

Long-Haul Truck Sleeper Heating Load Reduction Package for Rest Period Idling

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ABSTRACT

Annual fuel use for sleeper cab truck rest period idling is estimated at 667 million gallons in the United States, or 6.8% of long-haul truck fuel use. Truck idling during a rest period represents zero freight efficiency and is largely done to supply accessory power for climate conditioning of the cab. The National Renewable Energy Laboratory's CoolCab project aims to reduce heating, ventilating, and air conditioning (HVAC) loads and resulting fuel use from rest period idling by working closely with industry to design efficient long-haul truck thermal management systems while maintaining occupant comfort. Enhancing the thermal performance of cab/sleepers will enable smaller, lighter, and more cost-effective idle reduction solutions. In addition, if the fuel savings provide a one- to three-year payback period, fleet owners will be economically motivated to incorporate them. For candidate idle reduction technologies to be implemented by original equipment manufacturers and fleets, their effectiveness must be quantified. To address this need, several promising candidate technologies were evaluated through experimentation and modeling to determine their effectiveness in reducing rest period HVAC loads. Load reduction strategies were grouped into the focus areas of solar envelope, occupant environment, conductive pathways, and efficient equipment. Technologies in each of these focus areas were investigated in collaboration with industry partners. The most promising of these technologies were then combined with the goal of exceeding a 30% reduction in HVAC loads. These technologies included "ultra-white" paint, advanced insulation, and advanced curtain design. Previous testing showed more than a 35.7% reduction in air conditioning loads. This paper describes the overall heat transfer coefficient testing of this advanced load reduction technology package that showed more than a 43% reduction in heating load. Adding an additional layer of advanced insulation with a reflective barrier to the thermal load reduction package resulted in a 53.3% reduction in the overall heat transfer coefficient.

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INTRODUCTION

In the United States, long-haul trucks (trucks that travel more than 500 miles per day) use approximately 667 million gallons of fuel annually for rest period idling [1]. Sleeper cab climate control is one of the primary reasons for idling the main engine during these driver rest periods. This rest period idling is approximately 6.8% of the total long-haul truck fuel use and represents a zero freight efficiency operating condition for the truck. Fuel is one of the largest trucking costs per mile, averaging 35% of the total from 2008 to 2013 [2]; therefore, the increasing cost and cost volatility of fuel provide a significant financial incentive to reduce fuel use. Recent federal, state, and city anti-idling regulations [3] are providing further incentives to reduce truck idling. One example is the idle reduction technology credit in the Heavy-Duty Greenhouse Gas Emissions Standards, effective starting in 2014 [4].

By reducing thermal loads and enabling more effective idle-off climate control systems, there is an opportunity to reduce fuel use and associated emissions. Enhancing the thermal performance of long-haul truck sleepers will enable smaller, lighter, and more cost-effective idle reduction solutions. In addition, if fuel savings from new technologies provide a one- to three-year payback period [5], fleet owners will be economically motivated to incorporate the new technologies. Therefore, financial incentive provides a pathway to rapid adoption of effective thermal load and idle reduction solutions.

The U.S. Department of Energy's National Renewable Energy Laboratory's (NREL's) CoolCab project is researching efficient thermal management systems to maintain cab occupant comfort without the need for engine idling. The CoolCab project uses a system-level approach that addresses three aspects: reducing the thermal loads, efficient delivery of climate control for occupant

thermal comfort, and maximizing equipment efficiency. By reducing thermal loads, the occupant's climate control needs are reduced, and reduced-capacity equipment can then provide the conditioning. To advance the goals of the CoolCab project and the broader goals of increased national energy security and sustainability, the CoolCab team works closely with industry partners to develop and apply commercially viable solutions to reduce national fuel use and industry costs.

To achieve an effective solution, NREL first conducted baseline testing of vehicles to quantify their thermal behavior. This information was then used to build and validate a CoolCalc model. CoolCalc is NREL's rapid HVAC load estimation tool [6]. CoolCalc thermal models were then used in conjunction with experimental screening tests to identify promising thermal load reduction technologies. The most promising technologies were combined into a Complete-Cab Thermal Load Reduction Package. Previous tests showed that this reduced air conditioning (A/C) electrical loads by more than 35.7%, exceeding the 30% goal [7]. This paper describes testing of the impact of this Complete-Cab Thermal Load Reduction Package on heat loads using an overall heat transfer coefficient (UA) test procedure. This testing showed a 43% reduction in heating loads. The Complete-Cab Thermal Load Reduction Package was then updated with improved insulation (an additional thin layer of advanced insulation with a reflective barrier was added to the previously tested thermal insulation package), resulting in a UA heating load reduction of 53.3%.

APPROACH

Complete-Cab Thermal Load Reduction Package

NREL has identified four key climate control load technology focus areas: conductive pathways, the solar envelope, occupant environment, and efficient equipment. The first three of these technologies impact the cab's heat transfer and resulting thermal loads and are the focus of this report. The efficient equipment focus area translates the thermal loads into mechanical or electrical loads. The four technical focus areas are described below.

1. The conductive pathways focus area addresses heat transfer through walls and other surfaces of the cab/sleeper. Technologies in this area include insulation, advanced materials, and glass.
2. The solar envelope describes the interaction of surfaces with radiant energy from the sun and the surrounding environment. It is predominantly driven by radiant heat transfer and is most relevant during daytime operation; however, nighttime radiation to the sky is also included. This focus area includes the study of opaque and transparent surface properties of paints and glass, respectively. It also includes devices to modify these properties, such as window shades.
3. The occupant environment includes the volume of conditioned air, occupant heat exchange with the surroundings, and human factors such as thermal sensation/comfort. Designing the thermal environment to make every occupant comfortable rather than to meet the traditional temperature-based metric has a significant impact on design. Technologies in this area include sleeper curtains and control of the microenvironment.
4. The use of efficient equipment impacts conversion of thermal loads to mechanical, electrical, or chemical loads. A range of technology options and design considerations falls into this category. These options include battery electric A/C, fuel-fired heaters, and auxiliary power units. For the purposes of this study, battery electric idle-off systems were used; however, the idle-off thermal load reduction technologies applied to the cab/sleeper are largely independent of the equipment used.

Prior work used testing and modeling to down-select technologies from each of these focus areas to develop a Complete-Cab Thermal Load Reduction Package. The baseline experimental configuration for the test cab contained sections of insulation as part of the vehicle's stock insulation configuration. The stock insulation was affixed to portions of select upholstery panels that composed the sleeper compartment (Figure 1A). For the advanced insulation package, prefabricated insulation panels were installed throughout the sleeper compartment to occupy the void space between the upholstery panels and exterior frame wherever possible (Figure 1B). The advanced insulation package consisted of Thinsulate automotive acoustic insulation provided by Aearo Technologies. The areas of the sleeper cab insulation included the rear sleeper wall, sleeper ceiling, sleeper side walls, and portions of the cab ceiling. The installed insulation package contained a combination of one- and two-inch-thick blanket insulation with a nominal thermal conductivity of between 0.03 and 0.05 W/m-K. Prior testing of this load reduction package showed it to be effective for electrical load reduction for an electric-powered A/C unit. To improve on this load reduction package, an additional 0.25-inch layer of Thinsulate insulation with a reflective radiation barrier was added between the interior trim and cab structure to reduce thermal shorts between the wall structure and the interior (Figure 1C).



A.



B.

Figure 1. A (top), stock insulation; B (center), advanced insulation; C (bottom), additional layer with reflective barrier