security Training Center as a function of air leakage rate through the above grade walls and roof.

Figure 11 translates energy use to cost by assuming rates of \$0.1 per KWh for electricity and \$11.1 per MBtu for natural gas. Results indicate that by having an airtight envelope the HTC saves about \$3,000 per year than if it lacked an air barrier system. These savings could be higher because the measured leakage rate was likely greater than the actual value given the imperfect sealing of the large louvers by the mechanical dampers during the blower door test. Nevertheless, it should be taken into account that this estimate is highly dependent on numerous variables, such as the location of the building, building envelope materials, the type and efficiency of the HVAC system, HVAC heating and cooling set point temperatures, lighting and internal loads, HVAC operational schedule, occupancy schedule, and type of fuel used by the HVAC system.

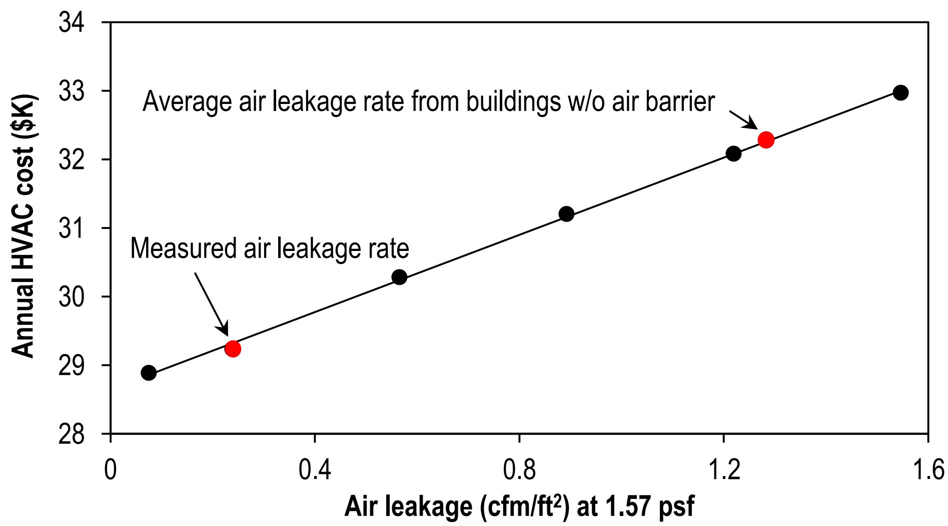

Figure 11. Simulation results of the annual HVAC energy cost for the Homeland Security Training Center as a function of air leakage rate through the above grade walls and roof.

Shrestha et al. (2016) are developing a free online calculator that estimates energy and cost savings due to improvements in airtightness for certain DOE commercial prototype buildings. The procedure that is followed by the calculator is somewhat similar to the simulation steps that were described in this report. The calculator may be useful to building owners and designers when trying to decide the airtightness level they want to target. A link to this calculator will be available through the Better Buildings Alliance Envelope Tech Team website.

6. CONCLUSIONS

LIQUIDARMOR™ CM Flashing and Sealant was used as one of the components of the air barrier system at the Homeland Security Training Center (HTC), which is one of the buildings of the College of DuPage campus in Glen Ellyn, IL. Blower door tests indicate that the average leakage rate of the HTC is 0.15 cfm/ft^2 at 1.57 psf or 63% lower than what is specified by the 2015 IECC. Simulation results suggest that by having an airtight envelope the HTC lowered its annual heating and cooling cost by about $3,000 or 9% compared to a similar building that lacked an air barrier system. This demonstration project serves as an example of the level of building envelope airtightness that can be achieved by using air barrier materials that are properly installed, and illustrates the energy and financial savings that such an airtight envelope could attain.

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